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Technical Report

Prediction of U.S. Annual Fuel Consumption by Passenger Automobiles

by

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NOTICE

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I. Introduction

The annual fuel consumption of U.S. passenger vehicles is an area of present and increasing concern. In order to assess EPA programs which may affect national fuel consumption, it is important to be able to predict future fuel economy trends and possible modifications of these trends.

This report presents a computer model which can be used to predict trends in U.S. passenger vehicle fuel consumption. While this model is relatively simple to allow easy use, it is sufficiently detailed to provide accurate relative predictions of different fuel conservation strategies. The model methodology was developed primarily to investigate the fuel consumption implications of various applications of tire technology. During the course of the model development it was decided to present this material as a separate report to facilitate use of this material in other fuel consumption prediction efforts.

The actual prediction model used in this is quite simple. However, the mathematical methodlogy of the model can be easily extended to address much more complex applications. In general, the limiting condition in using the model will be the availability of detailed input information.

II. Discussion

The development of a useful model requires two tasks: first, the model must be chosen, and second, there must be a literature search to provide the necessary model input parameters. While the first task may be conceptually more difficult, the second is often more time consuming, and is essential for applications of the model. Consequently, both the model and the development of currently suitable input parameters is discussed in the following subsections. The final section presents the predicted annual fuel consumption for 1975 through 1985, and compares the predicted values for current years with reported data.

A. The Model

The fuel economy prediction model was chosen as:

$$TFCON_i = \sum_j (VMIX_{ij})(MIT_{ij})(FC_j) \qquad (1)$$

where:

$TFCON_i$ = the total annual fuel consumed in the i^{th} year.

$VMIX_{ij}$ = the vehicle mix of j type vehicles in the year i.

MIT_{ij} = the annual vehicle miles traveled by j type vehicles in the year i.

FC_j = the average fuel consumption of j type vehicles.

This model is basically the model presented by H.H. Gould and A.C. Mallioris of DOT.1/* While the model is simple, it has great versatility, since the vehicle mix paramter j can represent as detailed subdivision of the vehicle population as is desired. For example, a k subscript could be introduced to each of the parameters VMIX, MIT and FC to represent different tire types.

The fact that the model equation (1) is so simple, yet extremely powerful means that much of the information content of the model resides in the values of the model paramaters VMIX, MIT, and FC. The subsequent section discusses how the values to these parameters were chosen and presents the values used in this analysis.

B. Values of the Model Parameters

In this analysis only the vehicle model year was considered as a subdivding parameter of the vehicle mixture parameter, VMIX. This approach was chosen because of the difficulty in obtaining more detailed information on the distribution of the vehicle population. With this choice of the vehicle subdivision parameter, the quantities which must be obtained or constructed for each of the i years of interest are $VMIX_{ij}$, MIT_{ij}, and FC_j, that is the number of vehicles of model year j existent in the calendar year i, the annual miles traveled by vehicles of model year j in calendar year i, and the average fuel economy of vehicles of model year j.

In general, this desired information is available for the past ten years. It is believed that these data can be accurately extrapolated for approximately the same time period into the future. Therefore, it was decided to predict the total annual fuel consumption from the present time until 1985. Consequently, the required parameters must be known or estimated for model years 1978 to 1985, inclusive.

1. The Vehicle Population Distribution

The distribution of vehicles by model year in past years is readily available, usually from data compiled by R.L. Polk from state registration lists.2/ Table 1 gives the currently available model year distribution. The first sub-task then is to take this distribution and use it to predict the vehicle population distributions for each year until 1985. This was accomplished by computing

* Numbers underlines (1/) indicate references at the end of this paper.

Table 1

Light-Duty Vehicle Registrations by
Model Year and Calendar Year
(millions)

Model Year	Calendar Year															
1977	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	7.17
1976	--	--	--	--	--	--	--	--	--	--	--	--	--	--	6.47	9.55
1975	--	--	--	--	--	--	--	--	--	--	--	--	--	4.68	7.68	7.47
1974	--	--	--	--	--	--	--	--	--	--	--	--	6.43	9.76	9.74	9.59
1973	--	--	--	--	--	--	--	--	--	--	--	7.98	11.26	11.33	11.13	10.85
1972	--	--	--	--	--	--	--	--	--	--	7.16	10.15	10.14	10.09	9.87	9.56
1971	--	--	--	--	--	--	--	--	--	5.92	8.91	8.71	8.62	8.54	8.24	7.86
1970	--	--	--	--	--	--	--	--	9.92	9.28	9.12	8.88	8.61	8.34	7.96	7.44
1969	--	--	--	--	--	--	--	6.45	6.28	8.88	8.85	8.61	8.49	8.33	7.77	6.96
1968	--	--	--	--	--	--	6.18	8.92	8.81	8.80	8.59	8.29	7.93	7.55	6.85	5.85
1967	--	--	--	--	--	5.82	8.12	8.05	7.87	7.77	7.49	7.12	6.62	6.11	5.36	4.41
1966	--	--	--	--	6.23	8.85	8.83	8.79	8.53	8.31	7.93	7.33	6.53	4.79	4.88	3.88
1965	--	--	--	6.40	9.01	8.94	8.93	8.85	8.50	8.17	7.58	6.71	5.71	4.82	3.92	3.02
1964	--	--	5.84	7.85	7.82	7.73	7.66	7.53	7.11	6.65	4.92	4.96	3.97	3.23	2.57	1.96
1963	--	5.29	7.34	7.31	7.30	7.18	7.05	6.82	6.26	5.62	4.71	3.69	2.82	2.22	1.74	1.31
1962	4.55	6.60	6.62	6.62	6.57	6.40	6.18	5.80	5.05	4.27	3.34	2.47	1.81	1.40	1.08	0.81
1961	5.50	5.54	5.45	5.38	5.28	5.02	4.65	4.08	3.26	2.52	1.82	1.26	0.90	0.68	0.52	2.093*

* Registrations of all previous model years.

Table 2

Average Ratio of Vehicles Surviving from One Calendar Year to the Next versus Vehicle Age

Years of Vehicle Life	Survival Ratio
1 to 2	1.386
2 to 3	1.022
3 to 4	0.991
4 to 5	0.981
5 to 6	0.972
6 to 7	0.959
7 to 8	0.933
8 to 9	0.895
9 to 10	0.856
10 to 11	0.813
11 to 12	0.785
12 to 13	0.773
13 to 14	0.773
14 to 15	0.763
15 to 16	0.755
All Years Beyond 16	0.750

vehicle survival ratios for each succeeding model year and projecting the new vehicle sales for each required future model year.

First, to compute the survival ratios, the ratio of vehicles surviving from each year to the subsequent year was computed for each of the years of the life of the vehicle. For example, the ratio of 1975 vehicles registered in 1975 to those 1975 vehicles registered in 1976 were computed, as well as 1976 vehicles registered in 1976 and 1977, 1977 vehicles registered in 1977 and 1978, etc. All of the ratios for survival from the first to second year of vehicle life were averaged as were the ratios for each sequential year. These average survival ratios are given in Table 2, and may be conveniently described as the survival probability vector.

It may be noted that the first elements of the survival probability vector are greater than one. This may appear surprising, however it is a logical result of using registration data compiled in June of each year. For example, assume x 1977 vehicles were sold and registered prior to July 1, 1977, and that an additional y 1977 vehicles were sold and registered after July 1, 1977. Neglecting the destroyed vehicles, the ratio surviving until July 1, 1978 would be computed as $(x + y)/x$, which of course, is greater than 1.0.

In general, a computation problem is incurred because the vehicle model year begins in September or October, the calendar year starts January 1, and the vehicle registration data are reported as of July 1. Since the purpose of this report is to present a simple method for investigating the relative aspects of fuel economy programs, this problem is not treated in detail. However, it is suggested that one approach to improve the prediction system would be to research quarterly, or monthly, new vehicle sales, and use this information to predict the vehicle use in the first months after the vehicle is sold, but before it is recognized in the July registration data.

The survival rate vector can be used to predict the number of vehicles of any model year existing in a given calendar year, if the number registered in any previous calendar year is known. Consequently, the survival rate vector can be used to predict the number of vehicles present in future years for all model year vehicles since 1977. For model years later than 1977, which was the last year of available registration data, some method must be used to predict the new vehicle sales in each year.

Considering the available data, it was decided to indirectly predict the new vehicle sales by predicting the total vehicle population. This approach has several advantages; first when attempting to model annual fuel consumption, the total vehicle population is a more important parameter than new vehicle sales. Second, vehicle sales vary considerably with the state of the

Table 3

ɔtal Light-Duty Vehicle Registrations
versus Calendar Year

Year	Registrations (in millions)
1965	68.9
1966	71.3
1967	73.0
1968	75.4
1969	78.5
1970	80.4
1971	83.1
1972	86.4
1973	89.8
1974	92.6
1975	95.2
1976	97.8
1977	99.9
1978*	102.8
1979*	105.5
1980*	108.2
1981*	110.9
1982*	113.5
1983*	116.2
1984*	118.9
1985*	121.6

* Predicted.

national economy. Finally, predicting the total vehicle population minimizes the tendency to accumuate errors which could occur if new vehicle sales were predicted.

Table 3 gives the available total vehicle population data.2/ These data were fitted with a linear regression to predict total future vehicle populations. These predicted future total vehicle populations are also given in Table 3, while the existing data and the predicted populations are plotted in Figure 1.

The survival ratios and the total population data provide the necessary information to predict the vehicle population distribution. Starting with the 1977 model year, the most recent year in which the population distribution is known, the survival ratios were used to predict the population distributions for 1977 and earlier model year vehicles in calendar year 1978. The sum of all 1978 and earlier model year vehicles was then computed and subtracted from the total predicted population for 1978 vehicles. The difference between the total population and the vehicles existing from previous years was assumed to be the 1978 model year sales. This process was then iteratively repeated for all subsequent years. The resulting predicted vehicle population matrix is given in Table 4.

2. Annual Vehicle Miles Traveled

The next required parameter is the number of the average annual vehicle miles traveled as a function of vehicle age. Unfortunately, little recent data are available on this parameter. The most frequently cited reference is the U.S. Census Bureau data from 1970.3/ These data are presented in Table 5. It should be noted that the Census data indicate a very high number of miles traveled during the first year the vehicle is in use. This implies that there is an initial period of intensive use for new vehicles. However, it might only reflect the manner in which some of the data were obtained. For example if a vehicle which was purchased in March had accumulated 10,000 miles by the time is was sampled in August, just after a 5,000 miles summer vacation trip, this could be interpreted as a vehicle accumulating distance at the rate of 20,000 miles per year. If vehicle use in the first few months after purchase were more extensively researched this potential problem could be reduced.

Since the Census Bureau data appeared to have some anomalies, such as vehicles of some ages traveling farther than newer vehicles, it was decided to "smooth" the data by fitting it with a linear regression. This approach had the additional advantage that the regression could be used to predict the annual vehicle miles traveled for vehicles more than ten years old. The vector of predicted annual miles traveled, which was used in all subsequent calculations, is presented in Table 6.

Total Vehicle Registrations
versus
Calendar Year

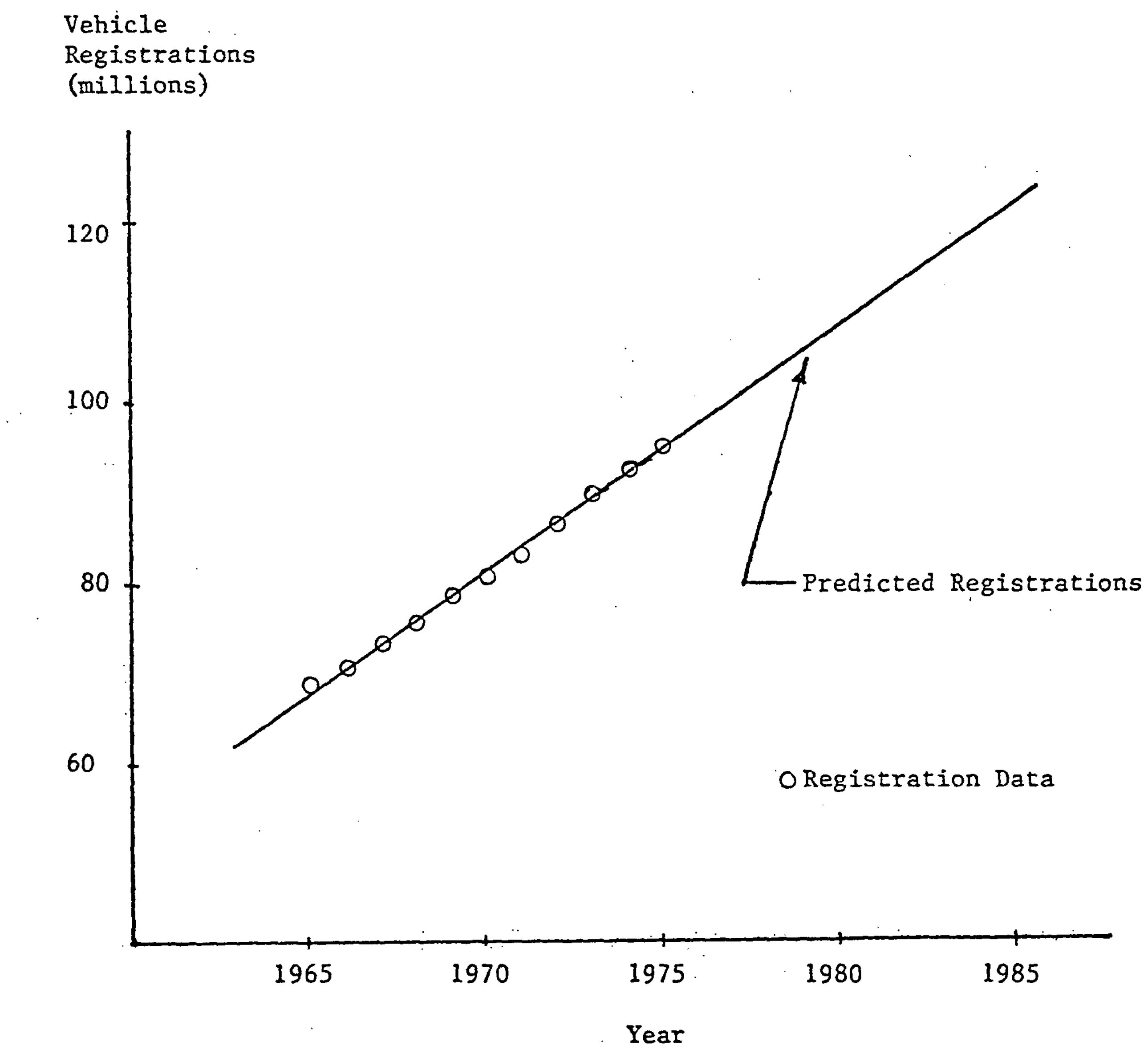

FIGURE 1

Table 4

Predicted Light-Duty Vehicle Registrations by
Model Year and Calendar Year
(millions)

Model Year	Calendar Year 1975*	1976*	1977*	1978	1979	1980	1981	1982	1983	1984	1985
1985											8.73
1984										8.61	11.94
1983									8.52	11.81	12.07
1982								8.43	11.68	11.94	11.83
1981							8.29	11.49	11.74	11.64	11.42
1980						8.19	11.36	11.61	11.50	11.28	10.97
1979					7.86	10.89	11.13	11.03	10.82	10.52	10.09
1978				8.26	11.44	11.70	11.59	11.37	11.05	10.60	9.89
1977			7.17	9.95	10.16	10.75	9.88	9.60	9.21	8.59	7.69
1976		6.47	9.55	9.77	9.67	9.49	9.23	8.85	8.25	7.39	6.32
1975	4.68	7.68	7.47	7.41	7.26	7.06	6.77	6.32	5.65	4.84	3.93
1974	9.76	9.74	9.59	9.41	9.14	8.77	8.18	7.32	6.27	5.09	4.00
1973	11.33	11.13	10.85	10.55	10.11	9.44	8.44	7.23	5.88	4.61	3.56
1972	10.09	9.87	9.56	9.17	8.55	7.65	6.55	5.32	4.18	3.23	2.50
1971	8.54	8.24	7.86	7.33	6.56	5.62	4.57	3.58	2.77	2.14	1.63
1970	8.34	7.96	7.44	6.66	5.70	4.64	3.64	2.81	2.17	1.60	1.25
1969	8.33	7.77	6.96	5.96	4.84	3.80	2.94	2.27	1.73	1.30	3.57+
1968	7.55	6.85	5.85	4.76	3.73	2.89	2.23	1.70	1.28	3.46+	
1967	6.11	5.36	4.41	3.46	2.68	2.07	1.58	1.19	3.32+		
1966	5.79	4.88	3.88	3.00	2.32	1.77	1.33	3.24+			
1965	4.82	3.92	3.02	2.33	1.78	1.34	2.98+				
1964	3.23	2.57	1.96	1.50	1.13	2.63+					
1963	2.22	1.74	1.31	0.99	2.38+						
1962	1.40	1.08	0.81	2.18+							
1961	0.68	0.52	2.09+								
1960	0.52	1.94+									
1959	1.74+										

* Actual registration data presented for these years.
\+ Registrations for all previous years.

Table 5

Average Annual Miles
versus
Vehicle Age

Year of Vehicle Life	Miles Traveled (thousands)
1	17.5
2	16.1
3	13.2
4	11.4
5	11.7
6	10.0
7	10.3
8	8.9
9	10.9
10	8.0

Table 6

Predicted Average Annual Miles
versus
Vehicle Age

Year of Vehicle Life	Miles Traveled (thousands)
1	15.9
2	14.9
3	14.0
4	13.1
5	12.2
6	11.3
7	10.4
8	9.5
9	8.6
10	7.7
11	6.8
12	5.9
13	5.0
14	4.0
15	3.1
16	2.2
17 and older	1.3

3. Vehicle Fuel Consumption by Model Year

The EPA data are the best indication of average annual vehicle fuel consumption.4/ These data, for both the EPA city cycle and the composite city/highway cycle, are plotted versus model year in Figure 2. This plot shows that a significant change occurred in fuel economy trends in 1975, the first year of the EPA voluntary fuel economy program. Assuming current improvements in the fuel economy of vehicles will continue, the future fuel economy trends were predicted from a linear regression of the data since 1974. These regression lines are shown in Figure 2, as are the current fuel economy standards for 1978 through 1985. Since the regression lines of the composite city/highway values are greater than the current standards, while the city cycle values are less than the standards, these regression predictions appear to be reasonable.

The fuel economy prediction model requires the fuel consumption of the vehicles be known. For this reason fuel consumptions, the reciprocal of the fuel economies, were calculated from the available data, and are presented in Table 7. Also presented in this table are the predicted fuel economy values and the subsequent predicted fuel consumptions for 1979 and later model years. The two fuel consumption columns of the table may be conveniently considered as the fuel consumption vectors for the city cycle and the composite cycle.

The vehicle population matrix, Table 4; the annual vehicle miles traveled vector, Table 6; and the fuel consumption vectors, Table 7; complete all of the information necessary to use the fuel consumption model equation (1).

C. Predictions of Annual Fuel Consumption

Using the model, equation (1), the total fuel consumed, $TFCON_i$, for each of the years of interest can be computed from the vehicle distribution matrix, $VMIX_{ij}$, given in Table 4, the vehicle miles traveled, MIT_{ij}, given in Table 6, and the fuel consumption, FC, given in Table 7. The results of this calculation are presented in Figure 3 and Table 8.

The computer program used to perform the fuel consumption calculation is given in the attachment of this report. It should be noted that this program divides the miles traveled during the first year of vehicle life by 2 prior to multiplying by the number of new model year vehicles. This is done because it is assumed that these vehicles have, on the average, been in service for only one half of the year prior to appearing on the annual registration data list.

In 1975, it is estimated that 76.01 billion gallons of fuel were consumed by passenger cars.5/ Based on this estimate, predic-

Fuel Economy
versus
Vehicle Model Year

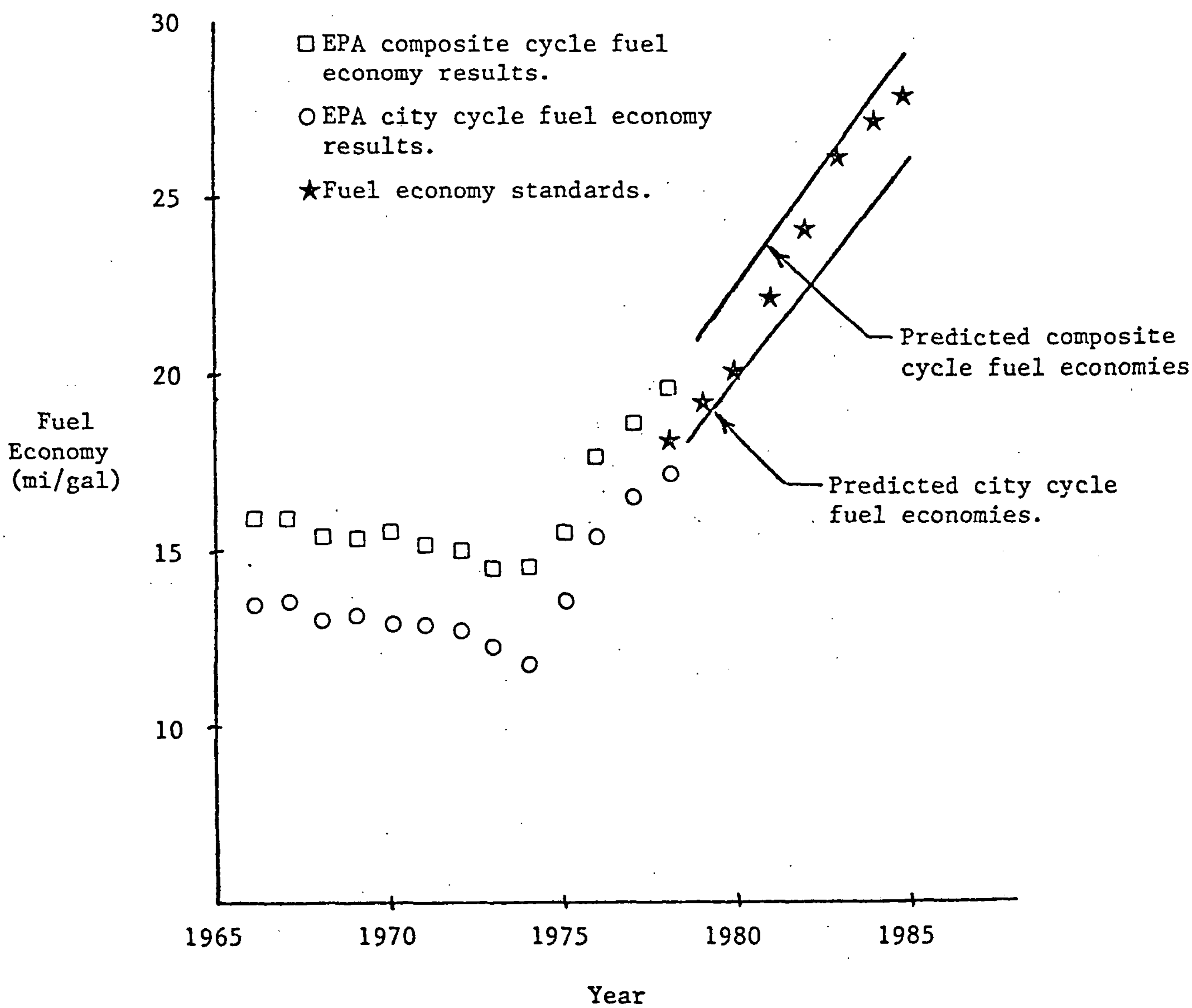

Figure 2

Table 7

Average Fuel Economy and Fuel Consumption by Model Year

Year	City Fuel Economy (mi/gal)	City Fuel Consumption (gal/mi)	Composite City/Highway Fuel Economy (mi/gal)	Composite City/Highway Fuel Economy (gal/mi)
Pre-1968	13.6	0.074	15.8	0.063
1968	13.2	0.076	15.4	0.065
1969	13.2	0.076	15.4	0.065
1970	13.1	0.076	15.5	0.065
1971	12.9	0.078	15.1	0.066
1972	12.6	0.079	15.0	0.067
1973	12.3	0.081	14.5	0.069
1974	12.2	0.082	14.4	0.069
1975	13.5	0.074	15.6	0.064
1976	15.4	0.065	17.7	0.056
1977	16.3	0.061	18.6	0.054
1978	17.0	0.059	19.6	0.051
1979*	18.6	0.054	21.2	0.047
1980	19.8	0.050	22.5	0.044
1981	21.1	0.047	23.9	0.042
1982	22.3	0.045	25.3	0.040
1983	23.6	0.042	26.6	0.038
1984	24.8	0.040	27.9	0.036
1985	26.0	0.038	29.2	0.034

* Values for model years past 1978 are predicted from a linear regression of the data from 1975 through 1978 inclusive.

National Annual Fuel Consumption

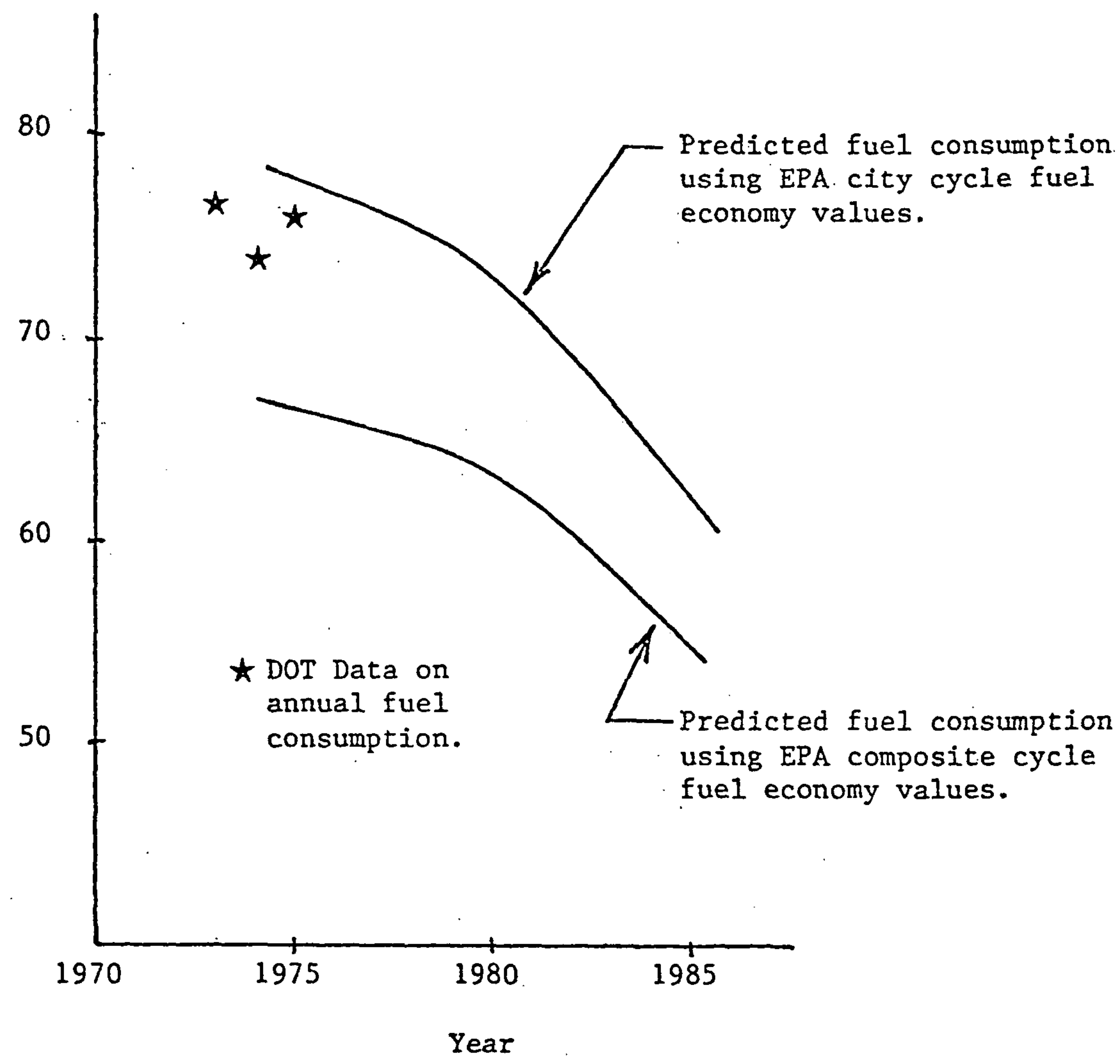

FIGURE 3

Table 8

Predicted Total Annual Fuel Consumption

Year	Consumption Predicted Using City Cycle Fuel Economies (billions of gallons)	Consumption Predicted Using Composite Cycle Values (billions of gallons)
1975	78.1	66.5
1976	77.3	65.9
1977	76.1	65.1
1978	75.5	64.7
1979	74.9	64.4
1980	73.3	63.2
1981	71.4	61.8
1982	69.3	60.2
1983	67.0	58.4
1984	64.7	56.6
1985	62.4	54.8

tions using the EPA composite fuel economy values appear to underestimate actual fuel consumption by twelve to thirteen percent. Using the urban cycle fuel economy values in the prediction model appear to provide better accuracy. In this case, the model overestimates the annual fuel consumption by about three percent. This is consistent with other observations, and with the decision to use only the urban fuel economy results for vehicle labels, beginning with the 1979 model year.6/ Using the urban fuel consumption, the predicted values are in good agreement with the reported data.

III. Conclusion

The model predictions agree well with reported data for the current years. It is therefore concluded that the prediction accuracy of the model should be quite good since major changes in vehicle usage are not expected in the next ten years. Even if unanticipated changes do occur in vehicle use, predicted relative effects of different technologies should still be valid. It is therefore recommended that the model be used primarily for the prediction of the relative effects of different technologies on the annual fuel consumption.

References

1/ H.H. Gould and A.C. Malliaris, "Highway Fuel Consumption Computer Model," Department of Transportation Report, DOT-TSC-OST-73-43, April 1974.

2/ R.M. Lienert (editor), "Cars Still in U.S. Use by Year Models," Automotive News, Detroit, Michigan, July 17, 1978.

3/ H.E. Strate, "Annual Miles of Automobile Travel," Nationwide Personnal Transportation Study, U.S. DOT, Report No. 2, 1972.

4/ J.D. Murrell, "Light-Duty Automotive Fuel Economy . . . . Trends Through 1978," Society of Automotive Engineers, Paper No. 780036.

5/ W.F. Gay, National Transportation Statistics, Department of Transportation Annual Report, DOT-TSC-OST-77-68, 1977.

6/ Federal Register, May 17, 1978 (43 FR 21412).

Attachment

Fuel Consumption Prediction Program

```
C
C
C     THIS PROGRAM IS DESIGNED TO CALCULATE THE ESTIMATED TOTAL VEHICLE MILES
C     TRAVELLED PER YEAR BY PASSENGER VEHICLES AND THE ESTIMATED TOTAL GALLONS
C     OF GASOLINE CONSUMED.
C
C
      DIMENSION VEHPOP(27,11),VMILES(30),CITYFE(30),VMT(30),GASC(30),SVMT(11),SGASC(11)
C
C
C     THIS SEQUENCE PRESETS THE ELEMENTS OF THE ARRAYS, DESIGNATED SVMT AND
C     SGASC RESPECTIVELY, TO BE ASSIGNED THE VALUE OF ZERO.
C
C
      DATA SVMT/11*0./
      DATA SGASC/11*0./
C
C
C     THIS SEQUENCE READS IN THE PREDICTED MATRIX, DESIGNATED VEHPOP, THE
C     ESTIMATED AVERAGE ANNUAL MILES PER AUTOMOBILE BY YEAR MODEL, AND THE
C     FUEL ECONOMY STANDARDS FOR PASSENGER VEHICLES.
C
C
      READ(5,1000)((VEHPOP(J,K),K=1,11),J=1,27)
 1000 FORMAT(12X,11F8.0)
      READ(6,2000,END=50)((VMILES(J),CITYFE(J)),J=1,27)
 2000 FORMAT(8X,F8.4,16X,F6.3)
   50 L=10
C
C
C     THIS STATEMENT WAS INTRODUCED WITH THE ASSUMPTION THAT A VEHICLE IS
C     DRIVEN HALF THE ANNUAL VEHICLE MILES ITS FIRST YEAR OF VEHICLE LIFE,
C     SINCE THE REGISTRATION DATA WERE OBTAINED ON JULY 1 OF EACH YEAR.
C
C
      VMILES(1)=VMILES(1)/2
C
```

```
C
C     THE FOLLOWING TWO DO LOOPS SCAN EACH SUCCESSIVE COLUMN, ROW-BY-ROW
C     AND PERFORM THE FOLLOWING OPERATIONS.
C
C
      DO 20 K=1,11
      DO 10 J=1,17
      JJ=J+L
C
C
C     THE FOLLOWING EQUATION CALCULATES THE TOTAL ANNUAL MILES TRAVELLED
C     BY VEHICLES OF EACH MODEL YEAR IN EACH CALENDAR YEAR.
C
C
      VMT(J)=(VEHPOP(JJ,K)*VMILES(J))
C
C
C     THE FOLLOWING EQUAITON CALCULATES THE GALLONS OF GASOLINE CONSUMED
C     BY VEHICLES OF EACH MODEL YEAR IN EACH CALENDAR YEAR.
C
C
   40 GASC(J)=VMT(J)/CITYFE(JJ)
      SVMT(K)=SVMT(K)+VMT(J)
      SGASC(K)=SGASC(K)+GASC(J)
   10 CONTINUE
      L=L-1
   20 CONTINUE
C
C
C     THIS SEQUENCE WRITES OUT THE TOTAL VEHICLE MILES TRAVELLED AND THE
C     TOTAL GALLONS OF GASOLINE CONSUMED PER YEAR.
C
C
      WRITE(7,3000)
 3000 FORMAT('1')
      WRITE(7,4000)
 4000 FORMAT(10X,'TOTAL VEHICLE MILES TRAVELLED PER YEAR',10X,'TOTAL GALLONS OF GASOLINE CONSUMED PER YEAR')
      WRITE(7,5000)((SVMT(K),SGASC(K)),K=1,11)
 5000 FORMAT('0',23X,F11.3,40X,F9.3)
      STOP
      END
```