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Technical Report

Heavy-Duty Vehicle Emission Conversion Factors 1962-1997

By

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Standards Development and Support Branch
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Office of Mobile Sources
Office of Air and Radiation
U. S. Environmental Protection Agency

I. Introduction

MOBILE3 is a computer program that generates in-use emission factors by calendar year, ambient temperature and driving situation in units of grams per mile (g/mi) for all vehicle classes, which are then used to determine emissions inventories in various localities. Because urban areas are modelled almost exclusively, urban emission factors are desired and generated. Because heavy-duty engine testing provides emissions in terms of grams per brake horsepower-hour (g/BHP-hr), brake horsepower-hour per mile (BHP-hr/mi) emission conversion factors are needed to convert the brake-specific emission levels into the necessary mile-specific (g/mi) units, as illustrated below:

Emission Factor = Emission Test Data x
Emission Conversion Factor

$$\frac{g}{mi} = \frac{g}{BHP\text{-}hr} \times \frac{BHP\text{-}hr}{mi}$$

This technical report outlines the methodology used to determine these conversion factors, as well as providing the specific conversion factors for heavy-duty gasoline and diesel engines, for the model years 1962 through 1997 (see Tables 1 and 2).

The BHP-hr/mi conversion factors were calculated from brake-specific fuel consumption (BSFC), fuel density, and fuel economy, (all of which can be measured) because it is difficult to measure BHP-hr/mi directly. The equation used was: heavy-duty vehicle conversion factor = fuel density/(BSFC X fuel economy), with corresponding units of BHP-hr/mi = (lb/gal)/[(lb/BHP-hr) X (mi/gal)].

The emission conversion factors were first calculated by specific gross vehicle weight (GVW) class for both gasoline- and diesel-powered vehicles, as both BSFC and fuel economy vary with gross vehicle weight and fuel type. Diesel and gasoline fleet-average conversion factors were then calculated using the appropriate vehicle miles traveled (VMT) weighting of the class-specific conversion factors. Gasoline and diesel fleet-average conversion factors were derived separately because MOBILE3 treats them separately.

Estimates of historic BSFC and fuel economy figures are available for vehicles of model year 1977 and earlier. Thus, historic class-specific conversion factors may be easily calculated using the equation given above. Future conversion factors will not be affected by changes in BSFC, as any

Table 1

Pre-1978 Fleet-Average Emission Conversion Factors (BHP-hr/mi)

Year	Gasoline	Diesel
1962	1.29	2.74
1963	1.31	2.74
1964	1.32	2.73
1965	1.33	2.72
1966	1.35	2.76
1967	1.36	2.82
1968	1.37	2.88
1969	1.37	2.94
1970	1.37	3.00
1971	1.37	3.08
1972	1.37	3.15
1973	1.34	3.19
1974	1.31	3.23
1975	1.28	3.27
1976	1.20	3.23
1977	1.12	3.19

Table 2

Post-1977 Fleet-Average Emission
Conversion Factors (BHP-hr/mi)

Year	Gasoline	Diesel
1978	1.08	3.07
1979	1.05	2.95
1980	1.01	2.84
1981	0.98	2.72
1982	0.95	2.60
1983	0.95	2.56
1984	0.95	2.51
1985	0.96	2.47
1986	0.97	2.43
1987	0.97	2.38
1988	0.97	2.38
1989	0.96	2.37
1990	0.96	2.36
1991	0.96	2.35
1992	0.95	2.34
1993	0.94	2.33
1994	0.94	2.33
1995	0.93	2.32
1996	0.92	2.31
1997	0.92	2.31

decrease in BSFC will be cancelled out by a corresponding increase in fuel economy. As fuel density is assumed to be constant, the only factors affecting future heavy-duty vehicle conversion factors are future non-engine-related fuel economy improvements. Future class-specific conversion factors are, thus, estimated by reducing the 1977 conversion factors in proportion to the projected increase in fuel economy due to non-engine-related factors. For this reason, historic and future conversion factors are calculated separately; the former using the above equation, and the latter using projected non-engine-related fuel economy improvements applied to the 1977 conversion factors.

This report begins with a description of the fuel densities, BSFCs, and fuel economies used to calculate the historic class-specific conversion factors. Following this discussion, the VMT-weighting methodology used to obtain the fleet-average conversion factors is presented and each factor used in the VMT weighting process is described. Future non-engine-related fuel economy improvements are then analyzed and their application to historic class-specific conversion factors described. A discussion of the VMT-weighting factors for future fleet-average conversion factors concludes the report.

A study was conducted by Energy and Environmental Analysis[1] (EEA) for the Motor Vehicle Manufacturers Association (MVMA) to estimate historic and future emission conversion factors as defined in this report. This study provides a background for estimating these conversion factors and is referenced throughout this report.

II. Historic Class-Specific Conversion Factors

Historic class-specific conversion factors were calculated using three basic parameters: fuel density, brake specific fuel consumption, and fuel economy, as detailed above. These three parameters are detailed in the subsequent paragraphs.

A. Fuel Density

The gasoline and diesel fuel densities used in the calculation of historic conversion factors were 6.16 and 7.07 pounds (lbs.) per gallon, respectively. These values were used by EEA[1] in their calculations and result from a conceptually indirect methodology, but one using readily available figures. They divided the number of grams of carbon per gallon of fuel by the ratio of carbon mass to total fuel mass and then converted this density from grams per gallon to pounds per gallon. The values used for grams of carbon per gram of fuel

(2421 for gasoline, 2778 for diesel fuel) and the carbon/total mass ratio (.866) were taken from the Code of Federal Regulations.[2] The resulting fuel densities are within 1 percent of the specific gravities of commercial gasoline and diesel fuel, as surveyed by MVMA[3,4] (.7444 for gasoline and .8572 for diesel) and were, thus, accepted for use in MOBILE3.

B. Brake-Specific Fuel Consumption

The class-specific gasoline and diesel BSFCs ("BSFCG" and "BSFCD," respectively, in Table A-1) from the EEA report[1] are similar to those from EPA engine dynamometer tests (see Table 3). Thus, they were accepted for use here in calculating historic class-specific conversion factors. The EEA report did not address transit buses. Since it is desirable to include the effect of such vehicles on the fleet-average diesel conversion factor, an historic BSFC for this class of vehicles had to be derived. As pre-1978 bus engines were almost entirely 2-stroke naturally-aspirated engines, they were estimated to be roughly 4-5 percent less efficient than Class V-VII engines (0.46 lb/BHP-hr) which are a mixture of naturally-aspirated and turbocharged 4-stroke engines. The resulting bus engine BSFC of 0.48 lb/BHP-hr was generally confirmed in a study by Southwest Research Institute,[6] where the BSFC of an 8V-71 bus engine was found to be 0.47 lb/BHP-hr. The MOBILE3 BSFCs are shown in Table A-2.

C. Fuel Economy

All fuel economies (except those form Class IIb vehicles and buses) were taken directly from the 1977 Truck In-use Survey (TIUS)[2] as detailed in the EEA report.[1] The fuel econommy for all Class II vehicles was reported by EEA. However, only Class IIb fuel economy is pertinent to heavy-duty vehicle emissions, as Class IIa vehicles are treated as light-duty trucks in MOBILE3. The Class II fuel economy of 11.12 mpg (gasoline) from the 1977 TIUS is a weighted average of Class IIa and Class IIb fuel economies. EEA[8] supplied information indicating that Class IIb sales make up 10.7 percent of Class II sales. This figure is very similar to that estimated by a previous EPA study.[9] Using an estimate that Class IIb fuel economy is 10 percent less than Class IIa fuel economy yields a Class IIb fuel economy of 10.12 mpg, this was taken to be constant for all years prior to 1978 as the TIUS data indicated Class II fuel economy was constant.[1] The transit bus fuel economy of 3.68 miles per gallon was estimated using data from the 1981 Transit Fact Book.[10] EEA fuel economies are shown in Table A-1, which uses "MPGG" for gasoline and "MPGD" for diesel fuel economies, and the MOBILE3 fuel economies are shown in Table A-2.

Table 3

Brake-Specific Fuel Consumption (lb/BHP-hr)

Diesels

Class VI

Average of 4 Engines:	$\overline{BSFC}$ = 0.4645 std. dev. = 0.21	EEA Estimate: 0.46

Class VIII

Average of 7 Engines:	$\overline{BSFC}$ = 0.440 std. dev. = .031	EEA Estimate: 0.43

Gasoline

Average of 2 Engines:	$\overline{BSFC}$ = .69 delta = .029	EEA Estimate: 0.70

Taken from Reference 5.

The TIUS fuel economies are national fuel economies (i.e., the result of a combination of rural and urban driving). Different fuel economy data from tests made by the Southwest Research Institute (SwRI)[11] over the EPA heavy-duty chassis dynamometer cycle are given in Table 4. Rural fuel economy was assumed to be represented by the Los Angeles freeway portion of the test, with urban fuel economy being that over the entire urban (composite) cycle. This data shows that the average composite (urban) fuel economy is 17 percent lower than an estimate of the average Los Angeles freeway (rural) fuel economy. This indicates that perhaps the TIUS national fuel economies should be revised downward to better represent urban fuel economies. However, data from a July 1976 report by Jack Faucett Associates[12] (see Table 5) show lower loads in urban driving than during over-the-road driving, resulting in a 5-10 percent increase in urban fuel economy over rural fuel economy. Combining the fuel economy effect of the lower urban load benefit and the national/urban differences based on SwRI data results in rural fuel economy still being 7-12 percent greater than urban fuel economy.

Track test data supplied by GM[12] (see Table 6) over SAE truck driving cycles contradicts this, showing urban fuel economy to be equal to or greater than rural fuel economy, if, as GM did, it is assumed that urban trucks are lightly loaded and over-the-road trucks are full loaded. The 1977 TIUS (see Figures 1 and 2) confirms this relationship between urban and over-the-road (intercity) fuel economy.

Upon consideration of the TIUS data, and acknowledging that: 1) the SwRI data is limited, and 2) the representativeness of the LA freeway portion of the EPA cycle as rural driving is uncertain, the TIUS national fuel economies were taken as being representative of urban fuel economy as well. Further investigation into this area is necessary, and it may be appropriate to adjust national fuel economies in the future to represent urban fuel economies if additional data confirm the need for such adjustment.

In summary, historic class-specific conversion factors were based on: fuel densities from EEA,[1] BSFCs from EEA,[1] and fuel economies from the 1977 TIUS,[7] with Class II adjusted to represent Class IIb. The only exception was for transit buses, where the BSFC was based on dynamometer testing and the fuel economy was based on UMTA data. These historic gasoline and diesel class-specific conversion factors ("GCF" and "DCF", respectively) are listed in Table A-3. The class-specific conversion factors must then be VMT weighted to determine historic fleet-average conversion factors, which is described below.

Table 4

Southwest Research Institute Fuel Economy Data

Engine Model	Test Type	Fuel Cons. L.A. FWY (L/100km)	Fuel Cons. Composite (L/100km)	Urban/Hwy FE Ratio	Wtd. FE Ratio
1982 Cummins 350	CS	44.40	54.59	.813	.834
	HS	42.92	51.26	.837	
1979 Cummins NTC290	CS	51.04	63.51	.804	.836
	HS	49.72	59.12	.841	
1979 Ford 370	CS	43.36	53.86	.805	.783
	HS	44.08	57.94	.761	
1979 IHC 345	CS	52.67	62.64	.841	.884
	HS	50.47	56.61	.891	
Overall Average Urban/Highway Fuel Economy Ratio					.834

Taken from Reference 11.

Table 5

Truck Class Size	Average Vehicle Load (tons) Local Gasoline	Local Diesel	All Trucks	Intercity Gasoline	Intercity Diesel
Class 1	.24	--	.24	.23	.23
Class 2	.45	.50	.45	.48	.50
Class 3	.79	.99	.83	.90	1.00
Class 4	.98	1.67	1.04	1.14	1.65
Class 5	1.20	1.89	1.26	1.34	2.38
Class 6	1.54	2.61	1.86	1.87	3.60
Class 7	2.12	3.38	3.01	2.48	4.56
Class 8	4.04	7.10	8.71	5.28	9.78
Total	.50	6.16	2.07	.88	9.28

Taken from Reference 12.

Table 6

Average Fuel Economies for different Loads and Scenarios
(miles per gallon)

SAE Driving Cycle:	Local			Short Range			Long Range		
Percent GVTW:	50	100	% diff.	50	100	% diff.	50	100	% diff.
Truck Class									
6	6.24	4.42	41	7.47	6.11	22.2	—	—	—
6	4.43	3.55	25	6.82	5.61	22	—	—	--
8	--	--	--	6.28	6.44	32	4.95	4.13	20
8	--	--	—	5.91	4.32	37	5.09	4.01	27

% GVTW = percent Gross Vehicle Test Weight
50% GVTW is used to simulate zero payload (roughly)
100% GVTW is used to represent full payload
% diff. = [(50% GVTW fuel economy/100% GVTW fuel economy)-1.00] X 100

Taken from Reference 13.

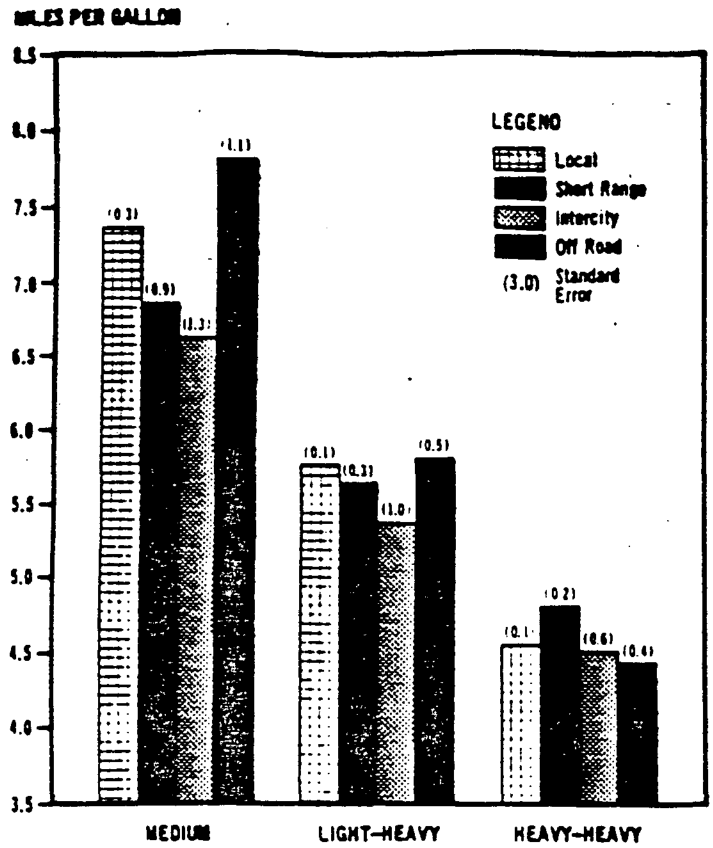


Fig. 1 - Average Fuel Economy by GVW Category and Area of Operation (Gasoline)

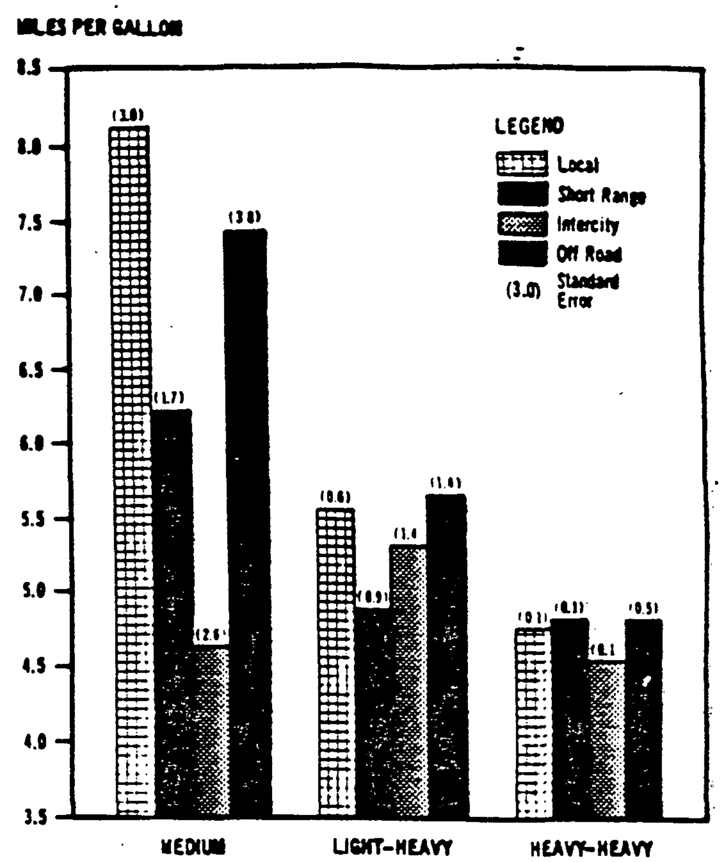


Fig. 2 - Average Fuel Economy by GVW Category and Area of Operation (Diesel)

III. Historic Fleet-Average Conversion Factors

Historic fleet-average conversion factors are calculated by VMT weighting the class-specific conversion factors. The VMT-weighting factor for each class is a product of: 1) the annual VMT per vehicle per year, 2) the urban travel fraction, 3) the HDV sales fraction, and 4) the diesel or gasoline sales fraction. The resulting diesel and gasoline VMT-weighting factors are listed in Table 7. The individual factors that make up the VMT weighting factor are discussed in the paragraphs below.

A. Annual Vehicle Miles Travelled

The annual VMTs per vehicle used for each vehicle class were those given in the EEA report[1] ("VMTD" for diesel and "VMTG" for gasoline in Table A-1) and came from the 1977 TIUS. The relationships of these figures for the various classes matched quite closely EPA estimates of lifetime VMTs per vehicle.[14] Thus, the TIUS figures appeared reasonable for use in MOBILE3.

The TIUS information did not include buses, so an equivalent annual VMT per bus had to be determined. While the EEA report uses annual VMT per vehicle to calculate the weighting factor and an analogous figure was derived and used for buses, lifetime VMT per vehicle would actually be a more appropriate measure of a vehicle's contribution to a model year's lifetime emissions. This is true because the conversion factors, as set out by EEA, are determined by model year and apply throughout the entire life of that model year's vehicles. When vehicles' lives are the same in terms of years, the two approaches (annual and lifetime VMT) yield the same results. However, the lives of buses are much longer than other heavy-duty vehicles, so the annual approach would underestimate their contribution to their model year's fleet-wide lifetime emissions. Thus, an equivalent annual transit bus VMT was estimated by multiplying the EEA annual Class VIII VMT per vehicle of 62,500 miles by the ratio of lifetime transit bus VMTs, to lifetime Class VIII VMT. This results in a transit bus annual VMT of 45,00-50,000 miles as illustrated in Table 8, depending on the figure used for lifetime Class VIII vehicle VMT. Forty-five thousand annual miles per vehicle was chosen as the best estimgae since the lifetime VMT of HHDVs (including rebuilds) is more likely to be near the upper end of the range estimated in Table 8 as opposed to the lower end.

Table 7

Pre-1978 VMT Weighting Factors

Class	1962	1965	1967	1970	1972	1975	1977
Diesel							
IIb	.000	.001	.001	.000	.000	.000	.001
III-V	.040	.042	.036	.002	.002	.002	.000
VI	.061	.095	.093	.062	.027	.044	.063
VII	.246	.158	.118	.088	.070	.091	.091
VIII	.486	.592	.652	.764	.817	.652	.791
Bus	.167	.112	.100	.083	.084	.212	.055
Gasoline							
IIb	.085	.117	.141	.199	.210	.409	.562
III-V	.491	.455	.365	.296	.285	.129	.096
VI	.258	.247	.308	.332	.375	.377	.286
VII	.068	.067	.078	.093	.069	.048	.036
VIII	.097	.113	.108	.080	.061	.038	.021

Table 8

Bus Annual VMT per Year

Year	Vehicle Miles Operated (x10^6)	Total New Bus Sales	Miles/Sales (Lifetime VMT)	Annual VMT_1*	Annual VMT_2**
1971	1,375.5	2,514	547,100	64,638	59,800
1972	1,308.0	2,904	450,400	53,200	46,900
1973	1,370.4	3,200	428,200	50,591	44,600
1974	1,431.0	4,818	297,000	35,100	30,900
1975	1,526.0	5,261	333,300	39,400	34,700
1976	1,581.4	4,745	666,100	78,700	69,400
1977	1,623.3	2,437	428,500	50,600	44,600
1978	1,630.5	3,805	474,900	56,100	49,500
1979	1,633.6	3,440	366,800	43,300	38,200
Average	1,497.7	3,680	443,600	52,400	46,500

* Annual VMT_1 is calculated using a lifetime heavy-duty vehicle VMT of 529,000 from reference 18.

** Annual VMT_2 is calculated using a lifetime heavy-duty vehicle VMT of 600,000, which may even be exceeded by rebuilt engines.

Bus data taken from Reference 10.

B. Urban Travel Fractions

The EEA report used urban travel fractions (listed as "UVMTG and UVMTD" in Table A-1) derived from the 1977 TIUS data. These urban travel fractions were based on the assumption that trucks operating predominantly in "short range" and "long range" applications are entirely rural while those operating predominantly in "local" areas were entirely (100 percent) urban. EEA also examined an alternate assumption that only 70 percent of all usage was in the predominant usage category with the other 30 percent being split between the other two usage categories.[1] EEA found this to have little effect, so they used the urban travel fractions derived using the 100 percent asumption. Upon examination, the 70 percent assumption did appear to have a significant effect for a few classes. In the example of the weighting procedure presented below, if 70 percent of a vehicle's VMT occurs in its primary use category, with the remaining 30 percent distributed between the other two use categories, the local VMT fraction is 22.2 percent, rather than 13 percent which results from EEA's 100 percent assumption. Acknowledging this, a mid-range assumption that 85 percent of a vehicle's VMT occurs in its primary use category, with the remaining 15 percent distributed between the other two use categories was used for the MOBILE3 urban VMT fractions. The resulting urban fractions ("UFG" and "UFD" for gasoline- and diesel-fueled vehicles, respectively) are given in Table A-2. An example of the weighting procedure is presented below.

	Local	Short Range	Long Range
TIUS Primary Use Breakdown	13%	34%	53%
EEA VMT Fractions (100%)	13%	34%	53%
VMT Fractions (70% Assumption)	22.2%	33.6%	44.2%
MOBILE3 VMT Fractions (85%)	17.6%	33.8%	48.6%

Where:

$$17.6\% = 0.85 \times 13\% + 0.075 \times 34\% + 0.075 \times 53\%$$

and

$$22.2\% = 0.70 \times 13\% + 0.15 \times 34\% + 0.15 \times 53\%$$

C. Sales Fractions

The historic sales figures used in the EEA report[1] ("SF" in Table A-1) were used as a base for the MOBILE3 sales fractions. The Class II sales figures were revised to represent Class IIb sales, as only Class IIb vehicles are treated as HDVs. Sales figures for buses were taken from the <u>1981 Transit Fact Book</u> (see Table 8).[10] These sales figures were divided by EEA total sales (revised with Class IIb sales replacing total Class II sales) to derive the sales fractions listed in Table A-2.

D. Diesel Fractions and Gasoline Fractions

The historic diesel sales fractions used in the VMT-weighting factors ("DF in Table A-1) were those derived by EEA[1] from factory sales of U.S. domestic manufacturers and exports from Canada to the U.S. The gasoline fractions are simply 1.0 minus the diesel fraction. These same diesel and gasoline fractions are also listed in Table A-2. All transit buses were assumed to be diesel-powered.[10]

IV. Future Class Specific Conversion Factors

Post-1977 class-specific gasoline and diesel conversion factors (GCF and DCF, see Table A-4) were estimated using 1977 class-specific conversion factors and projected future non-engine-related fuel economy improvements. Engine-related fuel economy improvements affect both BSFC and fuel economy (BSFC decreases as fuel economy increases) and, thus, do not affect the conversion factor. Future conversion factors are calculated by dividing the historic conversion factor by 1.0 plus the non-engine-related fuel economy improvement (in terms of percent) that is predicted to occur between the previous year and the year in question. The specific non-engine related fuel economy improvements are discussed in the following paragraphs.

A. Future Non-Engine Related Fuel Economy Developments

Several studies of future non-engine-related fuel economy improvements were conducted and submitted to EPA for use in deriving these conversion factors. The data and estimates were reviewed and that which was substantiated was used here.

The estimates of fuel economy improvements were derived according to GVW class (Classes IIb-IV or light heavy-duty vehicles (LHDVs), Classes VI-VIIIa or medium heavy-duty vehicles (MHDVs), and Class VIIIb or heavy heavy-duty vehicles (HHDVs)) as specific improvements will affect each class differently. These improvements are all detailed and referenced in Tables A-5 through A-8, and summarized in Table 9. Improvements to LHDVs are listed in Table A-6, MHDVs in Table A-7, and HHDVs in Table A-8. Each area of improvement is discussed in detail below.

Table 9

Total Non-Engine-Related Fuel Economy Improvements

Diesel (Percent Improvement)

Years	Class 2b	Class 6	Class 7	Class 8a	Class 8b	Buses
1977-1982	2.891	0.317	0.375	0.407	6.038	0.375
1982-1987	0.663	5.018	4.904	4.865	1.677	4.904
1987-1992	2.066	0.610	0.544	0.474	1.025	0.544
1992-1997	2.399	1.104	1.301	1.353	1.900	1.301

Gasoline (Percent Improvement)

Years	Class 2b	Class 6	Class 7	Class 8a
1977-1982	2.919	2.330	2.130	1.876
1982-1987	0.666	3.512	3.459	3.516
1987-1992	2.061	1.906	1.245	2.766
1992-1997	2.399	2.086	2.840	1.667

1. Weight Reduction

In EEA's report for MVMA,[1] EEA cites that a 500 lb. weight reduction was reported by Ford and GM for light-duty trucks (LDTs) in 1979-80 for a 6.6 percent fuel economy improvement. EEA[1] assumed that this same weight reduction would be made on LHDVs and that a similar fuel economy improvement would occur on these heavier vehicles. They estimated that 50 percent of the fleet would experience this weight reduction in each of the 1977-82 and 1987-91 time periods for a net 3.3 percent fuel economy improvement for each time period. There were no accompanying data to verify neither that these weight reductions occurred on LDTs or LHDVs nor that the 500 lb. weight reduction caused a 3.3 percent improvement on LDTs or LHDVs. The weight reduction figures used for LHDVs in MOBILE3 are listed in Table A-6.

In general, there is greater incentive to improve LDT fuel economy compared to LHDV fuel economy because: 1) LDTs are labeled with EPA-measured fuel economy, and 2) LDTs must comply with NHTSA-set fuel economy standards. Given the lack of substantiation presented, only the first fuel economy improvement was acknowledged (3.3 percent in 1979-80). Additional data in this area could change future projections. No fuel economy improvements were projected due to weight reduction for MHDVs or HHDVs, based on IHC[16] information which indicated that weight reduction is not valued highly by purchasers of these vehicles and, thus, is unlikely to occur. Were any weight reduction to occur in MHDVs or HHDVs, it would likely be offset by an increase in payload, thus there would be no fuel economy benefit.

2. Rolling Resistance (radials and advanced radials)

EPA used IHC data[17] from vehicle track tests as the primary basis for reduced rolling resistance benefits (i.e., use of radials and advanced radials). Fuel economy improvements were measured over three driving cycles (city/suburb/highway). EPA used the city figures as the average speed of this cycle matched that of EPA's urban driving cycle.

The percent fleet penetrations for radials reflect those used in the EEA reports (reference 15, if applicable, or if not, reference 1), and were supported by historic usage and cost benefit analysis supplied by IHC. There were a couple of exceptions to this. One, no penetration of advanced radials was made for LHDVs since the annual mileage of these vehicles is so low and because production technology for this size tire would have to be oriented specifically for LHDV use. Two, the fuel economy improvement associated with use of advanced radials on MHDVs estimated by IHC (8 percent) was lowered by 2 percent (in the absence of any supporting data), because their analagous estimate for HHDVs was 2 percent higher than the data showed. (IHC focused on a blend of city and suburban driving rather than on city driving alone.)

3. Aerodynamics

Aerodynamic improvements for MHDVs and HHDVs are taken primarily from IHC data for city driving.[17] The penetrations were taken from EEA, and were supported by historic usage and cost benefit analysis supplied by IHC.

EEA's[15] LHDV aerodynamic-related fuel economy improvements were based again on GM and Ford LDT body redesign, and they assume that these improvements will also be seen on LHDVs. Only body improvements are specified; no add-ons are expected for LHDVs. No evidence was submitted that these improvements carried over the LHDVs, nor that the fuel economy improvement was 3.4 percent. There is no guarantee that LDT modifications would make their way to LHDVs. Thus, without data to support this projection, no fuel economy improvement could be accepted for LHDVs.

4. Drivetrain Lubricants

Non-engine-related drivetrain lubricants are projected to improve fuel economy by 1.5 percent and to affect the entire fleet by 1997. All sources confirmed this improvement and both the availabiltiy and cost/benefit of such lubricants appeared reasonable.

5. Fan Drives

The fuel economy improvements resulting from fan drives were also taken from IHC's data.[17] All sources predicted 100 percent vehicle penetration of fan drives by 1992 and historical data supported this trend, so this figure was used by EPA. The 1982 penetration of 50 percent represents a compromise of the two available estimates.

6. Overdrive

LHDVs are the only vehicles for which overdrive improvements apply. MHDVs and HHDVs already have overdrive and have used overdrive to boost fuel economy for years, thus there is very little room for overdrive improvement to increase fuel economy for these vehicle classes. LHDVs are now imcorporating overdrive to increase fuel economy. Manual overdrive contributes a 5 percent fuel economy improvement according to both EEA[15] and IHC.[16] MOBILE3 uses EEA's percent penetration, which is confirmed by that of IHC. Automatic overdrive fuel economy improvements are greater than manual according to EEA[15] and IHC,[16] but MOBILE3 uses the same percent improvement for manual as for automatic overdrive. There was not sufficient data to justify EEA's high fuel economy improvements for automatic overdrive and a 5 percent improvement for essentially the entire LHDV fleet appeared reasonable for urban use.

7. Electronic Transmission Control (ETC)

EEA[15] estimated a 6.0 percent fuel economy improvement for LHDVs due to ETC based on LDT experience. In conversation with Ford,[19] they indicated that the driving force behind ETC was stringent emissions standards and that ETC will not be used in LHDVs until stringent LHDV (i.e., vehicle-based) emissions standards are put into effect. Therefore, no fuel economy benefit was projected for LHDVs due to use of ETC.

8. Speed Control

EEA[1] and IHC[16] projected similar speed control improvements with EEA projecting slightly higher percent fleet penetration. Speed control applies mainly to long range vehicles and over-the-road usage, however, these vehicles do accumulate for some of their mileage in urban areas (7.5 percent was used for MOBILE3 VMT fractions) and some of this mileage is at fairly constant speeds (e.g., freeway travel). For this reason, the long range speed control improvements were acknowledged. Even though fuel economy of local or short range vehicles would not benefit significantly from speed control improvements, urban fuel economy would increase some due to the long range vehicle fraction. EEA and IHC's common percent fuel economy improvement with EEA's penetration were used here.

B. Application of Non-Engine-Related Fuel Economy Improvements

The above non-engine-related fuel economy improvements were applied uniformly across the fleet by EEA.[1] (That is, local, short-range, and long-range use categories all received the same improvements and rural and urban fuel economies are both increased to the same degree. This contradicts the logic that, in nearly all cases where less than 100 percent of the fleet is affected, a fuel-saving change or device will be applied first to those vehicles where it is most cost effective, which are those vehicles with the highest annual mileage. Based on the 1977 TIUS, as would be expected, the long-range vehicles had the higher annual mileages, the short-range vehicle had the next highest, and the local vehicles the lowest. Thus, here these improvements were applied to long-range (over-the-road) vehicles first, short-range vehicles second, and local vehicles last.

If the percent fleet affected was less than the percent of vehicles used for long range transport then only long range vehicles were credited with fuel economy improvements. The percent of fleet affected had to be greater than both the combined long range and short range vehicle use fractions in order to credit any fuel economy improvement to the short range (local) vehicles. This method credits most fuel economy improvements that affect only a small fraction of the fleet to long range and short range vehicles, which each only account for 7.5 percent of the urban travel fractions. The fraction of each class' vehicles falling in each category was taken from the 1977 TIUS, as outlined in the EEA report.[1] The overall effect of a given technology is dependent on the degree that the technology is applied throughout the class and on the breakdown of the class between the various use categories.

After all of the future non-engine-related fuel economy improvements are calculated for each class and time period, they are applied to the historic class-specific (1977) conversion factors to yield future class-specific conversion factors. Some of the fuel economy improvements discussed had already penetrated a small portion of the fleet by 1977, and their increasing benefits were realized later as a larger percent of the fleet incorporated those improvements. This 1977 baseline penetration was subtracted from the 1982 penetration to obtain the net percent improvement from 1977 to 1982. This procedure was repeated for each 5-year interval up to 1997. These future class-specific conversion factors are shown in Table 10.

V. Future Fleet-Average Conversion Factors

A. Calculation of Post-1977 Fleet-Average Conversion Factors

Post-1977 fleet-average conversion factors (see Table 2) were calculated using the future GVW class-specific conversion factors (Table 10) and future VMT-weighting factors (Table 11). The latter were defined in the same manner as the pre-1978 weighting factors and are described below.

B. Vehicle Miles Travelled

The same gasoline and diesel annual VMTs specified in the EEA report[1] were used here ("VMTG" and "VMTD", respectively, in Table A-4). The previously discussed 45,000 annual VMT per

Table 10

Post-1977 Class-Specific Conversion Factors (BHP-hr/mi)

Class	1982	1987	1992	1997
Diesel				
IIb-IV	.970	.964	.944	.922
VI	1.865	1.776	1.765	1.746
VII	2.260	2.154	2.142	2.115
VIIIa	3.002	2.863	2.849	2.811
VIIIb	3.190	3.385	3.106	3.048
Bus	3.989	3.802	3.782	3.733
Gasoline				
IIb-IV	.845	.840	.823	.804
VI	1.536	1.484	1.456	1.427
VII	1.690	1.634	1.613	1.569
VIIIa	2.083	2.012	1.958	1.926

Table 11

Post-1977 VMT-Weighting Factors

Class	1982	1987	1992	1997
Diesel				
IIb-IV	.126	.189	.259	.247
VI	.026	.043	.041	.047
VII	.106	.234	.209	.209
VIIIa	.244	.028	.031	.034
VIIIb	.420	.421	.393	.394
Bus	.078	.086	.072	.070
Gasoline				
IIb-IV	.882	.825	.830	.845
VI	.041	.046	.046	.046
VII	.074	.124	.121	.109
VIIIa	.003	.005	.003	.000

vehicle for transit buses was used here also. These figures are very similar to the pre-1978 annual VMTs and are again consistent with EPA's own estimates of lifetime mileage relationships between the various classes.

C. Urban Travel Fractions

As was done with respect to the pre-1978 urban travel fractions, the urban travel fractions were modified using the TIUS vehicle use pattern and the 85/7.5/7.5 breakdown between usage categories. Here, a second change was made as well to take into account the dieselization of the fleet.

As the diesel engine is essentially a fuel-saving technology, like those discussed in the previous section, future dieselization is basically applied to long-range vehicles first. However, a slight deviation was made here from the strict long-range, then short-range, then local approach. The 1977 TIUS measured dieselization by class and use category and some diesels were used in short-range and local applicatons before all long-range applications were dieselized. Thus, further dieselization was assumed to occur according to the 1977 long-range/short-range/local diesel breakdown until all long-range applications were dieselized. After that, diesels were added according to the 1977 short-range/local diesel breakdown. The class-wide (gasoline and diesel) urban travel fractions were held constant using historical values, but the individual gasoline and diesel urban fractions changed from year to year depending on the degree of dieselization. The gasoline and diesel urban travel fractions used in MOBILE3 are listed in Table A-4 (UFG and UFD).

D. Diesel Sales Fractions

The diesel penetration (or diesel sales fractions) used here were taken directly from EEA's report.[1] These diesel penetrations are somewhat lower than earlier EPA projections. However, this is reasonable given that projections of fuel availability and price are more optimistic now than they were 2-3 years ago. Also, the figures do closely match information presented to EPA during recent heavy-duty engine rulemaking actions. The gasoline fractions are simply one minus the diesel fractions. These fractions are also listed in Table A-4 ("DF").

E. Sales Fractions

The breakdown of heavy-duty sales between the various classes (sales fractions) used here for post-1977 ("SF" in Table A-4) are based on those contained in the EEA report.[1]

Bus sales (not addressed by EEA) were derived by increasing an average historic annual sales figure from the 1981 Transit Fact Book by approximately ten percent over each 5-year period to represent projected sales growth. These class-specific sales (shown in Table 12) were divided by total sales to get the sales fractions ("SF" in Table A-4).

Table 12

Post-1977 HDV Sales Volume (gasoline and diesel)

Year	Light		Medium			Heavy	Buses
	IIB-IV	V	VI	VII	VIIIa	VIIIa	
1982	305,000	1,333	23,099	53,248	6,350	64,180	5,000
1987	428,000	-	35,000	1,210,000	10,000	115,000	5,500
1992	450,000	-	37,000	130,000	13,000	140,000	6,000
1997	470,000	-	41,000	135,000	14,00	150,000	6,500

Taken from Reference 1, except for buses.

VI. Summary of Results

The fleet-average emission conversion factors (in units of BHP-hr/mi) used in MOBILE3 are listed in Tables 1 and 2. MOBILE3 pre-1978 class-specific conversion factors are listed in Table A-3. The non-engine-related fuel economy improvements detailed in Tables A-5 through A-9, and summarized in Table 9, were applied to the 1977 class-specific conversion factors to develop the post-1977 class-specific conversion factors listed in Table 10. The past and future class-specific conversion factors were weighted by urban vehicle miles travelled to calculate the fleet average conversion factors. The weighting factors used are detailed in Tables A-1 through A-4 and Table A-6. Figures 3 and 4 illustrate the comparison between MOBILE3 and EEA [1], historic and future gasoline and diesel fleet average conversion factors.

The projected future fleet-average conversion factors show a steady decrease as time goes on, due to increased fuel economy. Diesel conversion factors decrease more rapidly than gasoline conversion factors. MOBILE3 conversion factors are higher than those projected by EEA for three primary reasons. One, EEA included Class IIa vehicles in their pre-1978 analysis, which is inappropriate since these vehicles are treated as light-duty trucks in MOBILE3. Two, the MOBILE3 urban VMT fractions for the heaviest diesel classes are larger than those of EEA, due to an attempt to more reasonably extrapolate urban VMT from primary truck usage (local, short range, and long range). Three, EEA estimates somewhat greater fuel economy improvements and applies these fuel economy improvements equally to local, short-range, and long-range vehicles. In MOBILE3, the somewhat lower fuel economy improvements are applied to long-range vehicles first, then short-range, and then local. This lowers the impact of the fuel economy improvements since long-range vehicle usage only comprises a small fraction of urban VMT.

FIGURE 3

PRE-1978 FLEET AVERAGE CONVERSION FACTORS

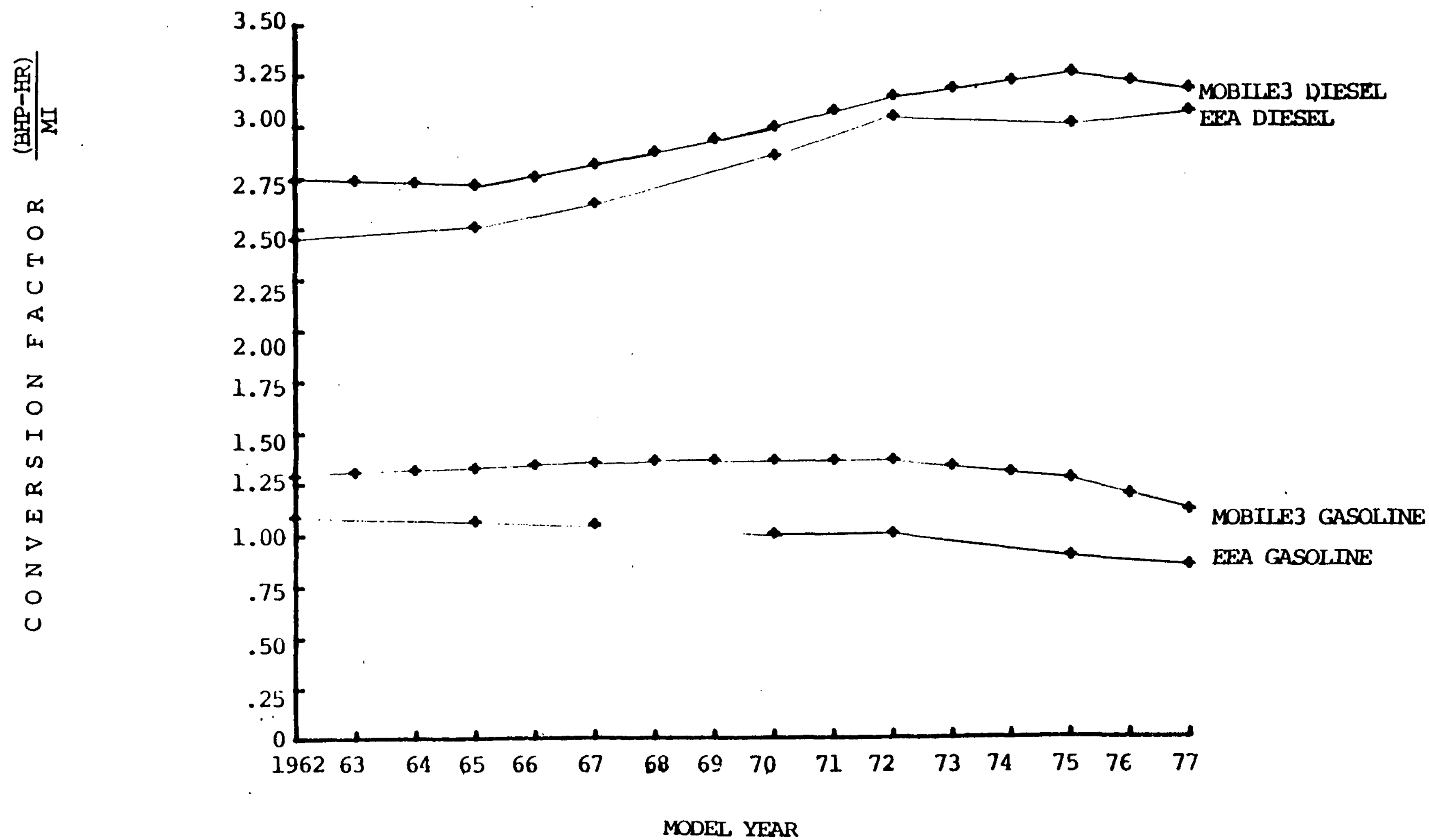
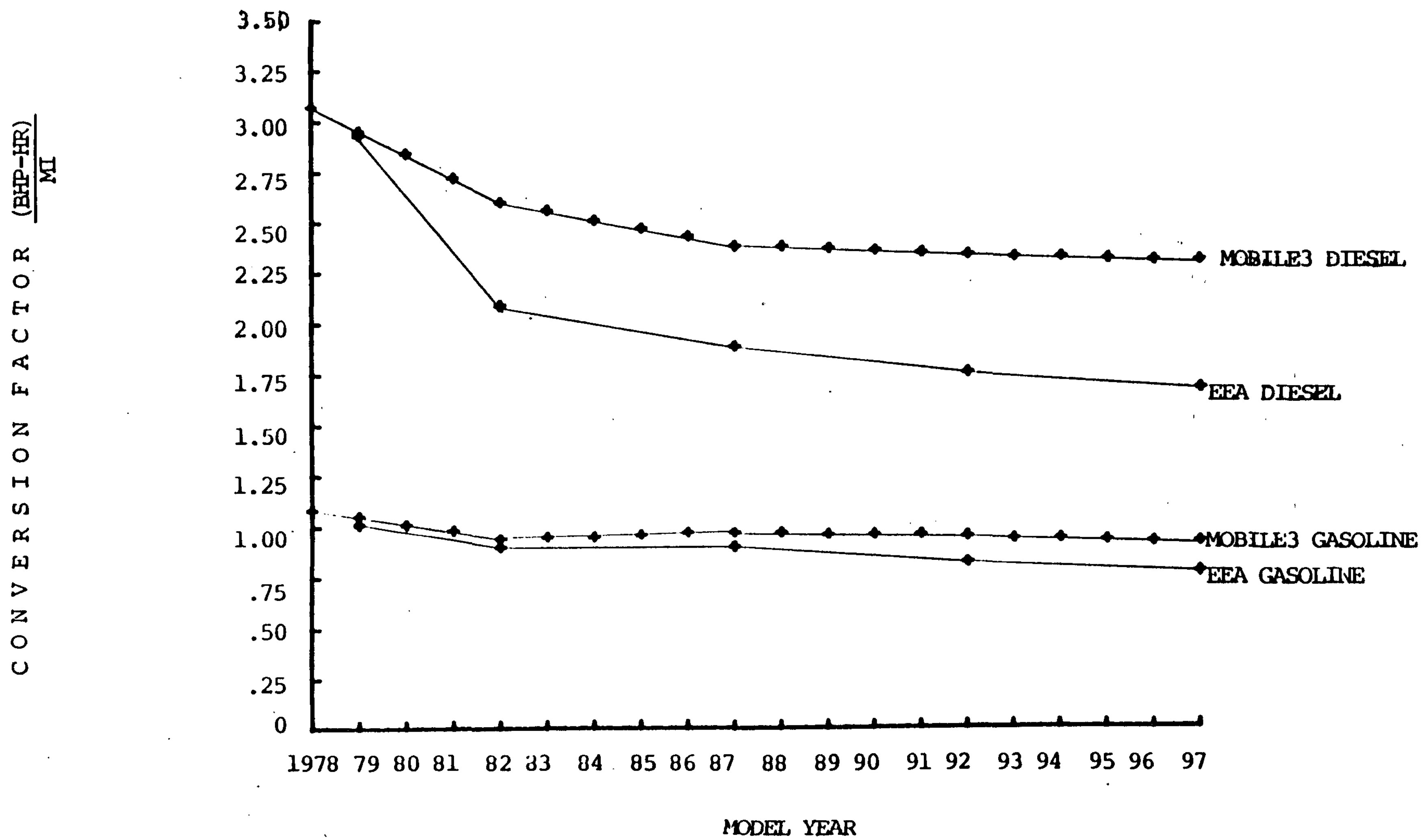


FIGURE 4

POST-1977 FLEET AVERAGE CONVERSION FACTORS



VII. Recommendations

The future gasoline and diesel conversion factors presented here are based on estimates and projections. There are several areas where the present degree of uncertainty is fairly high and where further data could significantly improve the accuracy of the results.

The most important area of concern is fuel economy. Better documented data on current urban fuel economy is needed, since the TIUS only addresses nationwide fuel economy and the accuracy of the submittals by surveyees is unknown. Equally important is the need for further information on the effects of future technology on urban fuel economy improvements. This is the main factor in projecting future conversion factors, assuming fuel density will not change significantly in the next 25 years. The urban fuel economy impact of technological developments in areas such as radial tires, lubrication, aerodynamic drag reduction, and speed control are not well known and the penetration of these technologies into the heavy-duty vehicle market is quite dependent on future fuel prices and manufacturers' marketing strategies. Any new data in these areas will be very useful in improving future projections of the emission conversion factors.

A second important area for further study is the estimation of the urban VMT fraction for the various classes of heavy-duty vehicles. Again, the TIUS only yields a surrogate for urban VMT fraction and more accurate estimates could be quite different.

References

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2. Code of Federal Regulations, Protection of Environment, 40, _ 600.113-78, revised as of July 1, 1983.

3. "MVMA National Diesel Fuel Survey," Summer Season Report, July 15, 1983.

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5. "Heavy-Duty Engine Emission Factors Program Update," Baines, T, U.S. EPA, OAR, OMS, ECTD, SDSB, May 17, 1984.

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9. "Evaluation of General Motors Heavy-Duty Engine Proposal," Attachment to EPA Memo from Chester J. France, SDSB, to Richard Wilson, OMS, May 16, 1983.

10. Transit Fact Book, American Public Transit Association, October, 1981.

11. Information received during a telephone call in November with Marian Warner-Selph, Research Scientist, Department of Emissions Research, Southwest Research Institute.

12. "Trucking Activity and Fuel Consumption-1973, 1980, 1985, and 1990", Jack Faucett Associates, Inc., prepared for Federal Energy Administration, July 1976

13. "Derivation of Heavy-Duty Diesel Engine Average Usage Period," U.S. EPA, OAR, OMS, ECTD, SDSB, July 1983.

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14. "Documentation of Market Penetration Forecasts," addendum to the report entitled "Historical and Projected Emissions Conversion Factor and Fuel Economy for Heavy-Duty Trucks, 1962-2002," prepared for MVMA by EEA, April 12, 1984.

15. Letter from T. M. Fischer, Director, Automatic Emission Control, General Motors, to Richard A. Rykowski, Senior Project Manager, U.S. EPA, Standards Development and Support Branch.

16. Meeting with International Harvester Corporation, MVMA and EPA, on the topic "Heavy-Duty Engine Fuel Economies and Future Fuel Economy Improvements," April 10, 1984.

17. Letter from R. W. Glotzbach, P.E., International Harvester Corporation to Mr. Charles Gray, Jr., Director, Emission Control Technology Division, U.S. EPA, April 19, 1984.

18. "Trends in Heavy-Truck Energy Use and Efficiency," Roberts, Glenn F. and David L. Greene, Oak Ridge National Laboratory, TM-8843.

19. Information received during a telephone conversation in April with Mike Schwartz, Ford Motor Company.

Appendix

Definitions of Headings for Appendices

CLASS	Class of heavy-duty vehicle that data applies to.
YEAR	Year data applies to.
VMTG	Gasoline annual vehicle miles travelled per vehicle.
VMTD	Diesel annual vehicle miles travelled per vehicle.
UVMTG	Urban fraction of gasoline vehicles miles travelled.
UVMTD	Urban fraction of diesel vehicles miles travelled.
MPGG	Miles per gallon for gasoline fueled vehicles.
MPGD	Miles per gallon for diesel fueled vehicles.
BSFCG	Gasoline fueled vehicle's brake specific fuel consumption (lb/BHP-hr).
BSFCG	Diesel fueled vehicle's brake specific fuel consumption (lb/BHP-hr).
SF	Sales fraction.
DF	Diesel fraction of sales.
GF	Gasoline fraction of sales.
UFG	Urban fraction of gasoline vehicle miles travelled, same as UVMTG.
UFD	Urban fraction of diesel vehicle miles travelled, same as UVMTD.
GCF	Gasoline conversion factor, class specific (BHP-hr/mi).
DCF	Diesel conversion factor, class specific (BHP-hr/mi).
GCFD	Gasoline conversion factor - denominator (product of VMTG, SF and GF).
GCFN	Gasoline conversion factor - numerator (product of GCFD and GCF).
DCFN	Diesel conversion factor - denominator (product of VMTD, UFD, SF and DF).
DCFN	Diesel conversion factor - numerator (product of DCFD and DCF).
TEG	Percent divided by 100 of fuel economy improvement over previous year listed for gasoline fueled vehicles.

TED Percent divided by 100 of fuel economy improvement over previous year listed for diesel fueled vehicles.

Table A-3

MOBILE3 Pre-1978 Class-Specific
Conversion Factors and Fleet-Average VMT Weighting

CLASS	YR	GF	GCF	DCF	GCFD	GCFN	DCFD	DCFN
2.	1962.	1.00000	.870	.998	512.874	446.195	0.	0.
2.	1965.	.99800	.870	.998	641.410	558.020	1.174	1.171
2.	1967.	.99700	.870	.998	763.808	664.504	2.098	2.09
2.	1970.	.99900	.870	.998	1010.313	878.961	.923	.92
2.	1972.	1.00000	.870	.998	1057.803	920.277	0.	0.
2.	1975.	1.00000	.870	.998	2243.325	1952.102	0.	0.
2.	1977.	.99900	.870	.998	2785.965	2423.758	2.546	2.54
2.	1978.	1.00000	.870	.998	2772.726	2412.241	0.	0.
3.	1962.	.96010	1.156	1.710	2942.379	3408.625	64.428	110.16
3.	1965.	.97450	1.187	1.710	2486.228	2950.062	101.061	172.79
3.	1967.	.96940	1.196	1.710	1978.703	2366.993	97.025	165.89
3.	1970.	.99690	1.219	1.710	1498.966	1827.885	7.241	12.38
3.	1972.	.99720	1.238	1.710	1440.081	1783.246	6.281	10.74
3.	1975.	.99539	1.190	1.710	705.360	839.215	5.174	8.84
3.	1977.	1.00000	1.154	1.710	474.689	547.745	0.	0.
3.	1978.	1.00000	1.129	1.710	869.149	981.056	0.	0.
6.	1962.	.95800	1.382	1.714	1549.116	2141.109	98.510	168.88
6.	1965.	.89500	1.436	1.714	1350.645	1939.881	229.837	394.03
6.	1967.	.90600	1.480	1.714	1666.168	2468.407	251.045	430.39
6.	1970.	.92400	1.531	1.749	1681.127	2574.108	200.565	350.87
6.	1972.	.96900	1.572	1.824	1692.486	2975.355	87.818	160.16
6.	1975.	.95900	1.601	1.864	2063.948	3303.925	131.038	244.16
6.	1977.	.90000	1.572	1.871	1416.589	2227.153	233.740	437.30
6.	1978.	.89400	1.564	1.860	1160.177	1814.303	199.529	371.08
7.	1962.	.56900	1.567	2.187	408.346	639.714	396.302	866.61
7.	1965.	.55300	1.601	2.187	366.711	590.225	361.858	835.0
7.	1967.	.62100	1.640	2.232	421.514	691.086	320.187	714.76
7.	1970.	.60700	1.683	2.280	470.658	792.316	283.859	647.1
7.	1972.	.65200	1.710	2.280	350.357	598.960	225.903	515.0
7.	1975.	.55100	1.743	2.295	261.021	455.070	272.523	625.3
7.	1977.	.42200	1.726	2.268	176.041	303.905	335.412	760.6
7.	1978.	.38500	1.710	2.198	171.495	293.182	381.078	837.6
8.	1962.	.44700	1.927	2.802	564.011	1125.121	783.043	2194.4
8.	1965.	.31500	1.987	2.864	618.511	1229.244	1427.839	4088.7
8.	1967.	.26900	2.024	2.970	583.490	1180.968	1761.782	5233.2
8.	1970.	.15600	2.096	3.083	404.055	847.004	2473.711	7627.3
8.	1972.	.11600	2.147	3.190	307.146	659.561	2626.294	8376.8
8.	1975.	.10600	2.174	3.260	205.741	447.260	1953.221	6368.4
8.	1977.	.03900	2.122	3.350	104.370	221.423	2927.072	9804.5
8.	1978.	.04200	2.072	3.296	103.753	214.934	2651.472	8738.9
9.	1962.	0.	2.392	4.004	-0.	-0.	270.000	1080.9
9.	1965.	0.	2.392	4.004	-0.	-0.	270.000	1080.9
9.	1967.	0.	2.392	4.004	-0.	-0.	270.000	1080.9
9.	1970.	0.	2.392	4.004	-0.	-0.	270.000	1080.9
9.	1972.	0.	2.392	4.004	-0.	-0.	270.000	1080.9
9.	1975.	0.	2.392	4.004	-0.	-0.	635.850	2545.7
9.	1977.	0.	2.392	4.004	-0.	-0.	202.050	808.9
9.	1978.	0.	2.392	4.004	-0.	-0.	256.950	1028.7

Table A-4

MOBILE3 Post-1977 Input Data

CLASS	YR	VMIG	VMTG	UFG	UFD	SF	OF
2	1977	11614	11614	.690	.630	.419	0.000
2	1982	11614	11614	.687	.633	.666	0.102
2	1987	11614	11614	.697	.633	.600	0.250
2	1992	11614	11614	.703	.633	.580	0.300
2	1997	11614	11614	.710	.633	.576	0.300
6	1977	9734	22168	.660	.426	.245	0.100
6	1982	9734	19115	.687	.447	.050	0.377
6	1987	9734	18826	.743	.452	.049	0.430
6	1992	9734	18826	.779	.456	.048	0.500
6	1997	9734	18545	.829	.473	.050	0.550
7	1977	11223	25883	.630	.377	.059	0.578
7	1982	11223	25697	.681	.385	.116	0.580
7	1987	11223	25250	.723	.387	.166	0.600
7	1992	11223	24634	.735	.392	.168	0.650
7	1997	11223	23488	.775	.396	.165	0.700
8	1977	15560	29950	.630	.358	.032	0.770
8	1982	15560	27037	.728	.359	.014	0.889
8	1987	15560	27037	.850	.359	.014	0.875
8	1992	15560	26393	.850	.366	.017	0.941
8	1997	15560	25779	.850	.394	.017	1.000
9	1977	0	62500	.000	.176	.241	1.000
9	1982	0	62500	.000	.176	.140	1.000
9	1987	0	62500	.000	.176	.161	1.000
9	1992	0	62500	.000	.176	.180	1.000
9	1997	0	62500	.000	.176	.184	1.000
10	1977	0	45000	.000	1.000	.004	1.000
10	1982	0	45000	.000	1.000	.011	1.000
10	1987	0	45000	.000	1.000	.005	1.000
10	1992	0	45000	.000	1.000	.008	1.000
10	1997	0	45000	.000	1.000	.008	1.000

Table A-5

Abbreviations for Referencing
Future Non-Engine Related Fuel Economy Improvements

EEA	=	Energy and Environmental Analysis, due. (contracted by MVMA)
IHC	=	International Harvester Corporation
GM	=	General Motors
ORNL	=	Oak Ridge National Laboratory (ORNL/TM-8843, Roberts and Greeve)
MOBILE3	=	Estimates used in MOBILE3
[#]	=	Referenced source of estimate

Table A-6

Class IIB-IV--Light Heavy-Duty Vehicles
Future Non-Engine Related Fuel Economy Improvements

Weight Reduction

Source	% Imprv.	% Penetration (cumulative) 1977	1982	1987	1992	1997
EEA [1]	6.6	0	50	50	100	100
[15]	6.6 based on LDTs, no data to justify historical or future EEA weight decrease.					
MOBILE3	6.6	0	50	50	50	50

Radials & Advanced Radials

Source	% Imprv.	% Penetration (cumulative) 1977	1982	1987	1992	1997
EEA [1]	4.0 (radial)	35	47.5	60	72.5	85
EEA [1]	8.0 (adv.rad)	0	12.5	25.0	37.5	50
IHC [17]	1.4/2.0/2.5 (radial) (city/suburb/hwy)					
MOBILE3	1.4 (radial)	35	55	70	80	90
MOBILE3	0.0 (adv. rad)					

Aerodynamics (add-on) None

Aerodynamics (body)

Source	% Imprv.	% Penetration (cumulative) 1977	1982	1987	1992	1997
EEA [1]	3.4	0	50	50	100	100
MOBILE3	0					

Drivetrain Lubricants

Source	% Imprv.	% Penetration (cumulative) 1977	1982	1987	1992	1997
EEA [1]	1.5	0	0	33.3	66.7	100
MOBILE3	1.5	0	0	33.3	66.7	100

Accessories (None)

Table A-6

Class IIB-IV--Light Heavy-Duty Vehicles
Future Non-Engine Related Fuel Economy Improvements

Weight Reduction

Source	% Imprv.	% Penetration (cumulative) 1977	1982	1987	1992	1997
EEA [1]	6.6	0	50	50	100	100
[15]	6.6 based on LDTs, no data to justify historical or future EEA weight decrease.					
MOBILE3	6.6	0	50	50	50	50

Radials & Advanced Radials

Source	% Imprv.	% Penetration (cumulative) 1977	1982	1987	1992	1997
EEA [1]	4.0 (radial)	35	47.5	60	72.5	85
EEA [1]	8.0 (adv.rad)	0	12.5	25.0	37.5	50
IHC [17]	1.4/2.0/2.5 (radial) (city/suburb/hwy)					
MOBILE3	1.4 (radial)	35	55	70	80	90
MOBILE3	0.0 (adv. rad)					

Aerodynamics (add-on) None

Aerodynamics (body)

Source	% Imprv.	% Penetration (cumulative) 1977	1982	1987	1992	1997
EEA [1]	3.4	0	50	50	100	100
MOBILE3	0					

Drivetrain Lubricants

Source	% Imprv.	% Penetration (cumulative) 1977	1982	1987	1992	1997
EEA [1]	1.5	0	0	33.3	66.7	100
MOBILE3	1.5	0	0	33.3	66.7	100

Accessories (None)

Table A-6 (cont'd)

Class IIB-IV--Light Heavy-Duty Vehicles (cont'd)
Future Non-Engine Related Fuel Economy Improvements

Automatic Overdrive

Source	% Imprv.	% Penetration (cumulative) 1977	1982	1987	1992	1997
EEA [1]	9.6	0	0	16.7	33.3	50.0
[15]	10.0					
MOBILE3	5.0	0	0	16	32	48

Manual Overdrive

Source	% Imprv.	% Penetration (cumulative) 1977	1982	1987	1992	1997
EEA [1]	5.0	0	10	20	30	40
[15]	5.0	0	12.5	25	37.5	50
MOBILE3	5.0	0	10	20	30	40

ETC.

Source	% Imprv.	% Penetration (cumulative) 1977	1982	1987	1992	1997
EEA [1]	6.0	0	0	0	25	50
MOBILE3	0.0					

Table A-7

Class VI-VIIIa--Medium Heavy-Duty Vehicles
Future Non-Engine Related Fuel Economy Improvements

Weight Reduction (none)

Radials

Source	% Imprv.	% Penetration (cumulative) 1977	1982	1987	1992	1997
EEA [1]	4	6	13.5	13.5	6	0
IHC [16]	6					
IHC [17]	3.2/4.9/5.3 (city/suburb/hwy)					
ORNL [18]		10.6		50 (max. penetration)		
GM [13]	3-5/4-8/5-9					
MOBILE3	3.2	7	14	14	7	0

Advanced Radials

Source	% Imprv.	% Penetration (cumulative) 1977	1982	1987	1992	1997
EEA [1]	8	0	0	6.25	15	30
IHC [16]	8	0	0	0	6	14.75
MOBILE3	6.0	0	0	6	15	30

Aerodynamics (body) - none

Aerodynamics (add-on)

Source	% Imprv.	% Penetration (cumulative) 1977	1982	1987	1992	1997
EEA [1]	6	3	6.3	8.3	11.3	16.3
EEA [15]	6	3				18
IHC [16]	4.8	3	5	7	13	23
IHC [17]	2.5/6.8/12.3 (city/suburb/hwy)					
GM [13]	1.1					
MOBILE3	2.5	3	5	7	13	20

Table A-7 (cont'd)

Class VI-VIIIa--Medium Heavy-Duty Vehicles (cont'd)
Future Non-Engine Related Fuel Economy Improvements

Drivetrain Lubricants

Source	% Imprv.	% Penetration (cumulative) 1977	1982	1987	1992	1997
EEA [1]	1.5	0	0	33	67	100
IHC [16]	3.0	0	0	12.5	50	100
IHC [17]	1.5					
MOBILE3	1.5	0	0	33	67	100

Fan Drives

Source	% Imprv.	% Penetration (cumulative) 1977	1982	1987	1992	1997
EEA [1]	4.0	18.0	73	100	100	100
IHC [16]	4.0	0.0	15.0	80	100	100
IHC [17]	5.3/5.1/4.2	(city/suburb/hwy)				
ORNL [18]		16.0	100% maximum penetration			
MOBILE3	5.3	18	50	100	100	100

Speed Control

Source	% Imprv.	% Penetration (cumulative) 1977	1982	1987	1992	1997
EEA [1]	6.0	0	5	6.7	10	15
IHC [16]	6.0	0	0	2	5	10
MOBILE3	6.0	0	0	5	10	15

Table A-8

Class VIIIb--Heavy Heavy-Duty Vehicles
Future Non-Engine Related Fuel Economy Improvements

Weight Reduction (none)

Radials

Source	% Imprv.	% Penetration (cumulative) 1977	1982	1987	1992	1997
EEA [1]	6.0	26	65	45	20	0
EEA [15]	6.0	26		70 max. penetration		
IHC [16]	8.4	-	50	50	25	0
IHC [17]	6.8/10.8/9.9	(city/suburb/hwy)				
ORNL [18]		100 percent max. penetration				
GM [13]	3-5/4-8/5-9	100 percent max. penetration				
GM [13]	6.4					
MOBILE3	6.8	25	65	45	20	0

Advanced Radials

Source	% Imprv.	% Penetration (cumulative) 1977	1982	1987	1992	1997
EEA [1]	12.0	0	1.7	25	50	70
IHC [16]	12.4	0	1.5	31.5	56.5	81.5
IHC [17]	10.2/15.0/13.8	(city/suburb/hwy)				
MOBILE3	10.2	0	1.7	25	50	70

Table A-8 (cont'd)

Class VIIIb--Heavy Heavy-Duty Vehicles (cont'd)
Future Non-Engine Related Fuel Economy Improvements

Aerodynamics (body) - none

Aerodynamics (add-on)

Source	% Imprv.	% Penetration (cumulative) 1977	1982	1987	1992	1997
EEA [1]	6.0	10	22	34	48	60
EEA [15]	6.0		58 (maximum penetration)			
IHC [16]	5	10	17.5	60	60	60
IHC [17]	2.4/6.7/10.9	(city/suburb/hwy)				
GM [13]	4.3-9					
ORNL [18]		11.2	24.4	50 max. penetration		
MOBILE3	2.5	10	22	34	48	58

Drivetrain Lubricants

Source	% Imprv.	% Penetration (cumulative) 1977	1982	1987	1992	1997
EEA [1]	1.5	0	0	33	67	100)
IHC [16]	3.0	0	0	12.5	50	100
[17]	1.5		100 (maximum penetration)			
MOBILE3	1.5	0	0	33	67	100

Fan Drives

Source	% Imprv.	% Penetration (cumulative) 1977	1982	1987	1992	1997
EEA [1]	6.0	45	98	100	100	100
EEA [15]	4.0	48	48	48	48	48
IHC [16]	6.0	-	98	100	100	100
IHC [17]	6.8/6.7/6.9	(city/suburb/hwy)				
ORNL [18]		47.7	100 (maximum penetration)			
MOBILE3	6.8	48	98	100	100	100

Table A-8 (cont'd)

Class VIIIb--Heavy Heavy-Duty Vehicles (cont'd)
Future Non-Engine Related Fuel Economy Improvements

Speed Control

Source	% Imprv.	% Penetration (cumulative) 1977	1982	1987	1992	1997
EEA [1]	5.0	8	6	18	30	50
IHC [16]	5.0	-	-	12	24	44
MOBILE3	5.0	8	8	16	30	50

Table A-9

EEA Post-1977 Input Data

CLASS	YEAR	VMTG	VMTD	UVMTG	UVMTD	TEG	TED	SF	DF	CF
C2B34	1979	11614	11614	0.79	0.00	0.0000	0.0000	0.5451	0.0000	1.0000
C2B34	1982	11614	11614	0.79	0.79	0.0750	0.0090	0.6730	0.1616	0.8384
C2B34	1987	11614	11614	0.79	0.79	0.0460	0.0460	0.6045	0.2500	0.7500
C2B34	1992	11614	11614	0.79	0.79	0.1010	0.1010	0.5844	0.3000	0.7000
C2B34	1997	11614	11614	0.79	0.79	0.0410	0.0410	0.5802	0.3000	0.7000
C2B34	2002	11614	11614	0.79	0.79	0.0410	0.0410	0.5702	0.3000	0.7000
C0005	1979	9979	9979	0.73	0.00	0.0000	0.0000	0.0047	0.0000	1.0000
C0005	1982	9979	9979	0.73	0.00	0.0274	0.0342	0.0029	0.0000	1.0000
C0005	1987	9979	9979	0.00	0.00	0.0456	0.0570	0.0000	0.0000	1.0000
C0005	1992	9979	9979	0.00	0.00	0.0440	0.0550	0.0000	0.0000	1.0000
C0005	1997	9979	9979	0.00	0.00	0.0440	0.0550	0.6000	0.0000	1.0000
C0005	2002	9979	9979	0.00	0.00	0.0440	0.0550	0.0000	0.0000	1.0000
C0006	1979	9734	22188	0.75	0.56	0.0000	0.0000	0.1532	0.1720	0.8280
C0006	1982	9734	19115	0.75	0.65	0.0274	0.0342	0.0510	0.3770	0.6230
C0006	1987	9734	[illegible]	0.75	0.66	0.0456	0.0570	0.0494	0.4300	0.5700
C0006	1992	9734	[illegible]	0.75	0.66	0.0368	0.0460	0.0481	0.5000	0.5000
C0006	1997	9734	18545	0.75	0.67	0.0440	0.0550	0.0506	0.5500	0.4500
C0006	2002	9734	18545	0.75	0.67	0.0440	0.0550	0.0506	0.5500	0.4500
C0007	1979	[illegible]	[illegible]	0.71	0.39	0.0000	0.0000	0.0595	0.6000	0.4000
C0007	1982	[illegible]	[illegible]	0.71	0.39	0.0274	0.0342	0.1175	0.5800	0.4200
C0007	1987	[illegible]	[illegible]	0.71	0.40	0.0456	0.0570	0.1675	0.6000	0.4000
C0007	1992	[illegible]	[illegible]	0.71	0.41	0.0368	0.0460	0.1688	0.6500	0.3500
C0007	1997	[illegible]	23488	0.71	0.43	0.0440	0.0550	0.1667	0.7000	0.3000
C0007	2002	11223	23488	0.71	0.43	0.0440	0.0550	0.1667	0.7000	0.3000
C0801	1979	12850	27959	0.71	0.37	0.0000	0.0000	0.0216	0.7700	0.2300
C0801	1982	12850	27037	0.71	0.41	0.0274	0.0342	0.0140	0.8890	0.1110
C0801	1987	12850	27037	0.71	0.41	0.0456	0.0570	0.0141	0.8750	0.1250
C0801	1992	12850	26393	0.71	0.42	0.0368	0.0460	0.0169	0.9411	0.0589
C0801	1997	12850	25779	0.71	0.43	0.0440	0.0550	0.0173	1.0000	0.0000
C0801	2002	12850	25779	0.71	0.43	0.0440	0.0550	0.0173	1.0000	0.0000
C0802	1979	0	62500	0.00	0.13	0.0000	0.0000	0.2159	1.0000	0.0000
C0802	1982	0	62500	0.00	0.13	0.0000	0.0570	0.1416	1.0000	0.0000
C0802	1987	0	62500	0.00	0.13	0.0000	0.0850	0.1624	1.0000	0.0000
C0802	1992	0	62500	0.00	0.13	0.0600	0.0740	0.1618	1.0000	0.0000
C0802	1997	0	62500	0.00	0.13	0.0000	0.0550	0.1852	1.0000	0.0000
C0802	2002	0	62500	0.00	0.13	0.0000	0.0550	0.1852	1.0000	0.0000