Proposed Methodology to Model Carbon Dioxide Emissions
and Estimate Fuel Economy

SUMMARY

This memorandum introduces a methodology to calculate carbon dioxide (CO_2) exhaust emissions for light duty passenger cars, light duty trucks, and medium duty vehicles in the Air Resources Board's (ARB) motor vehicle emission inventory model, EMFAC7G. Statistically, inertia weight and engine size were found to be the primary factors that affect the magnitude of CO_2 emissions; however, model year (MY) specific CO_2 emission rates when calculated using the technology groupings employed for hydrocarbon (HC), carbon monoxide (CO), and nitrogen oxides (NO_X) in the California Inspection and Maintenance Emission Factors (CALIMFAC) model produced similar results. An explanation for this is that engine size is implicitly weighted within each model year group.

Once CO_2 emissions were modeled, fuel economy and fuel consumption estimates were derived using a carbon balance methodology. During the last decade, Corporate Average Fuel Economy (CAFE) regulations were adopted such that the average fuel economy of vehicles increased from 18.0 miles per gallon to 27.5 miles per gallon. As a consequence, vehicles produce less CO_2 today than a decade ago. Despite decreases on a per vehicle basis, the overall magnitude of CO_2 emitted into the atmosphere will increase due to the steadily increasing vehicle population and vehicle miles of travel. This memorandum also presents an assessment of the impact that various motor vehicle regulations, which were intended to reduce HC and CO emissions, have on CO_2 emissions.

INTRODUCTION

Currently in EMFAC, there is no provision to model CO_2 exhaust emissions from motor vehicles. While CO_2 emissions are by far the largest amount of emissions produced by motor vehicles, they are thought to pose no immediate threat to the environment and health of human beings. Therefore, CO_2 has not been regulated as have HC, CO, and NO_X. Due to recent concerns about the increasing production of greenhouse gases and increasing use of fossil fuels, regulators have begun attempts to limit the release of CO_2 and other greenhouse gases into the atmosphere.

With a methodology to model CO_2 exhaust emission, fuel economy for driving conditions under different speeds can be determined since the basic byproducts of fuel combustion (CO_2, HC, CO) can be estimated. Another reason to model CO_2 emissions is to estimate fuel consumption. Currently, fuel consumption is estimated by weighing the model year specific

Corporate Average Fuel Economy standard by the registration fractions and vehicle miles traveled.

METHODOLOGY

CO_2 Basic Emission Rates

The current analysis includes 1,910 vehicles, ranging from model year 1975 through 1989. These vehicles were tested over the Federal Test Procedure (FTP) at the State's Haagen-Smit Laboratory (HSL) during various surveillance projects conducted by the ARB. The FTP is a driving cycle designed to simulate a typical trip in an urban area. The cycle consists of three parts: cold start (bag 1), stabilized or running portion (bag 2), and hot start (bag 3). During surveillance projects, vehicles from randomly selected owners are solicited and tested on the FTP to measure HC, CO, NO_X, and CO_2 emissions. The emissions test data provide the ARB with estimates of in-use emissions and status of the emission control systems for in-use vehicles. For the purpose of this analysis, CO_2 emissions of gasoline powered, light duty passenger vehicles were evaluated. The distribution of test vehicles by model year are shown in Table 1.

Table 1. Distribution of test vehicle by model year.

Model Year	Tested
1975	37
1976	41
1977	54
1978	66
1979	73
1980	133
1981	179
1982	224
1983	261
1984	248
1985	197
1986	158
1987	95
1988	82
1989	62

Total	1910

An initial Analysis of Variance (ANOVA) test was done to determine the trends and factors that affect CO_2 emissions. CO_2 emissions as a function of inertia weight, engine displacement group, power (or compression ratio), fuel delivery system, catalyst and transmission type were analyzed. The engine displacement group consisted of three sub-groupings (4 cylinder, 6 cylinder, and 8 cylinder). Engine displacement under 2.6 liters were placed in the 4 cylinder group, displacement over 2.6 and under 3.8 liters were placed in the 6 cylinder group, and displacement over 3.8 liters were placed in the 8 cylinder group. The results of this analysis indicated that inertia weight and engine displacement group were significant factors in modeling CO_2 emissions. Typically, inertia weight, engine displacement, and compression ratio describe engine characteristics and performance, while fuel delivery system and catalyst type represent the emission characteristics of a vehicle. Further analysis of correlation confirmed these results as shown in Table 2.

Table 2. Correlation analysis (R^2).

	Bag 1 CO_2	Bag 2 CO_2
Inertia Weight	0.741	0.699
Displacement Group	0.762	0.724
Power	0.425	0.344

Table 3 shows a significant correlation between engine displacement and vehicle inertia weight which implies that CO_2 emissions can be modeled by either engine displacement or inertia weight.

Table 3. R^2 between variable.

	Inertia Weight	Displacement Group	Power
Inertia Weight	1.000	0.854	0.412
Displacement Group	0.854	1.000	0.393
Power	0.412	0.393	1.000

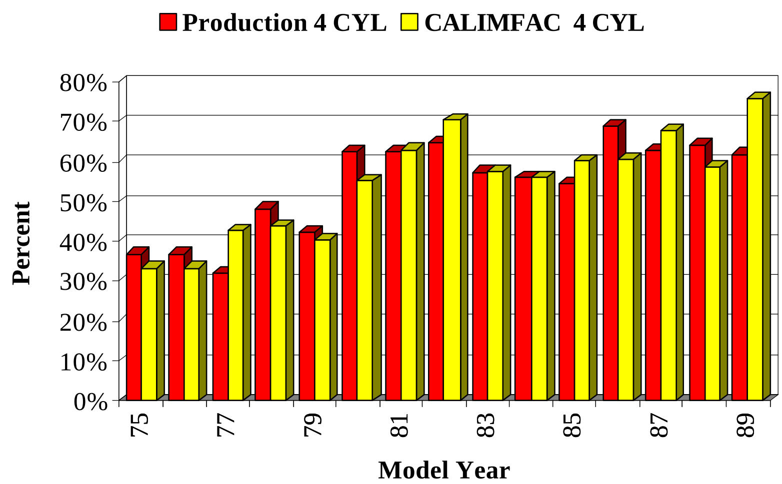
Further comparison of CO_2 emission estimates by engine displacement and by CALIMFAC's existing technology groups (non-catalyst, oxidation catalyst without secondary air, oxidation catalyst with secondary air, carburetted/throttle body injection with three-way catalyst, and multi-point fuel injection with three-way catalyst) indicated no significant difference. Results are shown in Table 4.

Table 4. Bag 2 model year specific CO_2 emission factors (g/mi) comparison by displacement and by CALIMFAC groups.

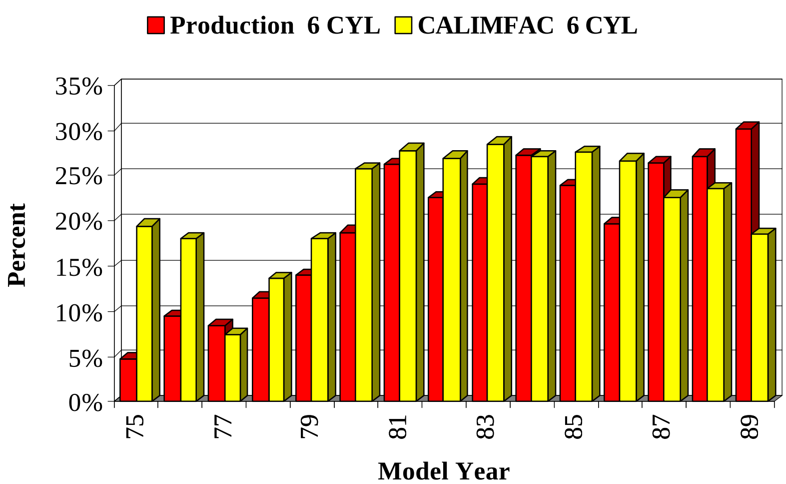
Model Year	Bag 2 Displacement Group	Bag 2 CALIMFAC Group	Difference
1975	585.22	564.42	3.6%
1976	555.16	554.19	0.2%
1977	596.06	587.27	1.5%
1978	536.13	533.85	0.4%
1979	561.63	559.37	0.4%
1980	455.76	456.99	0.3%
1981	427.55	425.17	0.6%
1982	417.76	404.76	3.1%
1983	438.05	438.92	0.2%
1984	437.65	441.15	0.8%
1985	429.67	418.26	2.7%
1986	400.65	411.03	2.6%
1987	410.24	402.59	1.9%
1988	411.33	421.56	2.5%
1989	413.80	406.91	1.7%

The similar trend of CO_2 emissions by engine displacement and by CALIMFAC technology groups can be explained based on the fact that within each model year grouping, engine size is implicitly weighted, as shown in Figure 1.

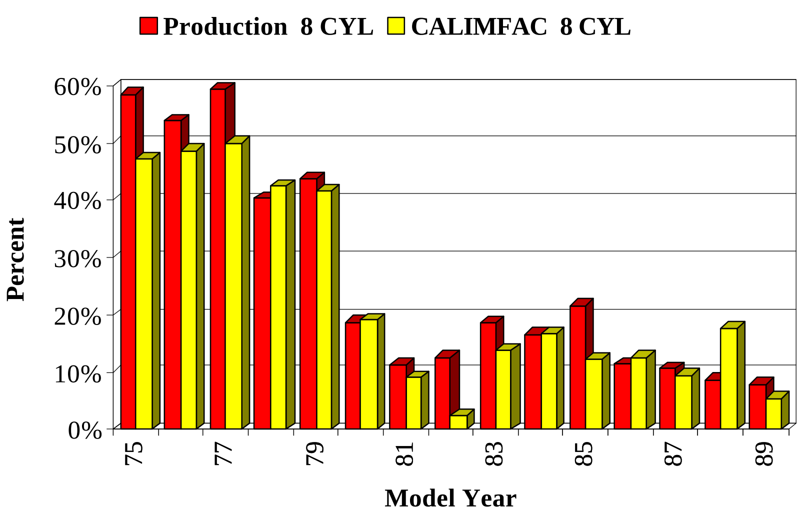
Figure 1. Comparison between actual production and CALIMFAC data.



(a). 4 cylinder group



(b). 6 cylinder group



(c). 8 cylinder group

The actual production figures were taken from a previous analysis of CO_2 emissions performed in 1990. Therefore, basic emission rates for CO_2 emissions were calculated using the technology groups that exist in CALIMFAC.

A least square regression analysis was performed with respect to the mileage of the vehicle (odometer reading) by model year and technology grouping to obtain FTP bag specific zero mile (ZM) and deterioration rates (DR) for 1975 to 1989 MY. The regression analysis showed that CO_2 emissions were not a function of the mileage of the vehicle. Thus, no deterioration rate was calculated for CO_2 emissions. Since least square regression could not be used, the basic emission rates for bag 2 CO_2 were calculated using an average of CO_2 emissions by model year and technology grouping. The results of the calculations are shown in Table 5.

Table 5. Bag 2 CO_2 emission rate (g/mi) by technology groups.

Year	Non-Catalyst	Oxidation Catalyst w/o Secondary Air	Oxidation Catalyst w/ Secondary Air	CARB/TBI TWC	MPFI TWC
1975	337.64	497.71	606.55		
1976	347.79	537.13	592.38		
1977	367.88	474.00	623.50		485.54
1978	369.37	392.18	581.56	363.83	*
1979	370.59	391.52	616.55	458.79	582.35
1980		345.86	418.00	501.80	463.79
1981		359.05	378.22	444.70	409.62
1982			340.49	422.35	403.97
1983			367.57	465.65	405.62
1984				453.48	399.58
1985				416.07	424.18
1986				400.00	427.29
1987				369.63	437.59
1988				387.67	447.18
1989				347.95	434.14

CARB - Carburetted
TBI - Throttle body injection
MPFI - Multi-point fuel injection
TWC - Three-way catalyst
* - No data available

Table 6 shows the technology fractions by model-year incorporated in CALIMFAC I.

Table 6. Technology fractions by model year.

Year	Non-Catalyst	Oxidation Catalyst w/o Secondary Air	Oxidation Catalyst w/ Secondary Air	CARB/TBI TWC	MPFI TWC
1975	10.0%	14.0%	76.0%		
1976	12.0%	16.0%	72.0%		
1977	9.0%	7.0%	82.0%		2.0%
1978	5.0%	10.0%	80.0%	3.0%	2.0%
1979	8.0%	11.0%	69.0%	7.0%	5.0%
1980		11.4%	26.5%	49.4%	12.7%
1981		8.9%	9.7%	66.9%	14.5%
1982			18.1%	66.8%	15.1%
1983			14.4%	64.6%	21.0%
1984				77.2%	22.8%
1985				67.8%	32.2%
1986				59.6%	40.4%
1987				51.5%	48.5%
1988				43.8%	56.2%
1989				32.0%	68.0%

The MY bag specific composite CO_2 emission rates were obtained by weighing CO_2 emissions by technology fractions as shown in Table 7.

Table 7. Model year bag specific composite emission factor (g/mi).

	Composite Emission Factor	
Year	Bag 1	Bag 2
1975	570.08	564.42
1976	562.83	554.19
1977	589.25	587.27
1978	528.66	533.85
1979	554.08	559.37
1980	456.12	456.99
1981	427.53	425.17
1982	407.79	404.76
1983	430.87	438.92
1984	432.11	441.15
1985	419.91	418.26
1986	405.02	411.03
1987	397.06	402.59
1988	406.34	421.56
1989	399.13	406.91

Adjustments to Basic Emission Rates

Emission rates for 1990 to 1997 model years were assumed to be the same as for 1989 model year because the CAFE standards did not change dramatically after 1989. Emission rates for 1998 plus model years were adjusted to account for the phase in of zero-emission vehicles (ZEV). The fleet average emissions for 1998 plus model years reflect no CO_2 emissions for ZEVs. The ARB's Low Emission Vehicle regulation mandates an implementation schedule that requires 2 percent ZEVs in 1998 to 2000, 5 percent ZEVs in 2001 and 2002, and 10 percent ZEVs in 2003 and later years.

The effect of the reformulated fuels regulations (Phase I fuel from 1992 through 1995 and Phase II fuel in 1996 plus years) on CO_2 emissions was found to be insignificant. Data on CO_2 emissions of vehicles tested on Phase I and Phase II fuels were obtained from Auto/Oil (16 vehicles), ARCO (9 vehicles), and General Motors(GM)/Western States Petroleum Association(WSPA)/Air Resources Board (20 vehicles) test programs. For example, data obtained from Auto/Oil were used to compare CO_2 emissions from industry average (before 1992) against Phase I fuel. ARCO's program was used to test fuels with composition similar to industry average and Phase II fuels requirement. Data obtained from GM/WSPA/ARB test program were used to compare fuels similar to Phase I and Phase II fuels. Results of the analysis are shown in Tables 8-10.

Table 8. Comparison of CO_2 emissions(g/mi) from Auto Oil test program.

	Industry Average	Phase I	Difference
CARB/TBI	359.43	364.34	1.4%
MPFI	398.56	400.46	0.5%

Table 9. Comparison of CO_2 emissions(g/mi) from ARCO test program.

	Industry Average	Phase I	Difference
CARB/TBI	342.91	354.30	3.3%
MPFI	419.99	419.03	-0.2%

Table 10. Comparison of CO_2 emissions(g/mi) from GM/WSPA/ARB test program.

	Phase I	Phase II	Difference
Non-Catalyst	489.23	497.15	1.6%
Oxidation Catalyst	520.97	502.38	-3.6%
CARB/TBI	330.49	316.05	-4.4%
MPFI	425.34	420.74	-1.1%

Speed correction factors (SCF) for CO_2 emissions on catalyst-equipped vehicles were developed using a similar methodology that was used for HC, CO, and NO_X emissions. The methodology for non-catalyst vehicles can be found in the appendix. U.S. EPA SCF data were combined with ARB SCF data to generate the SCF equations. The federal data consisted of CO_2 emissions for speed cycles ranging from 2.5 to 48 miles per hour. The ARB data consisted of CO_2 emissions for speed cycles ranging from 16 to 64.3 miles per hour. The generation of the SCFs involved the following steps:

1) At each speed, the ratio of the actual emissions for the cycle to the baseline emissions (at 16 MPH) of vehicles tested at both speeds was calculated. Separate calculations were performed for fuel injected and carburetted vehicles.

2) The ratios in terms of both grams/mile [SCF = (g/mi)/(g/mi @16 MPH)] basis as well as grams/hour [SCF = (g/hr)/(g/hr @ 16 MPH)] basis were analyzed.

3) Natural logarithm function was used on the calculated ratios.

4) Using a statistical software (SAS) and a trial and error approach, the best form of the equation (second, third, etc.) that fits the natural logarithmic data was determined.

5) For CO_2 SCFs, the grams/mile basis was determined to have a better statistical fit.

Using the above methodology, the following SCF equation and coefficients (shown in Table 11) were obtained:

$$SCF(S) = EXP[A*(S-16) + B*(S-16)^2 + C*(S-16)^3] \quad (1)$$

where

SCF = Speed correction factor at speed S
S = Speed in miles per hour
A,B,C = Coefficients of speed correction equation

Table 11. Speed correction factor regression coefficient.

	A	B	C
CARB/TBI	-0.0534517	0.0019033	-0.000018153
MPFI	-0.0528766	0.0018191	-0.000017102

The resulting regression equation was forced through unity at normalization speed of 16 MPH, or bag 2 speed of the FTP. Figure 2 and Figure 3 compare the predicted SCF with the observed SCF.

Figure 2. Predicted vs. actual speed correction factor (CARB/TBI).

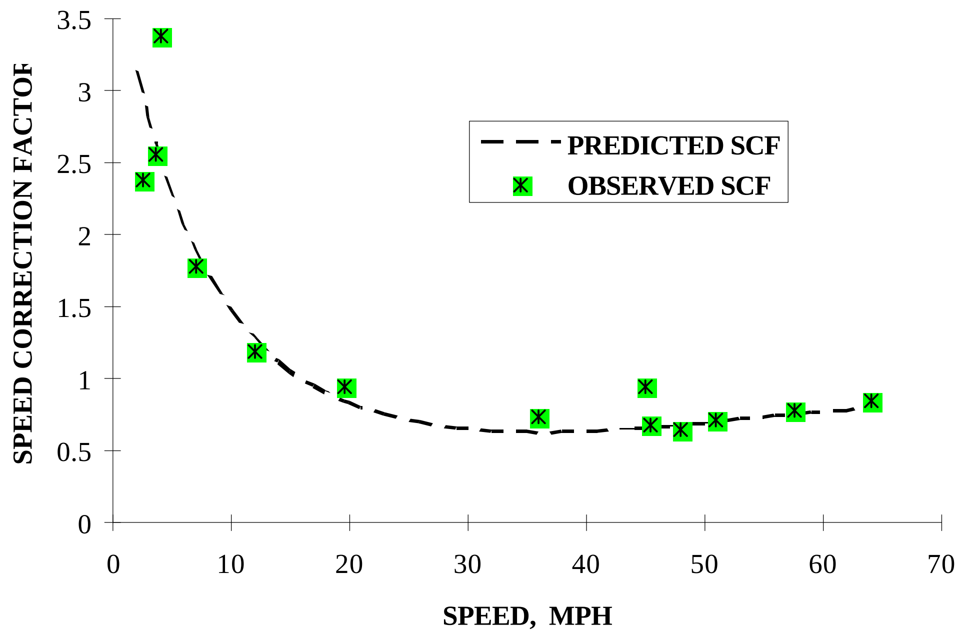
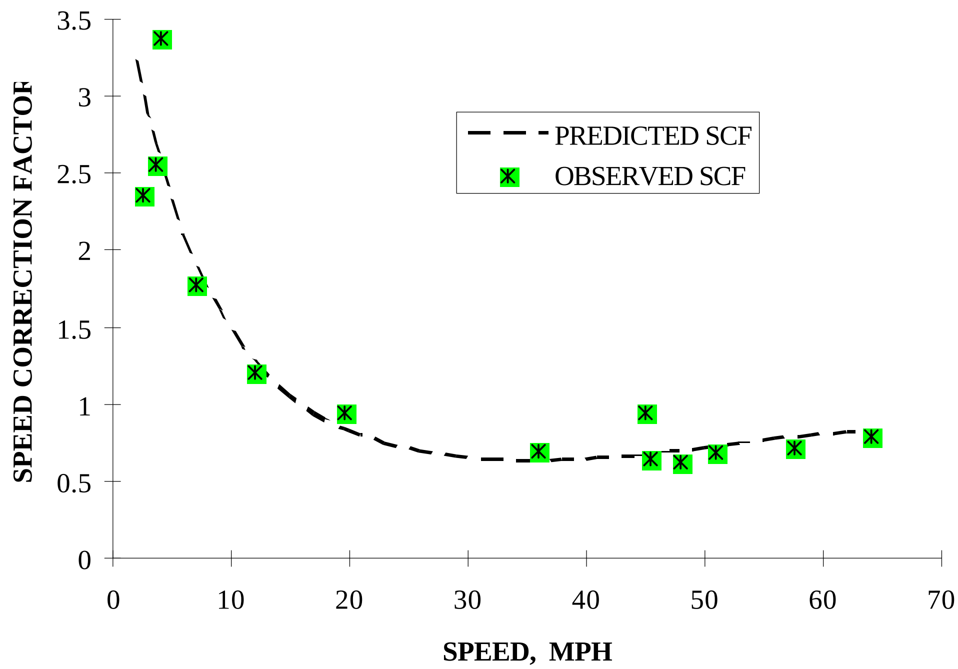


Figure 3. Predicted vs. actual speed correction factor (MPFI).



TONS PER DAY ESTIMATE

Model year specific bag 2 emission rates (Table 7) were used with activity factors, such as mileage accrual rates, vehicle registrations, and travel fractions, to obtain the fleet average running exhaust CO_2 emission factors for calendar years 1995 and 2010, as shown in Table 12 and Table 13. Start exhaust CO_2 emission were also calculated using the same methodology used for HC, CO, and NO_X in EMFAC7G. The starts methodology is described in detail in a separate document entitled "Methodology for Calculating and Redefining Cold and Hot Start Emissions."

Table 12. Fleet average CO_2 emission for 1995.

Year	Accrual Rate (mi)	Reg. Fraction	Travel Fraction	Composite (g/mi)	Running MYEF (g/mi)
1995	14169	0.064	0.0870	406.91	35.41
1994	13563	0.096	0.1251	406.91	50.91
1993	12956	0.091	0.1132	406.91	46.07
1992	12349	0.087	0.1024	406.91	41.65
1991	11742	0.082	0.0921	406.91	37.48
1990	11135	0.075	0.0798	406.91	32.49
1989	10528	0.071	0.0714	406.91	29.05
1988	9921	0.065	0.0618	421.56	26.06
1987	9314	0.060	0.0535	402.59	21.55
1986	8707	0.057	0.0477	411.03	19.62
1985	8101	0.049	0.0377	418.26	15.76
1984	7597	0.039	0.0287	441.15	12.64
1983	7164	0.031	0.0210	438.92	9.21
1982	6788	0.024	0.0154	404.76	6.23
1981	6457	0.021	0.0133	425.17	5.63
1980	6214	0.020	0.0118	456.99	5.37
1979	6071	0.019	0.0113	559.37	6.33
1978	5940	0.018	0.0101	533.85	5.37
1977	5819	0.014	0.0076	587.27	4.49
1976	5707	0.009	0.0052	554.19	2.87
1975	5603	0.007	0.0039	564.42	2.22
				Total	416.42

MYEF - Model year emission factor

Table 13. Fleet average CO_2 emission for 2010.

Year	Accrual Rate (mi)	Reg. Fraction	Travel Fraction	Composite (g/mi)	Running MYEF (g/mi)
2010	14169	0.061	0.0850	366.22	31.13
2009	13563	0.092	0.1222	366.22	44.77
2008	12956	0.087	0.1107	366.22	40.53
2007	12349	0.083	0.1001	366.22	36.68
2006	11742	0.078	0.0898	366.22	32.89
2005	11135	0.073	0.0797	366.22	29.19
2004	10528	0.067	0.0697	366.22	25.53
2003	9921	0.061	0.0591	366.22	21.65
2002	9314	0.056	0.0511	386.56	19.76
2001	8707	0.050	0.0430	386.56	16.61
2000	8101	0.044	0.0351	398.77	13.99
1999	7597	0.038	0.0286	398.77	11.39
1998	7164	0.033	0.0231	398.77	9.23
1997	6788	0.028	0.0186	406.91	7.57
1996	6457	0.023	0.0149	406.91	6.05
1995	6214	0.020	0.0120	406.91	4.87
1994	6071	0.016	0.0097	406.91	3.96
1993	5940	0.014	0.0079	406.91	3.23
1992	5819	0.011	0.0065	406.91	2.65
1991	5707	0.009	0.0052	406.91	2.13
1990	5603	0.008	0.0044	406.91	1.78
1989	5505	0.007	0.0038	406.91	1.54
1988	5414	0.006	0.0032	421.56	1.37
1987	5328	0.005	0.0028	402.59	1.14
1986	5247	0.005	0.0026	411.03	1.07
1985	5170	0.004	0.0021	418.26	0.90
1984	5098	0.003	0.0017	441.15	0.76
1983	5029	0.003	0.0013	438.92	0.59
1982	4963	0.002	0.0010	404.76	0.42
1981	4901	0.002	0.0010	425.17	0.41
1980	4842	0.002	0.0009	456.99	0.42
1979	4785	0.002	0.0009	559.37	0.52
1978	4730	0.002	0.0009	533.85	0.47
1977	4678	0.002	0.0007	587.27	0.41
1976	4628	0.001	0.0005	554.19	0.27
				Total	375.82

The final output of the motor vehicle emission model after applying vehicle miles traveled and speed correction factors is the tons per day (tpd) estimate. The tpd estimate includes the running exhaust contribution plus the start contribution. Table 14 shows the total tons per day estimates of CO_2 emissions in year 1995 and 2010.

Table 14. Projected vehicle miles traveled (VMT) population and tons per day.

Year	VMT Per Day SCAB	SCAB Tons Per Day Running	Start
1995	221,470 K	73.31 K	3.22 K
2010	274,984 K	82.51 K	3.70 K

FUEL ECONOMY

Using the carbon balance methodology from the Federal Register (40 CFR, Part 600), the equation to determine fuel economy estimate is:

$$FE = \frac{2421}{(CO_2 \times 0.273) + (HC \times 0.866) + (CO \times 0.429)} \quad (2)$$

where

- FE = Fuel economy in miles per gallon
- CO_2 = Carbon dioxide exhaust emissions in grams per mile
- HC = Total running exhaust plus running losses hydrocarbon emissions in grams per mile
- CO = Running exhaust carbon monoxide emissions in grams per mile

The above equation was used with certain assumptions to simplify fuel economy estimate calculations. Vehicles were assumed to be gasoline-fueled vehicles and tested with similar fuel properties. Fuel economy calculations with respect to different speeds are shown in Table 15.

Table 15. Effect of speed on fuel economy (mpg) for calendar year SCAB 1995 and 2010.

SCAB 1995		SCAB 2010	
Speed (MPH)	Fuel Economy (mpg)	Speed (MPH)	Fuel Economy (mpg)
5	9.30	5	10.05
10	14.60	10	15.67
15	20.46	15	21.90
20	26.02	20	27.83
25	30.47	25	32.60
30	33.33	30	35.69
35	33.44	35	35.75
40	34.60	40	37.02
45	34.30	45	36.74
50	32.96	50	35.37
55	31.05	55	33.45
60	28.93	60	31.41
65	26.46	65	29.48

Once fuel economy was calculated, the following equation was used to estimate fuel consumption:

$$\text{Fuel Consumption} = \frac{\text{VMT}}{\text{Fuel Economy}} \qquad (3)$$

In addition, fuel consumed during starts was added to calculate the total gallons consumed. Table 16 shows the comparison of the estimate of fuel consumption for calendar year 1995 and 2010 using the proposed methodology and current methodology.

Table 16. Fuel consumption (gallons) comparison for passenger cars.

Year	Proposed SCAB Running	Proposed SCAB Start	Proposed SCAB Total	Current SCAB Total
1995	7,680 K	535 K	8,215 K	8,944 K
2010	8,222 K	442 K	8,664 K	10,331 K

Per the current methodology, the calendar year specific fuel consumption is calculated by weighting model year CAFE standards for the vehicle fleet.

RECOMMENDATIONS

This methodology focused on the analysis of CO_2 emissions from light-duty vehicles. It is recommended that in future the following be analyzed:

1) CO_2 emissions for other gasoline powered vehicle categories (medium and heavy-duty vehicles) and all diesel powered vehicles.

2) Effects of temperature and emissions control component malfunction on CO_2 emissions should be investigated.

APPENDIX

SPEED CORRECTION FACTORS
Non-catalyst vehicle

To develop speed correction factors (SCF) for non-catalyst vehicles, a different dataset was required. Eleven vehicles consisting of passenger cars and light-duty trucks were tested over various test cycles from 2.5 to 64.4 miles per hour. The generation of the non-catalyst SCF involved the following steps:

1) Perform regression analysis using the eleven test points to determine SCF.

2) For non-catalyst CO_2 SCF, the grams/hour model was determined to have a better statistical fit than the gram/mile model.

Using the above methodology, the following SCF equation and coefficients (shown in Table 17) were obtained:

$$SCF(S) = [(A*S) + (B*S^2) + (C*S^3) + (D*S^4) + E] \quad \text{(in g/hr)} \qquad (4)$$

where

SCF	=	Speed correction factor at speed S
S	=	Speed in miles per hour
A,B,C,D	=	Coefficients of speed correction equation
E	=	Intercept term of equation

Converting the grams/hour model to grams/mile results in the following equation:

$$SCF(S) = \frac{[(A*S) + (B*S^2) + (C*S^3) + (D*S^4) + E]}{[(A*16) + (B*16^2) + (C*16^3) + (D*16^4) + E]} * \frac{16}{S} \qquad (5)$$

Table 17. Speed correction factor regression coefficient for non-catalyst vehicles.

	A	B	C	D	E
SCF	267.60355	0.00000	0.00000	0.00094	5194.99192

METHODOLOGY (LDT,MDT)

CO_2 Basic Emission Rates

The analysis of CO_2 basic emission rates for light-duty trucks (LDT) and medium-duty trucks (MDT) follows the same methodology as passenger cars. The set of test data includes 534 LDT and 4 MDT vehicles, ranging from model year 1975 through 1989. The distribution of test vehicles by model year are shown in Table 18.

Table 18. Distribution of test vehicle by model year.

Model Year	LDT	MDT
1975	18	
1976	11	
1977	14	
1978	18	
1979	21	1
1980	24	
1981	36	
1982	44	1
1983	65	2
1984	69	
1985	43	
1986	53	
1987	40	
1988	36	
1989	42	
Total	534	4

Similar to the analysis of passenger cars, LDT's CO_2 emissions can be best described by engine displacement group. The displacement groups were characterized by three categories: 4 cylinder, 6 cylinder and 8 cylinder. Table 19 shows the CO_2 emissions by number of cylinders group.

Table 19. LDT Bag CO_2 emissions by number of cylinders group.

	Bag 1			Bag 2		
Year	4 Cyl	6 Cyl	8 Cyl	4 Cyl	6 Cyl	8 Cyl
1975	431.50	579.36	641.08	455.31	573.25	629.93
1976	488.24	646.18	750.84	507.44	619.87	725.50
1977	444.07	533.65	657.41	443.49	574.77	659.10
1978	467.64	549.17	756.35	485.67	626.66	769.46
1979	459.97	602.65	680.10	469.45	614.00	666.54
1980	482.95	596.54	680.00	475.75	605.15	667.00
1981	439.70	607.67	593.63	441.80	639.91	584.81
1982	419.73	500.83	709.15	420.40	507.05	685.32
1983	423.09	481.43	673.92	411.98	501.54	687.23
1984	429.94	487.80	751.45	432.13	495.10	722.06
1985	407.47	478.98	729.59	409.46	480.61	706.77
1986	397.46	507.12	658.30	404.49	515.52	626.29
1987	404.04	523.97	658.00	392.13	549.51	630.00
1988	410.55	508.55	645.95	396.38	528.74	653.55
1989	400.55	497.15	607.29	399.54	501.72	609.05

In order to calculate the composite emission factors, the number of cylinder groupings were weighted by their respective fractions as shown in Table 20. The fractions were compiled from various surveillance programs and yearly California production totals as reported by LDT manufacturers.

Table 20. LDT displacement fractions.

Year	4 Cyl	6 Cyl	8 Cyl
1975	53.20%	9.38%	37.42%
1976	69.61%	6.27%	24.12%
1977	68.14%	8.69%	23.17%
1978	66.67%	11.11%	22.22%
1979	57.14%	14.29%	28.57%
1980	66.64%	29.16%	4.20%
1981	75.00%	19.44%	5.56%
1982	56.82%	27.27%	15.91%
1983	56.55%	21.24%	22.22%
1984	60.06%	27.75%	12.18%
1985	61.99%	26.51%	11.50%
1986	56.00%	33.50%	10.50%
1987	50.55%	40.40%	9.04%
1988	54.46%	37.94%	7.61%
1989	39.28%	44.49%	16.23%

The data from Table 19 were weighted with the displacement fractions in Table 20 to determine the composite bag specific LDT CO_2 basic emission rates as shown in Table 21.

Table 21. Bag specific LDT CO_2 basic emission rates (g/mi).

Year	Bag 1	Bag 2
1975	523.79	531.71
1976	561.45	567.06
1977	501.29	504.86
1978	540.86	564.40
1979	543.25	546.41
1980	524.35	521.51
1981	480.91	488.27
1982	487.89	486.18
1983	491.20	492.15
1984	485.17	484.93
1985	463.47	462.51
1986	461.58	464.97
1987	475.46	477.23
1988	465.63	466.16
1989	477.08	479.00

The LDTs CO_2 emission factors that were obtained by weighting cylinder groups were compared with emission factors obtained by using the CALIMFAC technology groups. Similar to the PC class, the differences were not significant. Table 22 shows the corresponding results.

Table 22. Bag 2 model year specific CO_2 emission factors (g/mi) comparison by cylinder grouping and by CALIMFAC groups.

Model Year	Bag 2 Grouping	CYL CALIMFAC	Bag 2 Difference
1975	531.71	519.97	2.2%
1976	567.06	592.84	-4.5%
1977	504.86	468.72	7.2%
1978	564.40	549.95	2.6%
1979	546.41	534.91	2.1%
1980	521.51	509.37	2.3%
1981	488.27	486.57	0.3%
1982	486.18	474.41	2.4%
1983	492.15	463.96	5.7%
1984	484.93	484.07	0.2%
1985	462.51	452.70	2.1%
1986	464.97	445.38	4.2%
1987	477.23	443.79	7.0%
1988	466.16	466.32	0.0%
1989	479.00	468.84	2.1%

The difference is rather insignificant due to the fact that engine size is implicitly weighted within the CALIMFAC technology groupings. Therefore, basic emission rates for LDTs CO_2 emissions were calculated using the technology groups that exist in CALIMFAC. In case of MDTs, there were only 4 data points available from the surveillance database. Yearly California production totals as reported by vehicle manufacturers indicate that majority of MDT vehicles are in the 8 cylinder groupings. Therefore, four data points for MDTs were combined with the 8 cylinder grouping data points of the LDT class to determine the basic emission rate for MDT vehicles as shown in Table 23.

Table 23. MDT CO_2 basic emission rates (g/mi).

Year	Bag 1	Bag 2
1975	641.08	629.93
1976	750.84	725.50
1977	657.41	659.10
1978	756.35	769.46
1979	687.50	672.06
1980	680.00	667.00
1981	593.63	584.81
1982	709.15	685.32
1983	674.92	687.42
1984	751.45	722.06
1985	729.59	706.77
1986	658.30	626.29
1987	658.00	630.00
1988	645.95	653.55
1989	607.29	609.05

Speed Correction Factor

Speed correction factors (SCF) for LDT's and MDT's CO_2 emissions were developed using a similar methodology that was used for PC's CO_2 emissions. Equations were developed from federal SCF data consisting of speed cycles ranging from 2.5 to 48 miles per hour. The LDT data consisted of 4 vehicles tested at the different speed cycles, while the MDT data consisted of 2 vehicles tested. The following steps summarize the method to obtain the speed correction factors:

1) At each speed, the ratio of the actual emissions for the cycle to the baseline emissions (16 MPH) of vehicles tested at both speeds was calculated.

2) The ratios in terms of both grams/mile [SCF = (g/mi)/(g/mi @16 MPH)] basis as well as grams/hour [SCF = (g/hr)/(g/hr @ 16 MPH)] basis were analyzed.

3) Natural logarithm function was used on the calculated ratios.

4) Using a statistical software (SAS) and trial and error approach, the best form of the equation that fits the natural log of the data was determined.

5) The gram/mile basis was determined to have a better statistical fit.

Using the above methodology, the following SCF equation and coefficients (shown in Table 24 for LDTs and Table 25 for MDTs) were obtained:

$$SCF(S) = EXP\ [A*(S-16) + B*(S-16)^2 + C*(S-16)^3] \quad (6)$$

where

SCF = Speed correction factor at speed S

S = Speed in miles per hour

A,B,C = Coefficients of speed correction equation

Table 24. LDT Speed correction factor regression coefficient.

A	B	C
-0.0530531	0.0014832	-0.00000309

Table 25. MDT Speed correction factor regression coefficient.

A	B	C
-0.0584881	0.0012904	0.00000652