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ABSTRACT

This paper describes the development of adjustment factors applicable to the EPA City and Highway MPG values. The paper discusses the data bases used, and the analytical methods employed to arrive at adjustment factors of 0.90 for the EPA City MPG value and 0.78 for the EPA Highway MPG value.

IT HAS BEEN WELL KNOWN FOR YEARS that the EPA MPG values in advertising, on new car labels, and in the Gas Mileage Guide overpredict actual consumer fuel economy experience. This subject is discussed in several earlier SAE papers (1)-(4).* To improve the MPG information available to consumers, EPA studied this shortfall and proposed (5) to adjust the MPG values by certain specific numerical adjustment factors.

NATURE OF THE ADJUSTMENTS

The development of MPG adjustment factors followed an EPA decision to adjust both the City MPG and the Highway MPG by "uniform constant adjustment factors". More sophisticated adjustment methodologies had been developed (1), but the use of uniform constant adjustments was preferred because these would preserve the overall MPG ranking of vehicles, and the marginal improvement of the more accurate adjustment methodology was not considered worth the perceived added complexity. Therefore, the analytical task was to find values of correction factors for city and highway driving, fc and fh, so that MPG values of:

$$\text{Adjusted City MPG} = fc \times \text{EPA City MPG}$$
and
$$\text{Adjusted Hway MPG} = fh \times \text{EPA Hway MPG}$$

were the most representative of the average MPG achieved in actual use.

Bi-Modal Analysis

In a bi-modal MPG label system, to develop the adjustment for the EPA city MPG value it was necessary to use data from vehicles that were operated in the city. The highway MPG adjustment was similarly concentrated on data from highway-driven cars. This limited the on-road MPG data bases to those that contained information on the degree of urbanization of the driving.

The data bases used contained two important parameters: city fraction (CF) and average miles per day (AMPD). The parameter CF is subjective, based on responses to a question of the type, "How much of

*Numbers in parenthesis refer to references listed at the end of this paper

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your driving was done in the city?", with a numerical response of CF = 100 if all driving was done in the city, and CF = 0 corresponding to all driving being non-city driving. The respondents were not given a definition of "city", so their responses reflect their own perceptions of city driving.

The other parameter, AMPD, is a non-subjective indicator of how vehicles are used. A vehicle driven many miles per day would tend to accumulate many of these miles in highway operation.

Stratifying the data by CF and AMPD, two vehicle subsets are isolated: those "city driven for shorter distances" and those "highway driven for longer distances". From these two data sets, the adjustment factors were to be derived.

Fuel Economy Data Base

Characteristics of the fuel economy data base are summarized in Tables 1 and 2.

The codes RAC, RMC, etc. refer to the drive ("F"ront, "R"ear), the transmission ("A"utomatic, "M"anual), and fuel system ("C"arbureted, fuel "I"njected, "D"iesel); a RAC vehicle is one with Rear wheel drive, an Automatic transmission, and a Carbureted engine.

Not all of the MPG data base was used. To focus on newer model year vehicles, MPG data used was restricted to 1979 and newer models. Also, as shown in Table 1, not all of the data sources had both CF and AMPD data. After screening for model year and the inclusion of both CF and AMPD, a total of some 43,000 data points remained.

Table 1

Qualitative Summary of In-use MPG Data

	GM*	EPA E.F.	Chrysler*	Ford*	DOE
Multimanufacturer:	yes	yes	no (Chry only)	no (Ford only)	yes
Technology coverage:	excellent	limited (no Diesels)	poor (minimal FI, no Diesels)	poor (minimal FI, no Diesels)	fair (minimal FI few Diesels
Vehicles consumer owned and driven:	yes	yes	company cars driven by executives	company cars driven by executives	some
Geographical coverage:	excellent	fair (7 locales)	poor (83% Mich.)	poor** (74% Mich.)	poor (unknown)
Seasonal coverage:	fair (biased to summr/fall)	fair (biased to sprng/fall)	fair (spring 81, winter 82)	fair (biased to summer)	poor (unknown)
City fraction data:	yes	sort of	yes	yes***	no
Miles/day data:	yes	yes	1981- no 1982- yes	yes	no

* model years 1979 and later.

** driving location known only by phone area code: all other sources (except DOE) known by ZIP code. There are 878 ZIPs but only 107 area codes.

*** systematic errors in 1979-80 Ford data as received; now corrected. Ford says 1981 data do not have this problem.

Table 2

Quantitative Summary of In-Use MPG Data

Total No. Data Points: 66,518

by data source:

Ford	GM	DOE	Chrys	EPA
37280	15280	9228	2630	2100

by model year:

1975	1976	1977	1978	1979	1980	1981	1982
2246	2160	3424	16207	13077	14303	13687	1414

by technology:

RAC	RAI	RAD	RMC	RMI	RMD
49494	1175	596	6216	349	32
FAC	**FAI**	**FAD**	**FMC**	**FMI**	**FMD**
3543	262	111	4017	436	287

by manufacturer:

Ford	GM	Chrys	AMC	VW+AP	Datsn
41184	14439	6591	871	836	625
Tyota	**Honda**	**Mazda**	**Volvo**	**MerBz**	**Peugo**
587	497	360	116	100	58

(balance of 254 divided among 6 others:
BMW, Subru, Fiat, Renau, Saab, Alfa)

by month:

Jan	Feb	Mar	Apr	May	Jun	
1190	5149	2473	1872	3764	4535	
Jul	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**?**
7141	2181	523	2626	2167	1165	2312

plus ... "Winter": 7934 "Summer": 13470 "Annual": 8016

by state:

Calif	Texas	NYork	Ohio	Penns	Illin	
5660	2303	1566	2333	1262	1610	
Flori	**Michi**	**NJers**	**Georg**	**NCaro**	**Indi**	**?**
1040	30292	695	658	530	797	7554

(balance of 10,218 divided among 38
other states, plus D.C. and P.R.
and 3 Canadian Provinces)

The CF/AMPD Data Base

The analysis required determination of "typical" values of CF and AMPD, to describe typical city and highway driving for consumer owned and driven vehicles. This determination of typical consumer CF and AMPD values used about 9,000 records of consumer data from the 43,000-record fuel economy data base (Ford and Chrysler non-consumer data were omitted), and some 10,000 records of J.D. Power data, which had valid consumer CF and AMPD data, although its perceived MPG data is considered unacceptable for MPG shortfall analysis.

This 19,000-record CF/AMPD data base was then divided into ninths, based on the tripartitioning of the number of data points for each of the two parameters. This subdivision of the data base is shown in Table 3.

The typical values of CF and AMPD were selected as the average values in two corners of the matrix: high CF, low AMPD; and low CF, high AMPD. These average values are given in Table 4.

Table 3

Cutpoints and Data Count for Tripartitioned CF/AMPD Data Base

	AMPD		
CF	26 or less	27 to 38	39 or more
75 or more	3249	2120	902
31 to 74	1707	2360	2204
30 or less	1314	1791	3165

Table 4

Characteristics of City-Driven and Highway-Driven Cars

Driving Mode	CF	AMPD
City-Driven	89	17
Highway-Driven	14	62

The analysis of the 43,000-record fuel economy data base then proceeded as follows: The data base was divided into nine subsets using the numerical cutpoints of CF and AMPD from Table 3.

To retain as much data as possible in each of the two modal subsets, the "city 4/9" of the data base was used as the "city" subset and the "highway 4/9" as the "highway" subset.

These vehicles in each subset represented different data sources, different times of the year, and a technological mix different from that of the fleet for which the adjustments would be used. These non-uniformities were addressed as follows.

The vehicles in each subset were subdivided into one of the twelve technology groups: 1) Front or Rear Drive, 2) Automatic or Manual Transmission and 3) Carbureted, Fuel Injected or Diesel. For each of the technology combinations, regression equations were developed relating their shortfall parameter, GPMR, to five variables: CF, AMPD, EPA 55/45 MPG, temperature, and odometer. To standardize for influencing variables, the temperature and odometer terms were reduced to constants by using 55 degF and 4000 miles for these variables, and the average value of the EPA 55/45 MPG of each class was substituted, resulting in class equations containing three terms: a constant, the CF term, and the AMPD term.

These class equations were aggregated by weighting each by its expected percentage in the future fleet (1).

The uniform adjustment factors (which equal 1/GPMR) are plotted as functions of AMPD, with CF as a parameter, in Figure 1. The CF effect on the highway adjustment factor is too small to show up on the graph.

DETERMINATION OF ACTUAL AMPD AND CF VALUES

Figure 1 shows how the value of the adjustment factors are influenced by CF and AMPD. In addition to the data bases that were used to determine the factors, other sources of data were investigated that contained information on why and where driving is done. The references found to be most useful were reports (6)-(7) from the 1977 Nationwide Personal Transportation Study (NPTS).

City Driving

Ref. 6 presents city travel stratified in several ways. Converting the miles per year data into miles per day, the average AMPD for overall driving is 27.9 miles. The data in reference (6) are stratified by degree of urbanization: inside or outside of Standard Metropolitan Statistical Area (SMSA). Investigating "city" travel characteristics leads to the choice of "inside SMSA, within central city". The AMPD for this type of travel is 27.4.

The value of 27.4 for AMPD characteristic of city driving represents driving on all types of roads within a central city of a SMSA. This consists of driving on city streets - the typical image of "city driving" - and also driving on freeways in the central city of a SMSA. Because this freeway driving is not considered really "city" in nature, the VM-1 Table for 1981 (8) was used to determine what portion of travel in urban areas was done on urban interstates; this value is 0.200.

Therefore the AMPD of 27.4 was corrected by a factor of 0.800 to adjust it to the AMPD most characteristic of city driving, which is 21.9 miles per day. From Figure 1, at 21.9 AMPD and CF = 100 the value for fc is 0.90.

Another way to define city driving is to extract from each of the surveys that data which can be said to be "pure city": those survey responses indicating CF values of 100. (Table 5)

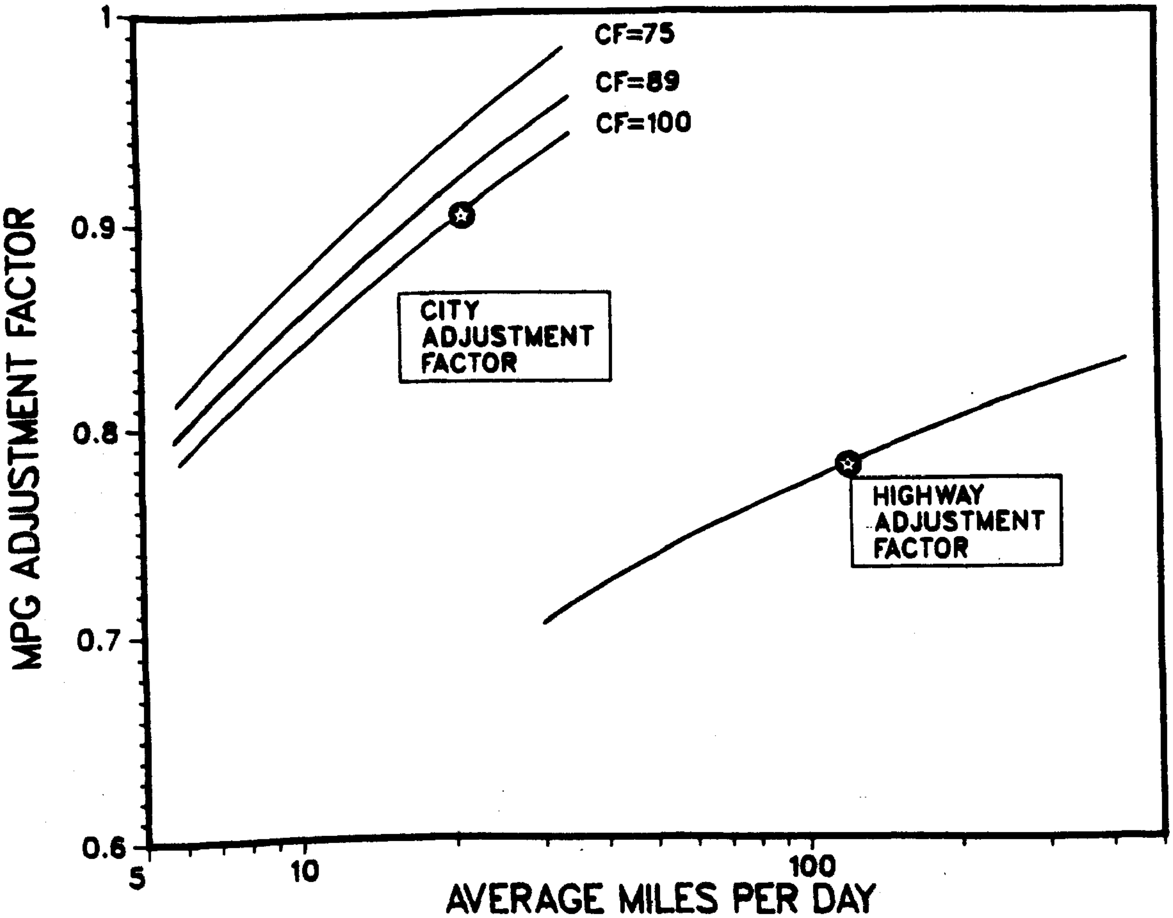

Figure 1 - Adjustment Factors

Table 5

"All City" Driving Respondents' Adjustment Factor

Data Source	Number Data Points	City Factor
Emission Factors	280	0.86
GM 1980	534	0.87
GM 1981	492	0.87
Chrysler 1981	117	0.87
Chrysler 1982	258	0.85
Ford 1979	943	0.89
Ford 1980	679	0.84
Ford 1981	497	0.87
All	3782	0.87

Highway Driving

The NPTS data do not cover highway driving in a manner comparable to that of city driving, which relates to a specifiable location. Determination of a "typical" AMPD for highway driving involves consideration of the more general parameters of trip type and trip length. The type of driving that most would agree corresponds to "highway driving" is the vacation trip. In data on vacation trip length from Reference (7), vacation driving accounts for 0.1% of trips and 0.6% of VMT, so it definitely is at an extrema end of the distribution. The overall average trip length for vacations is 95 miles, and for certain segments of the population it is higher. Table 6 lists the average vacation trip length for the highest trip length groups, for eight different ways of stratifying the data.

Table 6

Trip Length Data, Vacation Trips
(Average Vacation Trip Length = 95 miles)

Stratification	Highest Average Stratum Trip Length
By place of residence	In SMSA, not in central city .... 121 miles
By SMSA population	250,000 to 500,000 .... 150 miles
By annual household income	$15,000 to $25,000 .... 130 miles
By number of vehicles owned	Three vehicles .... 105 miles
By driver's age	21-25 years 120 miles
By driver's occupation	Service work 165 miles
By day of week trip began	Monday ...... 300 miles
By hour of day trip began	6 AM to 9 AM 141 miles

The average of the high-stratum vacation trip lengths is 154 miles. Assuming conservatively that one-way trips of this length occur in one day, we see from Figure 1 the value for fh at 154 miles per day is 0.79. (The value for fh at the average vacation AMPD of 95 is 0.77.) If vacation trips are the definition of highway driving the highway factor, fh, would be in the range of 0.77 to 0.79.

Table 7

Highway Factors Corresponding to the "No City Driving Equals Highway Driving" Definiton

Data Source	Number Data Points	Highway Factor
Emission Factors	56	0 78
GM 1980	383	0.79
GM 1981	390	0.77
Chrysler 1981	11	0.75
Chrysler 1982	136	0.74
Ford 1979	283	0.83
Ford 1980	12	0.82
Ford 1981	135	0.82
All	1407	0.79

Another possibility for the definition of highway driving could be those survey responses for which city fraction was zero. Using this "no city driving equals highway driving" definition, the values for fh are as shown in Table 7.

In the EPA Emission Factors survey, the respondents were asked to describe their driving by choices - one of which was "all highway". So for this survey there is no need for the assumption that "zero CF" equals "highway".

DISCUSSION

The choice of adjustment factors depends on what definitions of city and highway driving are used. Selection of a definition of city and highway driving carries with it a selection of miles per day and city fraction that correspond to that definition.

In some of the approaches used, travel characteristics entered into Figure 1 yield adjustment factors.

In other approaches, data yielded adjustment factors directly; from these factors, travel characteristics that correspond to these uniform adjustment factors can be deduced from Figure 1.

In comparing the results of the two approaches, consistency considerations allow the evaluation of definitions of city and highway driving that yield results compatible with both the directly-derived adjustment factors from the in-use surveys and the travel characteristics from the data in references (6) and (7).

Tables 8 and 9 summarize the results for city and highway adjustment factors. In the tables, values in parenthesis are those implied using Figure 1, and values not in parenthesis are those that come directly from the data.

With respect to city driving, it appears that the survey results for implied values of AMPD of 17, 23, and 27 AMPD are consistent with the SMSA central city definition of 21.9 AMPD.

It must be pointed out that the actual data sets yielded lower uniform adjustment factors (0.86 and 0.87) in Table 8 because the data sets contain distributions of vehicle technology different from what is projected for the future. Because the adjustments are to be used for future vehicles, the values given by Figure 1, which are suitably adjusted for future fleet characteristics, are the ones used.

With respect to highway driving, all highway uniform adjustment factors are clustered in a narrow range, 0.75 to 0.79, (see Table 9) because the highway adjustment is not as sensitive to AMPD as is the city adjustment.

Implied or actual AMPD values of 90 to 118 represent a consistent estimate of highway driving. The range of adjustments here is 0.77 to 0.79.

Table 8

Summary of City Adjustment Results

Definition of City Driving	City Adjustment Factor	City Fraction	Average Miles Per Day
Non-Emission Factors: "All City"	0.87 (0.92)	100 100	(17) 27
Emission Factors: "All City"	0.86 (0.91)	100 100	(14) 23
SMSA Central City	(0.90)	100	22
"Typical" AMPD	(0.90)	89	17

Table 9

Summary of Highway Adjustment Results

Definition of Highway Driving	Highway Adjustment Factor	Average Miles Per Day
High-stratum vacation trip	(0.79)	154
Non-Emission Factors: "Zero City"	0.79 (0.79)	(120) 118
Emission Factors: "All Highway"	0.78 (0.77)	(100) 90
Average vacation trip	(0.77)	95
"Typical" AMPD	(0.75)	62

CONCLUSIONS

1. Bi-modal adjustment factors for EPA City and Highway MPG values have been shown to be sensitive to the definition of city and highway driving.

2. Survey results and travel characteristics data agree on the nature of city and highway driving. City driving is characterized by AMPD values within 5 of 22 miles per day; highway driving is characterized by AMPD values within 15 of 105 miles per day.

3. The best uniform city adjustment factor is 0.90 and the best uniform highway adjustment factor is 0.78.

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