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PRELIMINARY CALCULATION OF FUEL ECONOMY ADJUSTMENT FACTORS. (TECHNICAL REPORT.)

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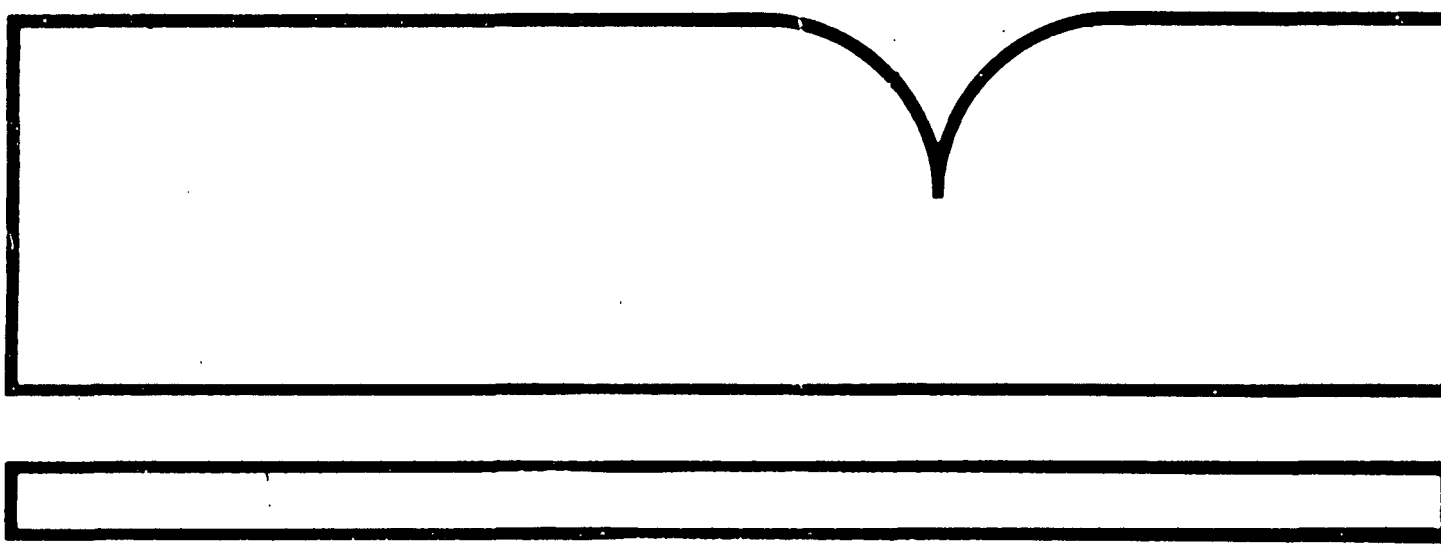

U.S. Department of Commerce
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EPA/AA/CTAB/FE-81-17

Technical Support Report for Regulatory Action

Preliminary Calculation of Fuel Economy Adjustment Factors

July, 1981

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Office of Air, Noise and Radiation
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16. ABSTRACT

This report is a dual purpose report: 1) it is a cover report for EPA Final report 460/3-81-003, "Development of Adjustment Factors for On-Road Fuel Economy" and 2) it is a preliminary determination of fuel economy adjustment factors in support of on-going fuel economy rulemaking activity.

In is role as a cover for the EPA report, it extracts key findings, critiques the findings and offers modifications to the findings where there is reason to adopt alternate assumptions. In its rulemaking support role as an initial estimate of MPG adjustment factors, it compares the EEA (Energy And Environmental Analysis) results with those of other recent, significant publications in this area. The resulting preliminary adjustment factors herein are thus an amalgam of the factors derived by these four data sources.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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ABSTRACT

This is a dual purpose report:

(a) It is a cover report for Contractor Final Report EPA-460/3-81-003, "Development of Adjustment Factors for On-Road Fuel Economy", March 1981, by Energy and Environmental Analysis, Inc., (EEA);

(b) It is a preliminary determination of fuel economy adjustment factors in support of on-going fuel economy rulemaking activity.

In its role as a cover for the EEA report, it extracts key findings in that report and the assumptions associated with them, critiques those findings and assumptions, and offers modifications to the findings where there is reason to adopt alternate assumptions. This is not done "in a vacuum", however. In its rulemaking support role as an initial estimate of MPG adjustment factors, it compares the EEA results with those of other recent, significant publications in this area. The resulting preliminary adjustment factors herein are thus an amalgam of the factors derived by these four data sources. Data analysis is continuing.

I. BACKGROUND and PURPOSE

There are currently four major "collection agents" for data on the in-use fuel economy of motor vehicles:

a) EPA's Emission Control Technology Division
b) DOE's Office of Policy Evaluation
c) General Motors Technical Center
d) Ford Motor Co. Fuel Economy Planning

EPA-ECTD, primarily through its Emission Factors and Inspection and Maintenance Programs, has been gathering in-use MPG data via owner questionnaires for several years, and has accumulated over 10,000 data points on owner-perceived MPG of cars and light trucks from model years 1975 through 1981. Recently, in-use data on a subpopulation of the questionnaire-surveyed Emission Factors owners has been collected using postcard-type fuel economy diaries, which give measurements of miles traveled and gallons of fuel for several successive fuel purchases. The vehicles surveyed by EPA-ECTD were localized in the vicinities of the four to six commercial test labs contracted by EPA to administer the Emission Factors and I/M Programs.

DOE has become the ad hoc national center for in-use vehicle MPG data, acquiring since 1977 a total of well over 50,000 data points on vehicles from the 1975 through 1980 model years. This data base covers a large number and variety of sources, including the aforementioned EPA and auto company surveys, along with those of oil and chemical companies, non-auto/oil light industry firms, utilities, commercial fleet operators, commercial collectors of auto maintenance data, and a host of state agencies who operate fleets. In addition to collecting, systematizing, and analyzing others' data, DOE has sponsored in-use MPG surveys of its own.

General Motors has surveyed the in-use MPG of a total of more than 6,000 General Motors cars from the 1975, 1976, and 1978 model years, and recently surveyed approximately 5000 model year 1980 in-use cars from thirteen manufacturers. These GM surveys were nationwide and generally multi-seasonal, and employed postcard diaries for logging in-use mileage and gallonage.

Ford's in-use MPG surveys are restricted to the more recent model years, but are respectably prolific nonetheless. Since 1978, Ford has collected postcard diary data on 29,000 Ford vehicles from model years 1978 through 1980. These vehicles were leased and operated by Ford Motor Co. employees in many parts of the country and over all parts of the year. Most of the data, however, represents vehicle operation in the Detroit, Michigan area.

Some parts of these data bases were examined by EPA to illustrate approaches to road adjustment factors in Technical Support Report for Regulatory Action EPA/AA/CTAB/FE-81-6,"Light Duty Vehicle Fuel Economy Labeling", October 1980. In the total universe of analyses that will lead to development of road factors for the MPG labeling rulemaking, that report represented Round One.

The EEA report is considered Round Two. It is a thorough, detailed analysis of the DOE data base (which included some of the ECTD data, some of the GM data, and some of the Ford data at the time); it perfected most of the analytical approaches that will be used in the final rule support analysis, and -- within the limits of its data base and assumptions -- began to zero in on the quantitative ballpark for road adjustment factors.

The final rule support analysis, Round Three, will use all of the data from all of the aforementioned sources, plus any data supplied to EPA in the rule making process, and will of course be performed in-house. The data now in hand are being cleaned and characterized. The data base has at this writing been augmented with climatic, demographic, and topographic data to permit careful examination of the distributions of fuel economy influences within and among the data sources. The data are now being assigned EPA MPG values to permit calculation of the "in-use shortfall". When this is completed, the full-scale analysis and determination of road factors will commence.

Pending completion of these analyses, however, it is necessary to identify the approximate range of values within which some forms of the final road adjustment relationships are expected to fall, so that all interested parties can respond from an informed standpoint to the Notice of Proposed Rulemaking for fuel economy labeling soon to be released. This report, then, provides that estimate of the probable range of road adjustment factors. It would be considered Round Two and a Half. It makes that estimate by examining [not data, but] reported results of analyses of data, from the four major in-use data sources. In so doing, it reviews the EEA Report results along with reports of analyses by the other three sources.

II. DISCUSSION

A. Data Sources

Table 1 lists the four reports which are the subject of this report. All are recent publicatons.

Details of each of the data bases used for the four reports' analyses appear in Table 2, and a narrative summary of the distinguishing features of the four surveys is given in Table 3.

None of the four data bases is considered "ideal" in all respects. The 1980 GM Survey might be evaluated as nearly ideal based on tables 2 and 3, but two aspects of that survey not addressed in these tables are worth mentioning: (a) The overall response rate was quite low (11.6% of mailed diaries were returned; after screening, 79% of these survived, leaving a net usable fraction of 9.2%); this leaves the possibility of non-response bias in MPG, which was not evaluated -- although the distribution of vehicle types in the returned sample was quite representative of the model year 1980 vehicle population. (b) While the GM cars in the survey were sampled from GM sales records, covering all states, the other manufacturers' cars were sampled via R.L. Polk registration data, which excluded 15 states. Most notable among the excluded states are Massachusetts, Connecticut, New Jersey, and Pennsylvania, which together account for most of the VMT in the Northeast.

B. Single Mode and Dual Mode Stratagies

At present, EPA is considering two alternative strategies for fuel economy labeling: a labeling system based on one MPG number, and a system based on two MPG numbers. The one-number system would use the EPA combined (55/45) MPG value as the basis for road adjustment ; the two-number system would use the EPA City and EPA Highway MPG values as the bases for adjustment.

The general case of the adjustment relationship for both strategies is an equation of the form "Label MPG equals a function of EPA MPG". Based on linear regression analysis in GPM ratio versus EPA MPG space, as discussed in detail in the EEA report, the general equation form is "Label MPG equals EPA MPG/(a + b EPA MPG)". For the final rule, the generalized case will be analyzed in detail.

The next section, Section C, addresses the one-number (single-mode) system. Almost entirely, it addresses the simple case of no dependence of the shortfall on EPA MPG level (b=o). This results in a simplified equation form: "Label MPG = K EPA MPG" (K = 1/a).

The section after that, Section D, addreses the two-number (dual-mode) system; it discusses some results in terms of terms of the "simple multiplicative factor" form of the equation, and some results in terms of the MPG-dependent form.

Table 1

Data Sources

"EEA":	Energy and Environmental Analysis, Inc., "Development of Adjustment Factors for On-Road Fuel Economy", EPA-460/3-81-003, March 1981.
"1980 Ford":	N. E. South, "1978 to 1980 Ford On-Road Fuel Economy", SAE Paper 810383, February 1981.
"1980 GM":	R.W. Schneider et al, "In-Use Fuel Economy of 1980 Passenger Cars", SAE Paper 810384, February 1981.
"EPA Emiss.Fact":	B. Bradley et al, "Fuel Economy of In-Use Passenger Cars: Laboratory and Road", SAE Paper 810780, June 1981.

Table 2

In-Use F. E. Data Bases: EEA and Three Other Sources

	EEA	1980 Ford	1980 Gen Mtrs	EPA Emis.Fact
Survey Characteristics				
Model Years	1975-80	1980[a]	1980[b]	1975-80
Manufacturers	95% Domestic	All Ford	76% Domestic	81% Domestic
Geographic Spread	Yes	Mostly Detroit	Yes	Mostly Houston
Seasonal Spread	Yes	Yes	Mostly Fall	Mostly Summer
Total No. Data Points	25,239[c]	8,689	4,871	440
Average EPA Comb.MPG	19.6	21.0	21.6	20.0
Vehicle Characteristics				
Car Size	60% mid-Lge	?	?	51% Mid-Lge
Engine Size	55% 8-Cyl	?	?	46% 8-Cyl.
Manual Transm.	13%	20%	33%	24%
Front Drive	5%	5%	28%	16%
Diesel	1%	None	5%	None
Air Conditioning	?	?	?	92%
Avg. Odometer	8,000[d]	3450	3958	24,000
Driving Characteristics				
Consumer Use,Measured	40%[d]	100%	100%	100%
Consumer Use,Perceived	40%[d]	--	--	--
Fleet Use, assumed meas	20%[d]	--	--	--
Avg.Miles per Day	?	52	45	33
Fraction City Driving	?	54%	53%	67%
Overall Road MPG Factor (vs. EPA Combined MPG)	0.90	0.86	0.84	0.83[e]

a/ Ford also ran surveys in 1978-79, Ford vehicles only.

b/ GM also ran surveys in 1975, 76, and 78, GM vehicles only.

c/ Includes the earlier Ford & GM data, and also EPA Emiss. Fact. and I/M questionaire (perceived) MPG data.

d/ Estimated.

e/ High odometer and temp. should make it higher; extensive A/C use, city driving fraction, and population density should make it lower; effects apparently cancel.

Table 3

Comparison of Data Bases

EEA:	Multi-manufacturer
	Most data points, good geographic & seasonal spreads
	Smaller cars underrepresented
	Imports underrepresented
	"Fuel Efficient" technologies underrepresented
	60% of data does not represent measured, consumer use
	Overall road factor 4%-7% higher than other surveys
1980 Ford:	Only Ford vehicles
	Southeastern Michigan = locale for most driving
	Front drives and Diesels underrepresented
	All data measured, consumer use (Ford employees)
	Highest miles per day
	Lowest Avg. odometer
1980 GM:	Multi-manufacturer
	Reasonably high import percentage
	Most data represents October & November
	All data measured, consumer use (private owners)
	Fuel efficient technologies well represented
	Avg. miles per day and city fraction are typical
EPA Emis. Fact:	Very small data base
	Multi-manufacturer
	Reasonable import percentage
	All data measured (private owners)
	Driving highly localized in geography & season
	Manuals & front drives well-represented; no Diesels
	Highest odometer average
	Low miles per day, high city fraction
	92% of vehicles were air-conditioned

C. Single Mode Analysis

Table 4 summarizes the four references' findings on single-mode road factors. Even within a given reference, "the answer" is not a fixed road factor, but depends upon how it is calculated. Using EEA as an example, if one takes the model year-specific average on-road MPG values (R) and average EPA MPG values (E) from EEA's table 3-4, the model year sample weightings from their table 3-3, calculates a total sample R of 16.5 and a total sample E of 19.6 and takes the ratio of these values, a road factor of 0.84 is obtained. But if one enters an E value of 19.6 in the EEA MPG-dependent algorithm, this produces an E/R ratio of 1.108, yielding a road factor (R/E) of 1/1.108 = 0.90. Thirdly, if the E/R ratio is taken for each vehicle in the data base and averaged, a figure of 1.109 results; the road factor from this method is then 1/1.109 = 0.90*.

Also shown in Table 4 is the fact that MPG dependence of the shortfall, at the fleet level of aggregation, is not the same for the three sources which evaluated it. For the EEA report, a 10 MPG increase in EPA fuel economy gives a 3.1% increase in road GPM ratio; for Ford, it is a 1.2% increase, and for GM it is a 4.9% decrease. This apparent inconsistency between sources can be due to a number of factors, some of which could be or could have been adjusted for, and some which cannot/could not.

One of these factors is the proportion of various unique-shortfall vehicle technologies in the respective survey populations. Given the wide variance in representation of various vehicle technology types among the four surveys (Table 2), technology specific shortfalls and weightings should be taken into account. Even if a road adjustment factor at the fully-aggregated level is all that is sought, the development of that one factor from these sources' results still requires disassembly of their findings into specific technology strata and reassembly using appropriate weightings of those strata. Remember: The ultimate use of road factors will be for post-1982 vehicle fleets, not on fleets with the technology mixes of these surveys.

Table 5 gives the road factors for twelve technology strata, as developed by the four analyses.

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* The EEA report does not include this calculation. It was furnished to EPA after publication.

Table 4

Single-Mode Road Factors

	EEA	1980 Ford	1980 Gen Mtrs	EPA Emis.Fact
Survey Average[a/]	.84-.90	.84-.86	.82-.84	.83-.84
MPG Dependence:				
- Method	Regress GPM Ratio vs. EPA MPG	Regress Road GPM vs. EPA GPM	Regress Road GPM vs. EPA GPM[b/]	Not Reported[c/]
- Shortfall increases/decreases with higher EPA MPG				
	Increases: f= .915 @ 15 f= .878 @ 30	Increases: f= .856 @ 15 f= .843 @ 30	Decreases: f= .808 @ 15 f= .859 @ 30	Not Reported[c/]
- Algorithm	$\frac{E}{R}$ = 1.047 +.0031(E)	$\frac{1}{R}$ = .0012 +1.150(1/E)	$\frac{1}{R}$ = -.0049 +1.311(1/E)	Not Reported[c/]

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a/ Depending upon method of calculation: { Ratio of Avg. E & R; Average of E/R ratios; From regression algorithm

b/ Also regressed Road MPG vs. EPA MPG; this essentially gave a constant offset of -2.9 MPG, and a decrease in % shortfall for higher EPA MPG.

c/ Currently being analyzed; will be reported in Round Three.

Table 5

Vehicle Technologies & Road Factors: Four Data Sources

Vehicle Technology	EEA	1980 Ford	1980 Gen Mtrs	EPA Emis.Fact
RWD/Auto/Carb	20127/.865[a]	6918/.826[b]	2539/ 800[c]	301/.798
RWD/Manu/Carb	2154/.888	1360/.867	729/.887	59/.818
RWD/Auto/FI	263/.891	--	--	(4 cars)
RWD/Manu/FI	(2 cars)	--	--	(7 cars)
RWD/Auto/Dsl	213/.898	--	201/.879	--
RWD/Manu/Dsl	(40 cars)	--	(23 cars)	--
FWD/Auto/Carb	168/.975	--	731/.855	(15 cars)
FWD/Manu/Carb	645/.982	411/.966	527/.975[c]	(28 cars)
FWD/Auto/FI	(19 cars)	--	--	(13 cars)
FWD/Manu/FI	124/.991	--	--	(13 cars)
FWD/Auto/Dsl	(2 cars)	--	66/.849	--
FWD/Manu/Dsl	72/.983	--	55/.949	--

a/ x/y denotes no. cars/road factor

b/ may include some FI; does include 3159 overdrives

c/ may include some FI.

The "Acceptable Stratum Sample Size" Issue

Also shown in table 5 are the sample sizes associated with the technology strata. We have not shown road factors for strata with sample sizes less than approximately 50*.

The "Which Vehicle Technology Weightings to Use" Issue

Table 6 shows projected sales penetrations for the twelve technology strata for the 1981 model year, the latest model year for which we have reliable predictions. At the very least, "new-fuel efficient" technologies should be represented at these sales fractions in re-aggregating technology specific shortfall observations.

Other Issues . Survey Findings Weighted Equally, not by Sample Size

Pooling of FI and Diesel Road Factors

Retain or Discard Obsolescent Technologies

In Table 7, the aforementioned source/technology road factors and strata weightings are brought together. For each stratum, one road factor was determined by combining the sources' individual road factors, equally weighted, consumption-combined (i.e. harmonically averaged). This approach was used rather than sample weighting. The rationale is illustrated by the following analogy. If four inspectors using identical copies of an NBS standard yardstick measure N_1, N_2, N_3, and N_4 widgets, the average widget length would, by all means, properly be calculated as a weighted average, using the individual inspectors' average measurements and their N_i weights. However, if they use four hand-crafted but uncalibrated yardsticks, sample-weighting does not a priori lead to the best estimate of average widget length. The measurements made by inspector #1 should not dominate an aggregate calculation just because he had a good day and measured more widgets than the other inspectors. So it is with in-use fuel economy surveys. Until there is a precise standard procedure (that is, a science) for conducting such surveys, the efforts of quite competent surveyors will feature distinguishable, individualistic traits (that is, art). Sample size, then, is used only to determine a threshold of acceptability (50 cars for this analysis), not as a weighting factor when aggregating across data sources.

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* To estimate MPG within a precision of $\pm$ 1 MPG in the neighborhood of 20 MPG ($\pm$5% precision), with a coefficient of variation of 20%, at a confidence level of 90%, a sample size of 45 is required; for 95% confidence, a sample size of 64 is required (from $P^2 = Z^2\ COV^2\ (1/N)$ and t-tables).

Table 6

Vehicle Technologies: Sales Fraction (1981) and MPG Range

Drive	Transm.	Engine	% Sales	EPA Combined MPG	Comments: Transmission
Rear	Auto	Carb	43.6	12-32	>50% Lockups
Rear	Auto	FI	3.2	10-28	Mostly non-lock,non-OD
Rear	Auto	Diesel	3.4	25-29	Mostly lockup
Rear	Manu	Carb	9.5	12-45	~50/50 OD/non-OD
Rear	Manu	FI	2.4	13-32	Mostly OD
Rear	Manu	Diesel	0.1	30-31	Mostly non-OD
Front	Auto	Carb	18.8	18-34	Mostly non-OD
Front	Auto	FI	2.0	17-29	No OD
Front	Auto	Diesel	0.6	23-25	No OD
Front	Manu	Carb	13.4	24-42	Mostly OD
Front	Manu	FI	1.8	23-33	Mostly OD
Front	Manu	Diesel	1.2	41-47	All OD

Note - Diesels: Each of the 4 strata has narrow EPA MPG range, and the 4 MPG ranges are mutually-exclusive (non-overlapping)

Note - FWD Automatics: There are no lockups in these strata in 1981.

Table 7

Sales Significance and Road Factors for
Technology Strata and Upward Aggregations of Them

	Carb	FI	Diesel	All	All Gasoline (Carb + FI)	All FI (FI + Dsl)
RWD-Auto (sales)	.436	.032	.034	.502	.468	.066
(road factor)[a/]	.82	.89	.89	.83	.83	.89
RWD-Manu (sales)	.095	.024	.001	.120	.119	.025
(road factor)	.86	--	--	.86	.86	--
FWD-Auto (sales)	.188	.020	.006	.214	.208	.026
(road factor)	.92	--	.85[b/]	.91	.91	.85[b/]
FWD-Manu (sales)	.134	.018	.012	.164	.152	.030
(road factor)	.97	.99	.97	.98	.98	.98
All RWD (sales)	.531	.056	.035	.622	.587	.091
(road factor)	.83	.89	.89	.84	.83	.89
All FWD (sales)	.322	.038	.018	.378	.360	.056
(road factor)	.94	.99	.92	.94	.94	.97
All Auto (sales)	.624	.052	.040	.716	.676	.092
(road factor)	.85	.89	.88	.85	.85	.88
All Manu (sales)	.229	.042	.013	.284	.271	.055
(road factor)	.92	.99	.97	.93	.93	.98
All (sales)	.853	.094	.053	1.000	.947	.147
(road factor)	.87	.93	.90	.87	.87	.92

a/ Road factor = simple average of the applicable surveys' road factors; all source/strata with ≥50 cars are counted.

b/ Obsolescent version of FWD-Auto technology?

The combining of technology strata in Table 7 was done via sales-weighted harmonic averaging.

Noting more similarity between the road factors of gasoline FI and Diesel cars than between those of gasoline FI and carbureted gasoline cars, a pooled road factor was calculated for both gasoline fuel injected and Diesel cars.

It should be noted that the road factor for front drive automatic Diesels comes mainly from cars whose design concept might be considered obsolescent: longitudinally-mounted V-8 Diesel engines. This road factor was not discarded, but it may be inappropriate for future vehicles of this technology class.

Table 8 recaps the road factor data of Table 7 in a more readable format. It shows the appropriate road factors to use for all combinations of the eight technology strata corresponding to drive type, transmission type, and induction type (with Diesel and gasoline FI pooled).

Table 9 shows the apparent effects of Combustion type (Diesel) or carburetion (fuel injection) on road factor, for various drive train combinations; these data come directly from Table 5. Table 10 shows the apparent effect of drive train type on road factor for the three combustion/carburetion types. This also came from Table 5.

The "MPG Dependency within Technology Strata" Issue

The three sources (EEA, GM, EPA) for which MPG dependency has been evaluated* are in general agreement that GPM ratio increases (road factor worsens) as MPG level increases, for specific technologies. Table 11 summarizes this evaluation. Recall the earlier discussion of Table 4, which pointed out changes in fully aggregated fleet GPM ratio of -4.9% to 3.1% for a 10 MPG change, de- pending on the source; compare to the figures in Table 11, which yield average changes in GPM ratio of +6% to +9% for a 10 MPG change for individual tech- nology strata. This leaves little doubt that MPG dependence exists at the technology level; this will be thoroughly evaluated in the final rule techni- cal support data analysis (Round Three).

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* The EPA Emission Factors SAE Paper did not address technology specific MPG dependence; this was determined later using the Emission Factors data.

Table 8

Summary - Constant Road Factors, One Mode

$$\left(f = \frac{\text{Road MPG}}{\text{EPA Combined MPG}} \right)$$

No. Strata	Road Factor(s)			
ONE:	0.87			
TWO[a]	(a) FWD .94	RWD .84		
	(b) Auto .85	Manu .93		
	(c) Carb .87	FI[b] .92		
FOUR[c]	(a) RWD-Auto .83	RWD-Manu .86	FWD-Auto .91	FWD-Manu .98
	(b) RWD-Carb .83	RWD-FI .89	FWD-Carb .94	FWD-FI .97
	(c) Auto-Carb .85	Auto-FI .88	Manu-Carb .92	Manu-FI .98
EIGHT	RWD-Auto-Carb .82		RWD-Auto-FI .89	
	RWD-Manu-Carb .86		RWD-Manu-FI (?)	
	FWD-Auto-Carb .92		FWD-Auto-FI .85[d]	
	FWD-Manu-Carb .97		FWD-Manu-FI .98	

a/ There are three two-strata options

b/ FI means gasoline FI and Diesel pooled

c/ There are three four-strata options

d/ Obsolescent version of FWD-Auto technology?

Table 9

Apparent Effect of Combustion/Carburetion Technology on Road Factor*

(Strata ≥50 cars)

	RWD-Auto	RWD-Manu	FWD-Auto	FWD-Manu
Gas FI vs. Carb.	D +3%	--	--	D +1%
Diesel vs. Carb.	D +3% G +8%	--	G -1%	D 0% G -3%
Diesel vs. Gas FI	D +1%	--	--	D -1%

D = DOE/EEA

E = EPA Emis. Fact

F = Ford

G = GM

* For example, in the GM survey, RWD-Auto Diesels had an 8 per cent higher Road Factor than did RWD-Auto Carbureted vehicles.

Table 10

Apparent Effect of Drive Train Technology on Road Factor

(Strata ≥50 cars)

	Carb Cars		FI Cars	Diesel Cars
Manu vs. Auto, RWD	D +2% E +2%	F +4% G +9%	--	--
Manu vs. Auto, FWD	D +1%	G +12%	--	G +10%
FWD vs. RWD, Auto	D +11%	G +6%	--	G -3%
FWD vs. RWD, Manu	D +9%	F +10% G +9%	--	--

D = DOE/EEA

E = EPA Emis. Fact.

F = Ford

G = GM

Table 11

MPG Dependency of GPM Ratio, evaluated at the Technology Stratum Level

	EEA	GM[a]	EmFac[b]
Range of MPG coefficients	.0033-.0159	.0023-.0082	.0030-.0156
Average of MPG coefficients	.009	.006	.006
Trend?[c]	No	No	No

[a] not counting one negative slope known to be influenced by spurious cars (Cadillacs) and mixing of Carb and FI cars

[b] not counting one negative slope based on 15 cars (R^2 = 0.017) in an MPG range that is too narrow to really develop an MPG dependence

[c] i.e. does the GPMR slope increase, or decrease, consistently with MPG level?

Histogram Tests of Single-Mode Road Adjustment Systems

Using the adjustment factors derived above, the effectiveness of road adjustment at various levels of technology aggregation was tested. The Emission Factors Postcard data base (the only one fully accessible for computer analysis at the time) was the test "subject".

The test consisted of multiplying each car's EPA combined MPG (Eo) by the appropriate road factor, taking the difference between this road-adjusted value (E') and actual road MPG, and histographing this difference.

Figure 1 is the histogram for road ΔMPG using unadjusted EPA MPG as the reference. Figure 2 is the road ΔMPG histogram using the single-factor (no strata) adjusted EPA MPG as the reference. The effect of the adjustment in moving the distribution toward zero average ΔMPG is obvious.

Table 12 summarizes the effects of the various road adjustment schemes. Conclusions that can be drawn from this test, in order of increasing subtlety/complexity, are:

Road adjustment unquestionably produces label values that reflect in-use average MPG better than the unadjusted EPA 55/45 values.

There is an average error of -3.6 MPG using raw EPA numbers, while average error is reduced to less than 1 MPG with road-adjusted numbers.

Unadjusted EPA numbers, even with a 2 MPG discount, are too high for two-thirds of the in-use cars; however--adjusted numbers, with a $\pm$2 MPG window, accurately reflect the road MPG experience of two-thirds of the population.

In this particular test, stratification produces no significant improvement in the adjusted label values' road representativeness, on the average.

The primary reason for the previous conclusion is that the four-source road factors are not the best set of factors to try on only one of the sources' data. The four-source no-strata adjustment factor is 0.87, while the appropriate factor for the Emission Factors data base is 0.83. Obviously, the 0.87 factor is not stringent enough, as verified by the consistently negative residual MPG errors remaining after road adjustment.

The distribution inclusion/exclusion results of this test also show little or no improvement for stratification compared to a single fleetwide adjustment factor.

The primary reason for this is that this one influence, vehicle technology, is responsible for only a fraction of the total in-use variation; all of the other influences (driving habits, etc., etc.) still contribute to the dispersions in the in-use data.

Figure 1

Difference: EPA 55/45 MPG minus Road MPG

DPOINT	HIST%	COUNT	
10.000	0.	0	+
9.000	0.	0	+
8.000	0.	0	+
7.000	0.	0	+
6.000	.2	1	+X
5.000	0.	0	+
4.000	.5	2	+XX
3.000	0.	0	+
2.000	.7	3	+XXX
1.000	1.1	5	+XXXXX
0.000	.5	2	+XX
.0000	2.0	9	+XXXXXXXXX
.0000	1.6	7	+XXXXXXX
.0000	7.0	31	+XXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
.0000	8.2	36	+XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
.0000	14.5	64	+XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
.0000	14.3	63	+XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
.0000	16.4	72	+XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
.0000	11.4	50	+XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
.0000	10.7	47	+XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
.	3.6	16	+XXXXXXXXXXXXXXXX
.0000	4.1	18	+XXXXXXXXXXXXXXXXX
.0000	1.1	5	+XXXXX
.0000	1.1	5	+XXXXX
.0000	.9	4	+XXXX
.0000	0.	0	+
.0000	0.	0	+
.0000	0.	0	+
.0000	0.	0	+
.0000	0.	0	+
0.000	0.	0	+
OTAL		440	

Figure 2

Difference: Adjusted EPA 55/45 MPG minus Road MPG

```
DPOINT   HIST%  COUNT

5.000      0.       0 +
4.000      0.       0 +
3.000      0.       0 +
2.000      0.       0 +
1.000      0.       0 +
0.000       .2      1 +X
.0000       .7      3 +XXX
.0000       .5      2 +XX
.0000      1.1      5 +XXXXX
.0000      1.6      7 +XXXXXXX
.0000      4.1     18 +XXXXXXXXXXXXXXXXXX
.0000      5.0     22 +XXXXXXXXXXXXXXXXXXXXX
.0000     10.5     46 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
.0000     16.4     72 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
.0000     18.2     80 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
.         12.0     53 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
.0000     13.2     58 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
.0000      6.6     29 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXX
.0000      4.1     18 +XXXXXXXXXXXXXXXXXX
.0000      3.0     13 +XXXXXXXXXXXXX
.0000       .9      4 +XXXX
.0000       .7      3 +XXX
.0000       .7      3 +XXX
.0000       .7      3 +XXX
.0000      0.       0 +
0.000      0.       0 +
1.000      0.       0 +
2.000      0.       0 +
3.000      0.       0 +
4.000      0.       0 +
5.000      0.       0 +

OTAL             440
```

Table 12

Results of Histogram Tests of Four-Source Composite Road Adjustment Factors: Test Subject = Emis. Fac. Data Base

(One-Mode Adjustment System)

Number of Strata	Strata Adjusted	Avg.Error (MPG)	% of Population Within 2 MPG of E'		
			Below		Above
1	No adjustment	-3.6	67	31	2
1	Fleet adjustment	-0.8	24	66	10
2	FWD/RWD	-0.6	20	68	11
2	Auto/Manual	-0.9	25	65	10
2	Carb/FI	-0.9	25	66	9
4	R-A/R-M/F-A/F-M	-0.6	22	68	11
4	R-C/R-FI/F-C/F-FI	-0.5	20	68	12
4	A-C/A-FI/M-C/M-FI	-0.9	25	66	9
8	Each Technology	-0.5	19	69	12

D. Dual-Mode Analysis

The dual-mode analysis that can be mined from the three non-EEA sources is narrower in scope than the foregoing single-mode analysis:

- The Ford paper did not separate "city-driven" cars and "highway-driven" cars and develop mode-specific road factors; it did compare all driving modes' aggregate MPG results with the EPA City value ($R = 1.01\ E_C$, a 1% overage) and with the EPA Highway value ($R = 0.68\ E_H$, a 32% shortfall); it also showed the percent of all of the sample cars' MPG experience that would be captured by two-number ranges built from several combinations of City and Highway adjustment factors.

- The Emission Factors paper did show road factors for city-driven and highway-driven cars for the sample fleet, but not for vehicle technology strata; like the Ford report, it also compared all of the data to the EPA city value ($R = 0.96\ E_C$, a 4% shortfall) and to the EPA Highway value ($R = 0.68\ E_H$, a 32% shortfall).

- The GM paper compared overall fleet MPG to the EPA City value ($R = 0.95\ E_C$, a 5% shortfall), but not to the Highway value. The GM paper also gave technology-specific equations involving city driving fraction and the EPA City value, from which road factors for city-driven cars of the specific technologies can be derived.

Table 13 lists the two-mode road factor results from the Ford, GM, and Emission Factors papers.

The EEA report presented an extensive two-mode analysis, including MPG dependence and technology stratification, and using two versions of two-mode analysis on the more highly-populated technology strata. The downside of EEA's two-mode analysis rests with its use of only perceived MPG data from the 1978-79 J.D. Power survey.

Table 14 gives the equations for MPG-dependent City and Highway GPM ratios from the EEA report, for conventional technology (carburetted, automatic transmission) vehicles. The A and B sets of equations come from the two alternate analysis techniques used by EEA to develop dual-mode factors. The techniques are described in the report, and will not be discussed further here except to point out that one technique calculates road factors directly by using only city-driven cars and highway-driven cars, and the other (more complex) technique uses all of the data and the full range of city driving fractions.

Dual-mode road factors for alternative technologies were determined in the "constant" form (MPG independent); they appear in Table 15. The factors shown as estimated (type B) do not exactly match those calculated by EEA for the two technologies shown; they are EPA estimates based on EEA report data but on different assumptions than those used by EEA. Two points should be noted about these estimates:

Table 13

Two-Mode Road Adjustment Factors from Non-EEA Sources

A. Ford Motor Co.

City Adjustment Factor	Highway Adjustment Factor	% Cars Included[a/] Between the Adjusted Numbers
0.79	0.81	80%
0.77	0.82	85%
0.74	0.84	90%
0.69	0.88	95%

a/ Excluded cars are equally distributed high and low.

B. Emission Factors

Type of Driving	% of Sample	City Adj. Factor	Highway Adj. Factor
All City	25%	.88	--
Mostly City	32%	.93	--
Both	57%	.91	--
All Highway	2%	--	.79
Mostly Highway	10%	-	.73
Both	12%	--	.74

C. General Motors

City Adjustment Factors, by Technology [b/]:

RWD-Auto-Gas,	.89	FWD-Auto-Gas,	.95
RWD-Manu-Gas,	.92	FWD-Manu-Gas,	.97
RWD-Auto-Dsl,	.95	FWD-Auto-Dsl,	.93
		FWD-Manu-Dsl,	1.03

b/ From the paper's table 12; all technologies evaluated at 100% city fraction, 44.6 miles/day, 3958 odometer miles, and 54.6°F. These factors are MPG-dependent.

Table 14

Two-Mode Road Adjustment Algorithms from the EEA Report

(Conventional Technology vehicles)

A. Using subsets of pure mode-driven cars (46% of the data)

City GPM ratio*:	RWD-Auto-Carb (1978 + 1979),	$0.782 + .0181E_C$
	RWD-Manu-Carb (1978 + 1979),	$0.717 + .0134E_C$
Hwy GPM ratio:	RWD-Auto-Carb (1978 + 1979),	$1.130 + .0097E_H$
	RWD-Manu-Carb (1978 + 1979),	$1.017 + .0097E_H$

B. Using all of the data

City GPM ratio:	RWD-Auto-Carb (1978),	$.845 + .0136E_C$
	(1979),	$.963 + .0091E_C$
	RWD-Manu-Carb (1978),	$.591 + .0208E_C$
	(1979),	$.557 + .0166E_C$
Hwy GPM ratio:	RWD-Auto-Carb (1978),	$1.127 + .0096E_H$
	(1979),	$1.144 + .0088E_H$
	RWD-Manu-Carb (1978),	1.312 (no MPG dependence)
	(1979),	1.343 (no MPG dependence)

* road MPG adjustment factor is the inverse of GPM ratio.

Table 15

Two-mode Road Adjustment Factors from the EEA Report

(Alternative Technology Vehicles)

A. As presented in EEA report:

Technology	1-mode GPM ratios: All data[a/]	JDPower[b/]	2-mode GPM ratios(JDPower): City	Highway
FWD-Auto-Carb	1.025	1.052	.922	1.154
FWD-FI[c/]	1.034	1.075	.877	1.219
RWD-FI[d/]	1.118	1.193	1.021	1.371

B. Estimated, using EEA data but different assumptions:

Technology	1-mode GPM ratios: All data	JDPower	2-mode GPM ratios (JDP): City	Highway
FWD-Manu-Carb	1.086	1.152	.950	1.315
FWD-Diesel	1.026	1.049	.881	1.185

---

a/ From the single-mode chapter in the EEA report.

b/ From the dual-mode chapter.

c/ Here, FI means gasoline FI.

d/ Here, FI means gas FI and Diesel pooled.

- for good reason at the time, EEA excluded certain 1978 models from the 2-mode road factor calculation for RWD-Manu-Carb vehicles; EPA used all of the data.

- due to sample size considerations, EEA chose not to recommend specific two-mode factors for RWD-Diesels; although somewhat risky, we did estimate them.

Before filling the matrix of two-mode road factors for all of the technology strata, we must return to the matter of the MPG-dependent factors for conventional technologies (Table 14). Since the alternate technology factors are MPG - independent, upward aggregation of all technologies' factors is best done in a constant-factor scenario, as was done in the one-mode analysis.

The question for the conventional technologies is: what MPG values should be selected to extract constant factors from the equations? The answer chosen for this report is as follows. (a) given a fleet 55/45 MPG level, estimate the fleet City MPG and Highway MPG using reasonable Highway to City, City to 55/45, and Highway to 55/45 MPG ratios; (b) assume that the manual transmission subfleet will have higher average MPG values than the automatic transmission subfleet, as has been the case historically; (c) select reasonable MPG ranges for the subfleets consistent with (a) and (b) and use them in the factor equations to determine constant City and Highway factors.

Table 16 summarizes this process and its results.

To make a conservative estimate* of the range of the two-mode GPM ratios, it is assumed that a 20 MPG Automatic-RWD-Carb subfleet has with it a 25 MPG Manual-RWD-Carb subfleet, and a 25 MPG Automatic-RWD-Carb subfleet has with it a 30 MPG Manual-RWD-Carb subfleet. A consistent pairing of GPM ratios would be RWD-Auto-Carb, City, 1.100 and RWD-Manu-Carb, City, 0.996. These lower-bound values are the ones that correspond to the alternate technology GPM ratios in Table 15. Thus, for the EEA data base, an array of constant, technology-specific GPM ratios would be (next page):

*An assumption of a 5 MPG difference between automatic and manual subfleets' EPA average is conservative compared to actuality:

	Auto MPG	Manual MPG
EPA Emission Factors Survey	18.3	28.2
1979 Models	18.9	26.9
1980 Models	21.9	28.2
1981 Models	23.3	30.8

	City	Hwy
RWD-Auto-Carb	1.10	1.36
RWD-Manu-Carb	1.00	1.30
FWD-Auto-Carb	0.92	1.15
FWD-gas FI	0.88	1.22
etc.	.	.
etc.	.	.
etc.	.	.

Projecting the conventional technologies' GPM ratio growth of 0.06 for a 5 MPG increase in fleet MPG onto the alternate technologies as well, GPM ratios appropriate to cars in a higher MPG space might be:

	City	Hwy
RWD-Auto-Carb	1.16	1.42
RWD-Manu-Carb	1.06	1.36
FWD-Auto-Carb	0.98	1.21
etc.	.	.
etc.	.	.
etc.	.	.

The technology-specific dual mode road MPG adjustment factors (the inverse of the above GPM ratios) can now be specified, and also collapsed into four-, two-, and one-strata systems, sales-weighted, as was done in Tables 7 and 8 for the single-mode analysis. The resulting two-mode MPG adjustment factors are given in Table 17.

Histogram Tests of Dual-Mode Road Adjustment Systems

As was done in the Single-Mode analysis, the effectiveness of two-mode road adjustment was tested at various levels of technology aggregation, using the Emission Factors postcard data base as the test subject. These tests used adjustment factors in the middle of the ranges given in Table 17.

For the dual-mode system, there are two measures of the usefulness of adjusted MPG values. One is the degree to which the two numbers accurately represent their respective types of driving; in effect, the adjusted City

Table 16

Estimation of Single Two-Mode Factors for Conventional Vehicles

A. Reference MPG levels

If EPA 55/45 MPG is:	20[a]	25[b]	30
then EPA City MPG is (approx):	17.4	21.8	26.1
and EPA Hwy MPG is (approx):	24.4	30.5	36.6

B. Pooled road GPM ratios[c] at the indicated MPG levels

RWD-Auto-Carb,	City	1.100	1.165	--
	Hwy	1.364	1.421	--
RWD-Manu-Carb,	City	—	0.996	1.065
	Hwy	--	1.305	1.365

---

[a] Approximately equal to the Model Year 1979 U.S. fleet EPA average and approximately equal to the four data sources' EPA average.

[b] Approximately equal to the Model Year 1981 U.S. fleet EPA average.

[c] Calculated from the equations in Table 14 and averaged.

Table 17

Summary - Constant Road Factors, Two Modes

$$\left(f_i = \frac{\text{Road MPG for driving type i}}{\text{EPA MPG}_i}\right) \quad (i = C,H)$$

No. Strata		Road Factors	
ONE:		C .93-.98, H .73-.77	
TWO	(a)	FWD C 1.01-1.08, H .78-.82	RWD C .88-.93, H .71-.75
	(b)	Auto C .91-.96, H .73-.77	Manu C .98-1.04, H .73-.77
	(c)	Carb C .94-.98, H .73-.77	FI* C .97-1.03, H .73-.76
FOUR	(a)	RWD-Aut C .87-.92, H .70-.73	RWD-Man C .94-1.00, H .73-.76
		FWD-Aut C 1.02-1.09, H .82-.86	FWD-Man C 1.00-1.07, H .74-.77
	(b)	RWD-Crb C .87-.92, H .71-.74	RWD-FI C .93-.98, H .70-.73
		FWD-Crb C 1.01-1.06, H .78-.82	FWD-FI C 1.07-1.14, H .78-.82
	(c)	Aut-Crb C .90-.96, H .73-.77	Aut-FI C .96-1.02, H .72-.75
		Man-Crb C .97-1.03, H .73-.76	Man-FI C 1.00-1.06, H .75-.78
SEVEN		RWD-Aut-Crb C .86-.91, H .70-.73	RWD-Man-Crb C.94-1.00,H .73-77
		RWD-FI C .93-.98, H .70-.73	FWD-gasFI C 1.07-1.14, H .78-.82
		FWD-Aut-Crb C 1.02-1.08, H .82-.87	FWD-Man-Crb C .99-1.05, H .73-.76
		FWD-Dsl C 1.06-1.14, H .80-.84	

* FI means gasoline FI and Diesel pooled unless noted otherwise.

number is tested as a mode MPG estimator against the in-use MPG of city-driven cars, and the adjusted Highway number is tested against highway-driving MPG. The other measure is the fraction of the total MPG population captured between the two numbers (also of interest is the distribution of the MPG tails outside the inclusion range).

The results of the first kind of test, mode MPG estimates, are typified by figures 3 through 6. Figure 3 is the City histogram for unadjusted City values, and Figure 4 the corresponding Highway histogram. Figure 5 is the City histogram for the first (unstratified) level of adjustment, and Figure 6 is the corresponding Highway histogram.

Table 18 summarizes the mode estimate histogram test for all levels of technology stratification. The need to adjust the EPA Highway numbers is obvious. There is a slight hint that increased technology specificity helps the adjusted City number to become increasingly representative; considering that the adjustment factor system comes from J.D. Power data, it is encouraging that this test on a totally different data base shows any such trend at all.

Figures 7 through 10 illustrate the range inclusion type of test. Figures 7 and 8 compare <u>all</u> MPG experience to the unadjusted City and Highway numbers, respectively, and Figures 9 and 10 give the same type of comparison against fleet-adjusted numbers. The included range is easily determined from such pairs of histograms: those data which fall neither below the City value nor above the Highway value are, by definition, included in the range between the two numbers. Table 19 summarizes the results of all of the range inclusion tests. When viewed in the range inclusion sense, it is again clear that road adjustment of some kind is beneficial. Again, technology specificity shows a weak tendency to improve representativeness.

Figure 3

Difference: EPA City MPG minus Road MPG

(City-driven Cars)

MIDPOINT	HIST%	COUNT	
-13.000	0.	0	+
-12.000	.4	1	+X
-11.000	0.	0	+
-10.000	0.	0	+
-9.0000	.8	2	+XX
-8.0000	0.	0	+
-7.0000	1.6	4	+XXXX
-6.0000	.8	2	+XX
-5.0000	7.3	18	+XXXXXXXXXXXXXXXXX
-4.0000	7.7	19	+XXXXXXXXXXXXXXXXXX
-3.0000	14.2	35	+XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
-2.0000	19.1	47	+XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
-1.0000	17.9	44	+XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
0.	13.4	33	+XXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
1.0000	6.9	17	+XXXXXXXXXXXXXXXX
2.0000	4.5	11	+XXXXXXXXXXX
3.0000	2.8	7	+XXXXXXX
4.0000	.8	2	+XX
5.0000	.8	2	+XX
6.0000	.4	1	+X
7.0000	.4	1	+X
8.0000	0.	0	+
9.0000	0.	0	+
10.000	0.	0	+
TOTAL		246	

Figure 4

Difference: EPA Highway MPG minus Road MPG
(Highway-driven Cars)

MIDPOINT	HIST%	COUNT
-22.000	0.	0 +
-21.000	0.	0 +
-20.000	1.7	1 +X
-19.000	1.7	1 +X
-18.000	0.	0 +
-17.000	1.7	1 +X
-16.000	1.7	1 +X
-15.000	1.7	1 +X
-14.000	3.4	2 +XX
-13.000	1.7	1 +X
-12.000	1.7	1 +X
-11.000	6.8	4 +XXXX
-10.000	3.4	2 +XX
-9.0000	10.2	6 +XXXXXX
-8.0000	11.9	7 +XXXXXXX
-7.0000	10.2	6 +XXXXXX
-6.0000	15.3	9 +XXXXXXXXX
-5.0000	6.8	4 +XXXX
-4.0000	11.9	7 +XXXXXXX
-3.0000	5.1	3 +XXX
-2.0000	1.7	1 +X
-1.0000	0.	0 +
0.	0.	0 +
1.0000	1.7	1 +X
2.0000	0.	0 +
TOTAL		59

Figure 5

Difference: Adjusted EPA City MPG minus Road MPG
(City-driven Cars)

MIDPOINT	HIST%	COUNT	
-12.000	0.	0	+
-11.000	0.	0	+
-10.000	.4	1	+X
-9.0000	0.	0	+
-8.0000	.8	2	+XX
-7.0000	0.	0	+
-6.0000	1.2	3	+XXX
-5.0000	1.2	3	+XXX
-4.0000	8.1	20	+XXXXXXXXXXXXXXXXXXX
-3.0000	7.3	18	+XXXXXXXXXXXXXXXXX
-2.0000	16.3	40	+XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
-1.0000	20.7	51	+XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
0.	17.1	42	+XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
1.0000	12.2	30	+XXXXXXXXXXXXXXXXXXXXXXXXXX
2.0000	4.9	12	+XXXXXXXXXXX
3.0000	5.3	13	+XXXXXXXXXXXX
4.0000	2.0	5	+XXXXX
5.0000	.8	2	+XX
6.0000	1.2	3	+XXX
7.0000	0.	0	+
8.0000	.4	1	+X
9.0000	0.	0	+
10.000	0.	0	+
11.000	0.	0	+
12.000	0.	0	+
TOTAL		246	

Figure 6

Difference: Adjusted EPA Highway MPG minus Road MPG

(Highway-driven Cars)

MIDPOINT	HIST%	COUNT	
-12.000	0.	0	+
-11.000	0.	0	+
-10.000	0.	0	+
-9.0000	1.7	1	+X
-8.0000	3.4	2	+XX
-7.0000	1.7	1	+X
-6.0000	1.7	1	+X
-5.0000	3.4	2	+XX
-4.0000	1.7	1	+X
-3.0000	3.4	2	+XX
-2.0000	16.9	10	+XXXXXXXXXX
-1.0000	22.0	13	+XXXXXXXXXXXX
0.	15.3	9	+XXXXXXXXX
1.0000	11.9	7	+XXXXXXX
2.0000	6.8	4	+XXXX
3.0000	5.1	3	+XXX
4.0000	1.7	1	+X
5.0000	3.4	2	+XX
6.0000	0.	0	+
7.0000	0.	0	+
8.0000	0.	0	+
9.0000	0.	0	+
10.000	0.	0	+
11.000	0.	0	+
12.000	0.	0	+
TOTAL		59	

Table 18

Results of Histogram Tests of Two-Mode Adjustment Factors

Test Subject = Emis. Fac. Data Base

** Mode MPG Estimate **

Number of Strata	Strata Adjusted		Average MPG Error	% of mode-specific experience Below	Within 2 MPG	Above
1	No adjustment	City	-1.6	33	62	5
		Hwy	-7.9	97	3	0
1	Fleet adjustment	City	-0.7	19	71	10
		Hwy	-0.9	17	73	10
2	FWD/RWD	City	-0.2	14	75	11
		Hwy	-1.1	24	63	14
2	Auto/Manual	City	-0.6	18	74	8
		Hwy	-0.9	17	73	10
2	Carb/FI	City	-0.8	19	71	9
		Hwy	-0.9	17	73	10
4	R-A/R-M/F-A/F-M	City	-0.1	13	79	8
		Hwy	-0.8	24	64	12
4	R-C/R-FI/F-C/F-FI	City	-0.1	13	76	11
		Hwy	-1.1	27	61	12
4	A-C/A-FI/M-C/M-FI	City	-0.1	18	74	8
		Hwy	-1.0	17	73	10
7	Each technology	City	-0.1	14	77	9
		Hwy	-0.9	20	68	12

Figure 7

Difference: EPA City MPG minus Road MPG
(All Cars)

DPOINT	HIST%	COUNT	
3.000	0.	0	+
2.000	.2	1	+X
1.000	0.	0	+
0.000	.2	1	+X
.0000	.5	2	+XX
.0000	.7	3	+XXX
.0000	1.4	6	+XXXXXX
.0000	.7	3	+XXX
.0000	5.2	23	+XXXXXXXXXXXXXXXXXXXXXXX
.0000	5.7	25	+XXXXXXXXXXXXXXXXXXXXXXXXX
.0000	9.3	41	+XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
.0000	16.1	71	+XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
.0000	17.7	78	+XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
.	14.1	62	+XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
.0000	10.0	44	+XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
.0000	6.8	30	+XXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
.0000	4.5	20	+XXXXXXXXXXXXXXXXXXXX
.0000	2.5	11	+XXXXXXXXXXX
.0000	2.0	9	+XXXXXXXXX
.0000	.7	3	+XXX
.0000	.9	4	+XXXX
.0000	0.	0	+
.0000	.7	3	+XXX
).000	0.	0	+
ITAL		440	

Figure 8

Difference: EPA Highway MPG minus Road MPG

(All Cars)

```
MIDPOINT   HIST%  COUNT

-23.000      0.       0 +
-22.000       .2      1 +X
-21.000       .2      1 +X
-20.000       .5      2 +XX
-19.000       .9      4 +XXXX
-18.000       .9      4 +XXXX
-17.000       .5      2 +XX
-16.000      1.1      5 +XXXXX
-15.000      1.4      6 +XXXXXX
-14.000      3.0     13 +XXXXXXXXXXXXX
-13.000      3.2     14 +XXXXXXXXXXXXXX
-12.000      4.8     21 +XXXXXXXXXXXXXXXXXXXX
-11.000      8.2     36 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
-10.000      7.5     33 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
-9.0000     12.0     53 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
-8.0000     13.4     59 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
-7.0000     13.0     57 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
-6.0000     10.7     47 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
-5.0000      8.9     39 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
-4.0000      5.2     23 +XXXXXXXXXXXXXXXXXXXXXX
-3.0000      2.3     10 +XXXXXXXXXX
-2.0000      1.4      6 +XXXXXX
-1.0000       .7      3 +XXX
 0.          0.       0 +
 1.0000       .2      1 +X
 2.0000      0.       0 +

 TOTAL               440
```

Figure 9

Difference: Adjusted EPA City MPG minus Road MPG
(All Cars)

```
DPOINT   HIST%  COUNT

2.000     0.      0 +
1.000     0.      0 +
0.000      .2     1 +X
.0000     0.      0 +
.0000      .7     3 +XXX
.0000      .2     1 +X
.0000     1.4     6 +XXXXXX
.0000     1.1     5 +XXXXX
.0000     5.2    23 +XXXXXXXXXXXXXXXXXXXXXXX
.0000     5.9    26 +XXXXXXXXXXXXXXXXXXXXXXXXXX
.0000    10.7    47 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
.0000    17.3    76 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
.        17.0    75 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
.0000    13.4    59 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
.0000     9.3    41 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
.0000     7.0    31 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
.0000     3.2    14 +XXXXXXXXXXXXXX
.0000     3.2    14 +XXXXXXXXXXXXXX
.0000     2.0     9 +XXXXXXXXX
.0000      .5     2 +XX
.0000      .5     2 +XX
.0000      .5     2 +XX
).000      .7     3 +XXX
1.000     0.      0 +
2.000     0.      0 +

)TAL            440
```

Figure 10

Difference: Adjusted EPA Highway MPG minus Road MPG

(All Cars)

```
:DPOINT   HIST%  COUNT

 2.000      0.      0 +
 1.000       .5     2 +XX
 0.000       .7     3 +XXX
 .0000       .7     3 +XXX
 1.0000      1.1    5 +XXXXX
 .0000       2.3   10 +XXXXXXXXXX
 .0000       3.6   16 +XXXXXXXXXXXXXXX
 .0000       8.4   37 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 .0000       8.2   36 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 .0000      12.7   56 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 .0000      17.3   76 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 .0000      17.3   76 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 .          10.7   47 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 .0000       7.7   34 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 .0000       3.6   16 +XXXXXXXXXXXXXXXX
 .0000       2.0    9 +XXXXXXXXX
 .0000       1.4    6 +XXXXXX
 .0000       1.4    6 +XXXXXX
 .0000        .5    2 +XX
 .0000       0.     0 +
 .0000       0.     0 +
 .0000       0.     0 +
 0.000       0.     0 +
 1.000       0.     0 +
 2.000       0.     0 +

OTAL            440
```

Table 19

Results of Histogram Tests of Two-Mode Adjustment Factors

** Range Inclusion **

Number of Strata	Strata Adjusted	% of all MPG experience Below	Between C'-1 and H'+1	Above
1	No adjustment	40	60	0
1	Fleet adjustment	25	66	9
2	FWD/RWD	20	70	10
2	Auto/Manual	26	65	9
2	Carb/FI	27	65	9
4	R-A/R-M/F-A/F-M	19	69	11
4	R-C/R-FI/F-C/F-FI	19	71	10
4	A-C/A-FI/M-C/M-FI	25	66	9
7	Each technology	19	69	12

III. CONCLUSIONS

A. The preferred general equation for analyzing and expressing the relation between Road MPG (R) and EPA MPG (E) is an MPG-dependent fuel consumption ratio: $(1/R) \div (1/E) = a + b\,E$;

this is equivalent to: $E/R = a + b\,E$;

the general expression for road adjustment factors to multiply EPA MPG numbers by is: $f = 1/(a + b\,E)$;

a special case of the road adjustment factor, wherein there is no MPG dependence and therefore b = zero, is: $f = 1/a$;

a road adjusted EPA MPG number (E') is: $E' = f \times E$.

B. All four data sources evaluated herein agree that the EPA 55/45 MPG value overestimates average in-use fuel economy in the range from 10% to 20%. A road adjustment factor between 0.8 and 0.9 is therefore indicated. (Road factors will be calculated to two decimal places in susbsequent analyses.)

C. In single-mode analyses, there is a consensus among those data sources which investigated vehicle technology stratification that:

- Front wheel drive (FWD) cars have less MPG shortfall than rear wheel drive (RWD) cars, for carburetted, automatic or manual transmission power trains;

- Diesel powered cars have less MPG shortfall than carburetted gasoline cars, for RWD-automatic transmission configurations;

- Manual transmission cars have less MPG shortfall than automatics, for carburetted FWD and RWD power trains;

- Generally, specific vehicle technology strata show a worsening MPG shortfall as MPG level increases.

D. Depending on the mix of technology strata in a data base, MPG dependence of shortfall for the strata may be obscured when the data base is analyzed at high levels of aggregation; however, such obscuration of MPG dependence via high aggregation analysis does only that: it obscures it. It does not make it cease to exist.

E. Using emission factors data, histograms show that 67% of in-use MPG experience falls more than 2 MPG below the EPA 55/45 MPG value; however--when single-mode road adjustment factors are applied to these data, more than 65% of the population is accurately represented (within a window of $\pm$ 2 MPG) by the adjusted 55/45 value.

F. In dual-mode analysis, 33% of city driving MPG experience falls more than 2 MPG below the EPA City value (70% of city-driven MPG falls below

the City value); however, road-adjusted City values accurately represent more than 70% of the city driving population, within a ± 2 MPG window;

For highway driving, 97% of in-use MPG experience falls more than 2 MPG below the EPA Highway value (99.8% of it falls below the Highway value); with road adjustment, more than 60% of the highway driving MPG experience (± 2 MPG) is accurately represented.

G. At the fleet level, city adjustment factors of 0.9 to 1.0 are indicated; highway factors of 0.7 to 0.8 are indicated. (Road factors will be calculated to two decimal places in subsequent analyses).

IV. ISSUES FOR FUTURE ANALYSES

Some of the issues which surfaced in this analysis are listed below. Section II described how this analysis dealt with them, but future analysis will reconsider them carefully; they may be dealt with differently in these future analyses.

A. Is minimum acceptable sample size for a given stratum to be fixed by preordained precision and confidence level specifications and an estimated measure of variance, or are precision and confidence level to be outputs of a stratum analysis, given its sample size and actual measure of variance?

B. When aggregating across data sources, should they be equally weighted or sample-weighted, i.e., is the analogy of the widget inspectors accurate?

C. When aggregating technology-specific road factors or road factor algorithms, what sales-weighting values should be used?

D. Should data from obsolescent vehicle technologies be discarded?

E. What vehicle technologies can/should be pooled, and what criteria should determine whether to pool or not to pool: sample size? engineering argument? similarity of shortfall behavior?

F. Should pre-1979 models of manual transmission vehicles whose shortfall changed significantly in 1979 be excluded from future road factor development (the premise being that shift schedule optimization has been stopped), or should they be included (the premise being that the return of shift schedule optimization cannot/will not be prevented)?

G. What method ("driving-mode extremes" versus "all data") should be used to develop two-mode adjustment factors?

H. Will perceived MPG data be accepted as though it were measured, thrown out because it isn't, or can it be "corrected" to make it comparable to measured MPG data?

I. Is an analysis at the model-type level an appropriate one to employ?