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DYNAMIC MODELS OF THE U. S. AUTOMOBILE FLEET

F.T. Rabe
ENVIRONMENTAL IMPACT CENTER, INC.
55 Chapel Street
Newton MA 02158

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16. Abstract

This report examines some of the dynamic properties of the automobile fleet. The focus is not on new-car demand, but rather on the overall behavior of the system. Relationships derived from previous studies have been incorporated and integrated in a single model. This lends empirical credence to the model as well as allowing a test of internal consistency for a group of parametric relationships estimated independently. An additional objective of the work is to test the utility of the Systems Dynamics modeling approach and the DYNAMO software package for a dynamic automotive fleet model.

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PREFACE

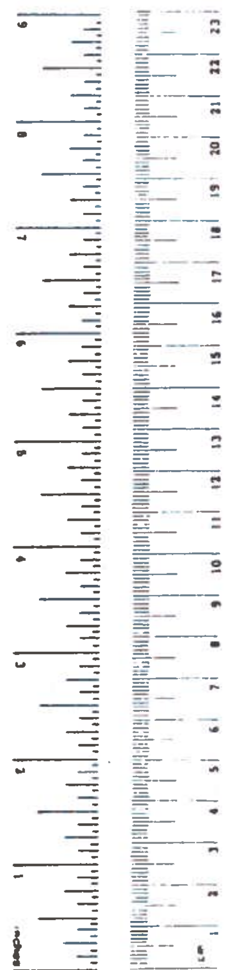
This report examines some of the dynamic properties of the U.S. automobile fleet, which serve as input data for a model. The focus is not on new-car demand, but on the interrelation of variables that contribute to the overall behavior of the system. Data derived from previous studies is incorporated and integrated into the model. The model will be used in evaluating public policies with regard to the automobile.

This report was prepared by the Environmental Impact Center, Newton, Massachusetts for the U.S. Department of Transportation (DOT), Transportation Systems Center (TSC). The work was accomplished under the Transportation Energy Efficiency Program (TEEP) at TSC.

METRIC CONVERSION FACTORS

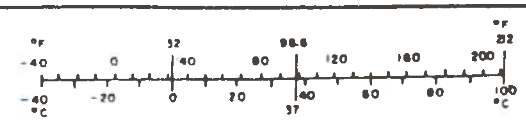
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1. INTRODUCTION

Many crucial public-sector questions today involve the automobile and its regulation. The use of automobiles and the characteristics of the vehicles themselves impinge directly on such diverse problem areas as energy conservation, air quality, public safety, and macro- and microeconomics. For a decade now, automobiles sold in the United States have been regulated in terms of safety; nationally, automotive-pollutant emissions have been limited by law since 1968; at present, the Congress is giving serious consideration to establishing mandatory fuel-economy levels for new cars sold in the United States. Simultaneously, exhaust-emissions standards are being re-examined for their fuel-economy implications.

Such regulatory actions can and have caused profound repercussions because of the ubiquity and importance of the automobile in the American economy and society. Yet, so many interrelated variables are involved that the implications of alternative public policies concerning the automobile can be anticipated with difficulty.

Several mathematical models of the U.S. automobile fleet have been developed to aid in policy analysis. Most are based on econometric studies and simple regression equations. Most of these models are also built around new-car demand as the most important element; only perfunctory study has been given to the dynamic characteristics of the auto fleet, to interactions among variables, and sensitive parameters that determine overall fleet behavior.

This report examines some of the dynamic properties of the automobile fleet. The focus is not on new-car demand, but rather on the overall behavior of the system. Relationships derived in previous studies have been incorporated and integrated in a single model. This not only lends empirical credence to the model, but also allows an unusual test of internal consistency for a group of parametric relationships estimated independently. An additional objective of the work was to test the utility of the System Dynamics modeling approach and the DYNAMO software package for a dynamic automotive fleet model.

The remaining sections of the report concern the findings and conclusions. Section 2 describes the principal relationships embodied in the model and their origins. Section 3 presents simulation results and evaluation for several assumptions and parameter variations. Section 4 reviews our findings and conclusions.

2. MODEL DESCRIPTION

2.1 GENERAL

The automobile fleet may be disaggregated along many different lines including age, manufacturer and model, weight, and size, to name only a few. Because this model is concerned primarily with fleet dynamics, it was determined to subdivide the fleet only by age. Fifteen groups were specified with each group, excluding the last, containing a yearly age of cars. The last group includes all cars aged 15 and older.

Given this simplified structure, the behavioral relationships governing flows between classes are precisely analogous to demographic relationships. The rate of sales of new cars is equivalent to a birth rate, establishing a flow of new cars into the initial age class. Subsequently, cars either age into older classes or are scrapped; scrappage being analogous to deaths from a population. Those cars reaching the final age class (15 and older) remain there until they are scrapped. These relationships are depicted in Figure 2-1.

Because the automobile population represents a conservative system of stocks and flows, the relationship among new-car sales, total scrappage, and total fleet size is a mathematical identity:

$$F_t = F_{t-1} + NCS_{(\Delta t)} \; S_{(\Delta t)}$$

where:

F_t = Fleet size at time t;

F_{t-1} = Fleet size at time t-1;

$NCS_{\Delta t}$ = New Car Sales between t-1 and t; and

$S_{\Delta t}$ = Scrappage between t-1 and t.

This implies that only two of the three principal variables in the system need be estimated; the third will then be given through the above relationship.

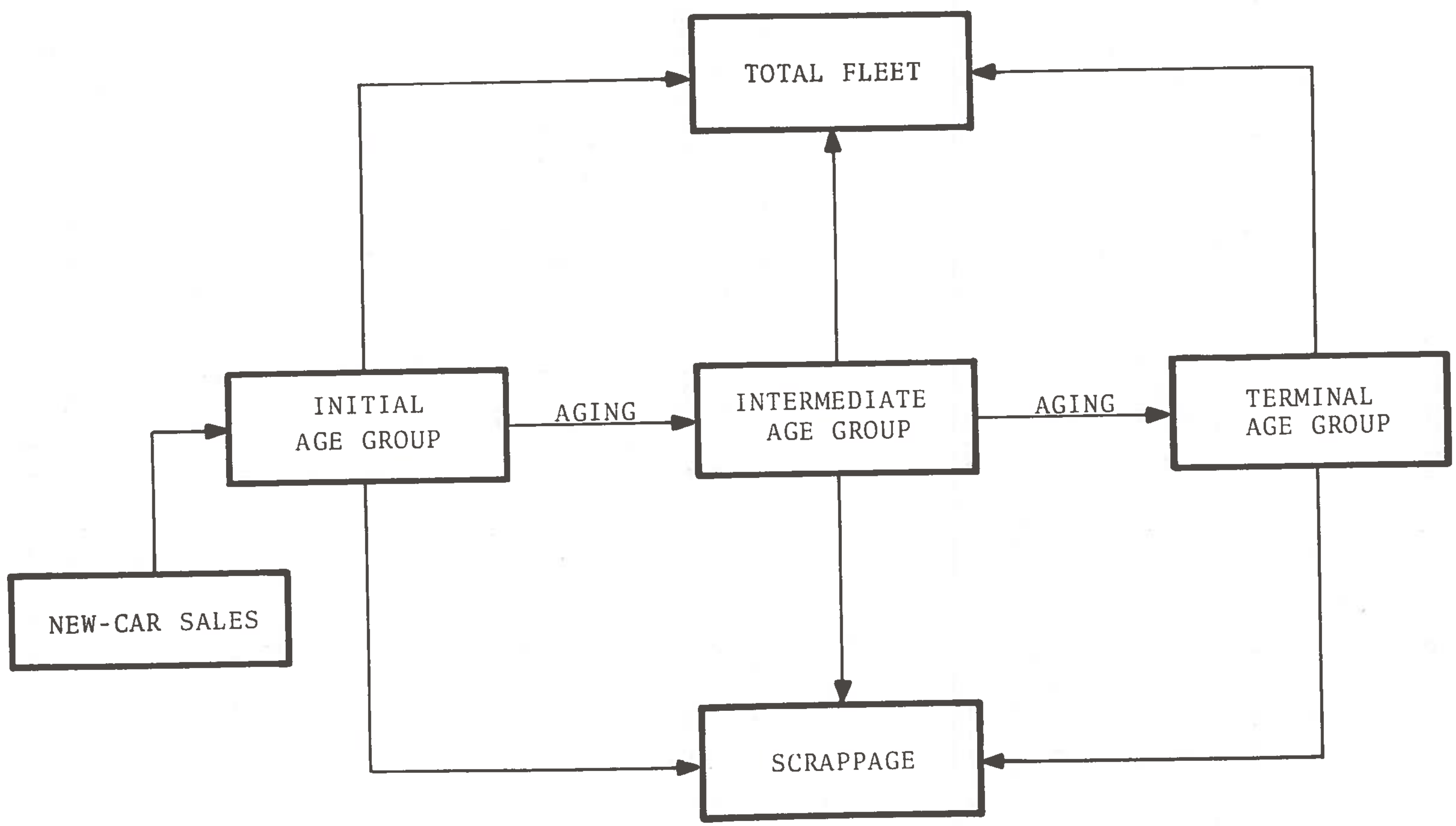

FIGURE 2-1. STRUCTURE OF FLEET MODEL

Most previous models[1,2,3*] have represented new-car sales and overall fleet size explicitly, allowing scrappage to fall out as the residual third variable. There does not appear to be a strong theoretical reason for this choice, however, and it was decided to explore other alternatives in this work. Both remaining possibilities were tested: specifying new-car sales and scrappage, with overall fleet size the residual; and specifying total fleet size and scrappage, while new-car sales are determined by those variables. All other components of the model were the same for the two specifications, allowing an evaluation of the implications of each for overall system behavior. The alternatives are described in detail below.

2.2 NEW-CAR SALES SPECIFICATION

In this specification, dynamic representations of new-car sales and scrappage determine total fleet size. Since there is no external constraint on fleet size, while new-car sales and scrappage are determined by largely independent equations, this formulation represents a good test of the accuracy and dynamic stability of the new-car sales and scrappage mechanisms.

For new-car sales, RAND Corporation's simple regression equation was used:

$$NCS = -\underset{(1.984)}{0.5080} - \underset{(5.512)}{0.20869}Pn + \underset{(1.632)}{0.09318}Pu + \underset{(2.757)}{0.7305}(Y/Y\text{-}1),$$

where:

NCS = New Car Sales per household;

Pn = Price of new cars (index);

Pu = Price of used cars (index); and

Y/Y-1 = Ratio of this year's income to last year's income per household.

The numbers in parenthesis are *t* statistics. A dummy variable for auto-industry strikes was dropped from the equation since it has no forecasting influence.

*Superscripts refer to references listed in Appendix C.

The equation implies that new-car sales are increased by low new-car prices, high used-car prices, and growing income per household. This particular version was selected over several viable alternatives,[2,3,4] principally because RAND also estimated a used-car price equation consistent with their new-car sales equation. The importance of this feature is its representation of used-car market dynamics. Structurally, the equation is similar to most new-car sales equations estimated in previous research.

2.3 FLEET-SIZE SPECIFICATION

In the second specification, total auto-fleet size is determined as a function of the size of the driving-age population. This, together with scrappage, gives new-car sales as:

$$NCS_{\Delta t} = F_t - (F_{t-1} - S_{\Delta t})$$

Such a formulation, with new-car sales a residual variable, has not been previously tested, perhaps because so much economic interest centers on demand for new cars. For an aggregate fleet model, however, it appears to have some theoretical justification. Demand for automobiles is widely recognized[5,6] to be primarily a replacement phenomenon. In addition, aggregate demand for autos may be viewed as derived from an original demand for travel. Under this interpretation, demand for travel fixes a desired auto-fleet size, which is compared to the actual fleet size corrected for scrappage as cars wear out. New-car sales, then, are equal to scrappage (replacement) plus the desired growth in fleet size from the previous time period.

Ideally, of course, such a formulation should be based on a carefully specified and empirically estimated equation for overall fleet size, relating it to socioeconomic variables, demand for travel, and auto-price variations. Unfortunately, research in this direction has been limited, and no such equation was availabl Therefore, aggregate fleet size was related to the size of the driving-age population. The historical and projected relationship of these variables is shown in Figure 2-2. While clearly an

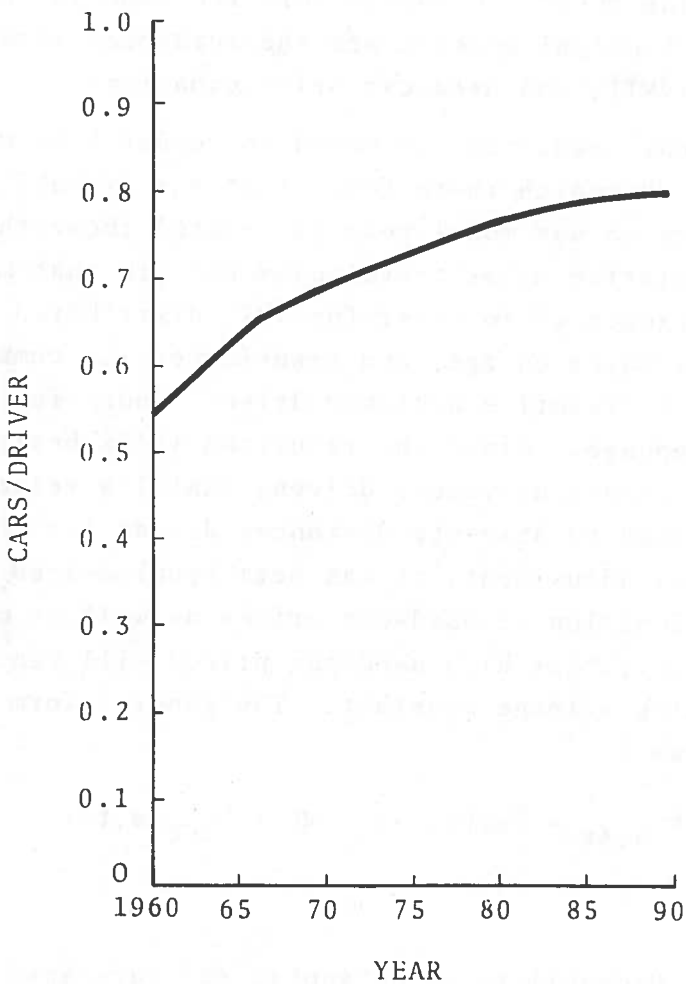

FIGURE 2-2. AUTO DEMAND PER DRIVER, BASELINE FLEET-SIZE SPECIFICATION

oversimplification, the specification does permit sensitivity analyses and tests of dynamic behavior which were the principal concern.

2.4 OTHER MODEL COMPONENTS

The remaining model components were the same for both specifications. Of principal concern are the scrappage rate, vehicle miles traveled (VMT), and used-car price equations.

This scrappage equation was based on research by Daniel[7] at General Motors. Research there found that the probability of survival for cars in any model year is related logarithmically to the average cumulative miles traveled by cars in that model year. Daniel took an exogenous forecast for VMT, distributed VMT among auto-model years based on age, and transformed the cumulative distance driven to a "relative distance driven" index for use in determining scrappage. Since the resulting index bears no explicit relationship to actual distances driven, Daniel's relative numbers were re-transformed to absolute distances driven for the model here. As a final adjustment, it was here hypothesized that scrappage is a function of used-car prices as well as mileage accumulation, i.e., that high used-car prices will tend to reduce scrappage, holding mileage constant. The general form of the final equation was:

$$PS_{a,\Delta t} = \bar{P}u/Pu,t-1 * ME * M_{acc}\ a,t-1$$

where:

$PS_{a,\Delta t}$ = Probability of Scrappage for cars aged a, time interval t-1 to t;

$\bar{P}u$ = The 10-year average of used-car prices;

$Pu,t-1$ = Last year's used-car price;

ME = The Mileage Effect on scrappage (shown in Fig. 2-3)

$M_{acc}a,t-1$ = The Mileage accumulated by an a-year old car as of t-1.

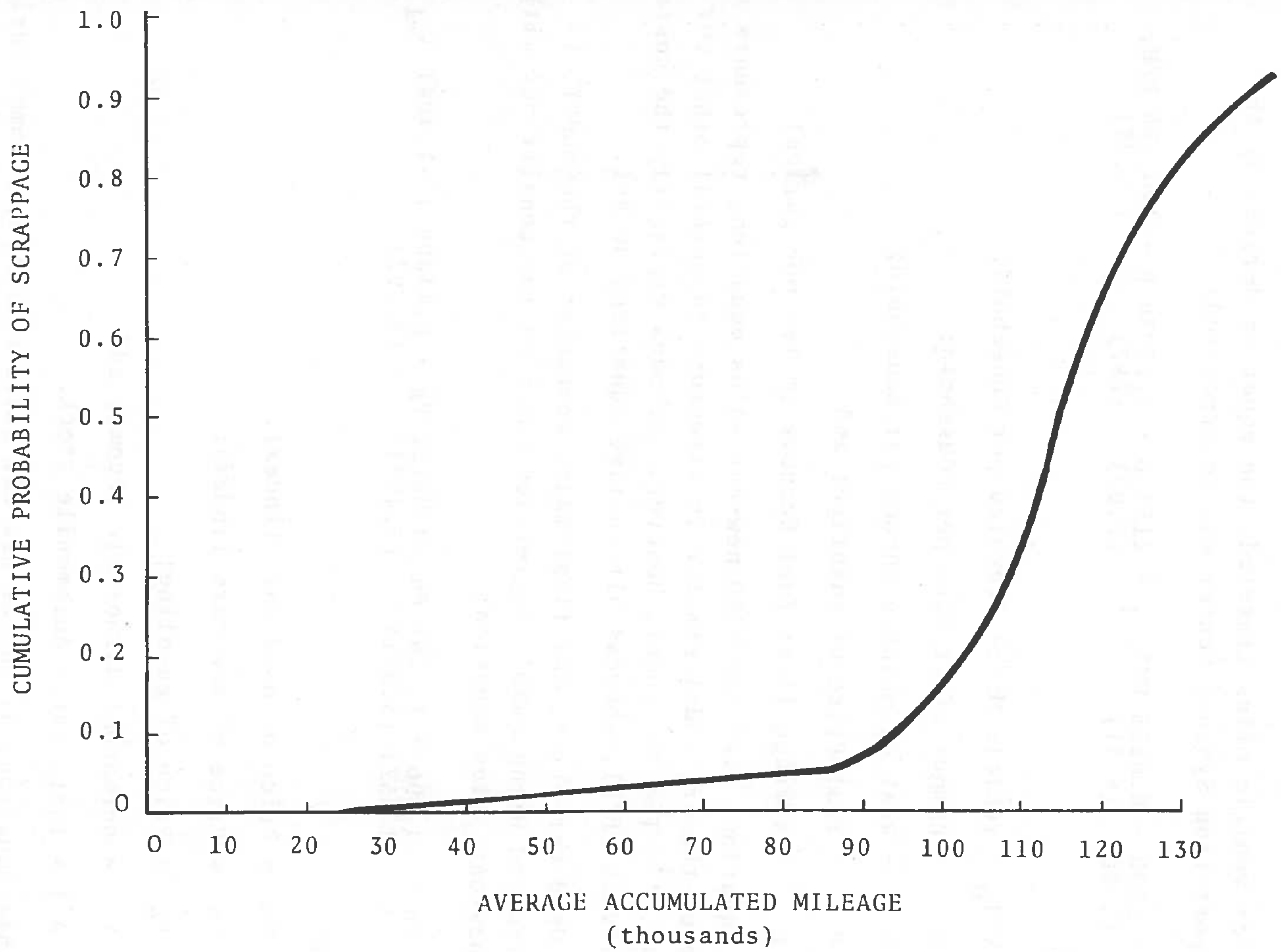

FIGURE 2-3. EFFECT OF ACCUMULATED MILEAGE ON SCRAPPAGE RATE

This probability, multiplied by the stock of a-year old cars, gives the number of such cars scrapped during the interval.

For vehicle miles traveled, the equation derived by the Transportation Systems Center was incorporated:

$$VMT_H = \underset{(1.06)}{1590} + \underset{(6.31)}{0.6233}\ VMT_{t-1} + \underset{(2.07)}{2153}\ D + \underset{(257)}{0.13936}\ R - \underset{(-5.75)}{140{,}580}\ P/E,$$

where:

VMT_H = Vehicle Miles Traveled per Household;

D = number of Drivers per household;

R = Real disposable income per household;

P = real Price of gasoline; and

E = average fleet fuel Economy (miles per gallon).

This equation, like the RAND new-car sales equation, represents a state-of-the-art model similar in structure to several other VMT models.[3,4] The TSC model, however, includes explicitly the costs of driving (P/E), whereas alternative equations do not.

Used-car price, the final major component of the model, is represented using RAND's regression equation for consistency with the new-car sales equation:

$$Pu = \underset{(2.052)}{-0.896} + \underset{(5.941)}{1.7268}\ Pn \underset{(3.467)}{-0.98122}\ Pg + \underset{(3.892)}{0.44809}\ Y - 1.4041\ A_{-1},$$

where:

Pu = Price of used cars (index);

Pn = Price of new cars (index);

Pg = Price of gasoline;

Y = permanent disposable Income; and

A-1 = last year's Automobile stock.

In this equation, as in the new-car sales equation, a dummy variable for strikes in the auto industry was omitted since it has no forecasting influence.

In addition to these endogenous variables, several variables were specified exogenously. They include: gasoline price, new-car price, disposable income, driving-age population, and number of households. The fleet average fuel economy was also set. Historical data and projections were supplied by the Transportation Systems Center. Historical data on the stock of cars by model year were taken from the research by Daniel.[7]

3. SIMULATION RESULTS

3.1 GENERAL

The same series of tests was performed on each of the two versions of the model. First, simulations were made with actual historical values for all parameters as well as projected future values considered to be most likely. They constituted the baseline runs. Then, certain parameters and exogenous inputs were varied to determine model sensitivity to their influence. Reported here are tests on aggregate auto demand per driver (in the second specification), gasoline price, and new-car price.

3.2 BASELINE RUNS

Table 3-1 and Figure 3-1 show values for new-car sales, scrappage, and fleet size simulated with the car-sales specification. The table also shows historical values for these variables.

This specification generates historical estimates that are substantially too high for new-car sales and fleet size, while scrappage is lower than historical values. New-car sales rise very rapidly to over 11 million in 1965, then remain relatively constant until 1970. The fleet simultaneously grows to more than 100 million in 1970, above the actual 85 million for 1970. These inaccurancies can be partially explained by the internal dynamics of the RAND model.

TABLE 3-1. NEW-CAR SALES SPECIFICATION, BASELINE RUN VERSUS HISTORICAL DATA

	New-Car Sales (millions)		Scrappage (millions)		Fleet Size (millions)	
Year	Projected	Actual	Projected	Actual	Projected	Actual
1960	6.6	6.6	4.0	4.2	58.6	58.6
1965	11.5	9.4	4.6	6.0	77.4	70.8
1970	12.3	8.5	6.4	8.5	102.3	84.5
1975	10.9	-	9.7	-	116.5	-
1980	15.3	-	8.4	-	133.0	-
1985	17.5	-	9.9	-	159.1	-
1990	20.4	-	1.20	-	189.0	

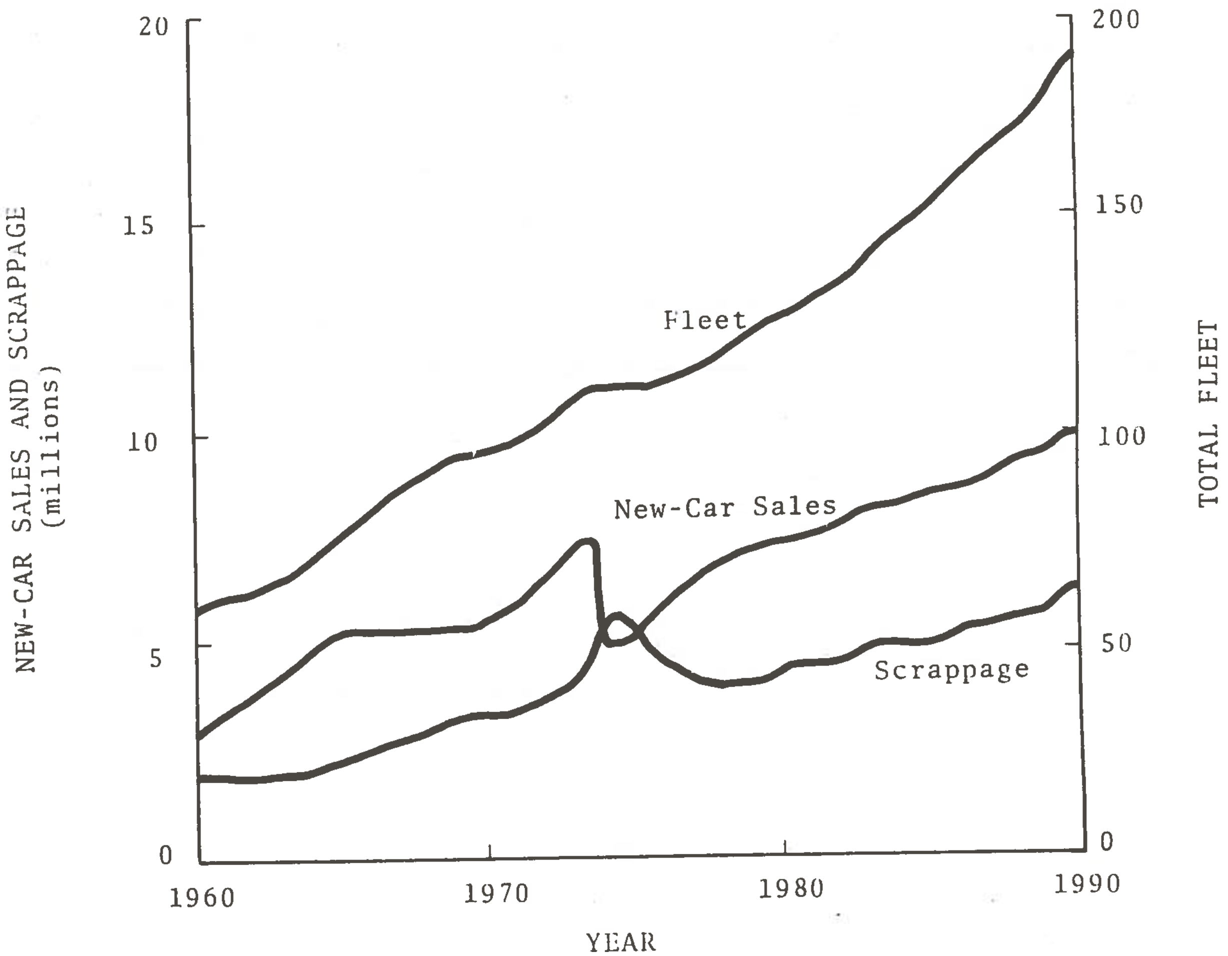

FIGURE 3-1. BASELINE, NEW-CAR SALES SPECIFICATION

Figure 3-2 depicts the movements of three more variables during the simulation: average miles per car, lagged cars per household, and the used-car price trend. They are important internal variables for simulating scrappage, used-car price, new-car sales, and of course, fleet size. Starting from new-car sales, it is clear that the system is in disequilibrium as sales double in only five years. The causes are rapidly growing disposable income, increasing used-car prices, and decreasing real new-car prices. As these new-car sales cause large increases in fleet size, however, the number of cars per household rises dramatically. This in turn exerts a growing negative influence on used-car price, which ultimately begins to fall, thus slowing new-car sales. By 1965, new-car sales, used-car prices, and cars per household have reached a relatively stable relationship in which sales rise gradually.

During the same 1960-1965 period, the average distance driven per car drops by 500 miles per year because the rapid increase in the size of the fleet outstrips growth in VMT. This implies a reduction in the accumulation of mileage on vehicles, so that scrappage decreases as well. This positive feedback loop -- larger fleet, less miles driven per car, lower scrappage, larger fleet -- is the principal source of errors in fleet size and scrappage. Since overestimates of new-car sales initiate the loop, the RAND equation is the ultimate cause of the major forecasting errors. Feedback through used-car price eventually stabilizes the system, but only after major errors have been introduced.

The reason why the RAND equation produced overestimates of historical new-car sales was not able to be determined, and conversations with RAND personnel did not even clarify the problem. There are, however, three principal possibilities: (1) historical input data were taken from different sources; (2) price indices are defined differently; and (3) RAND equations are incorrectly documented.

The specification appears to perform better for the period 1970-1980, particularly in capturing the sudden decrease in new-car

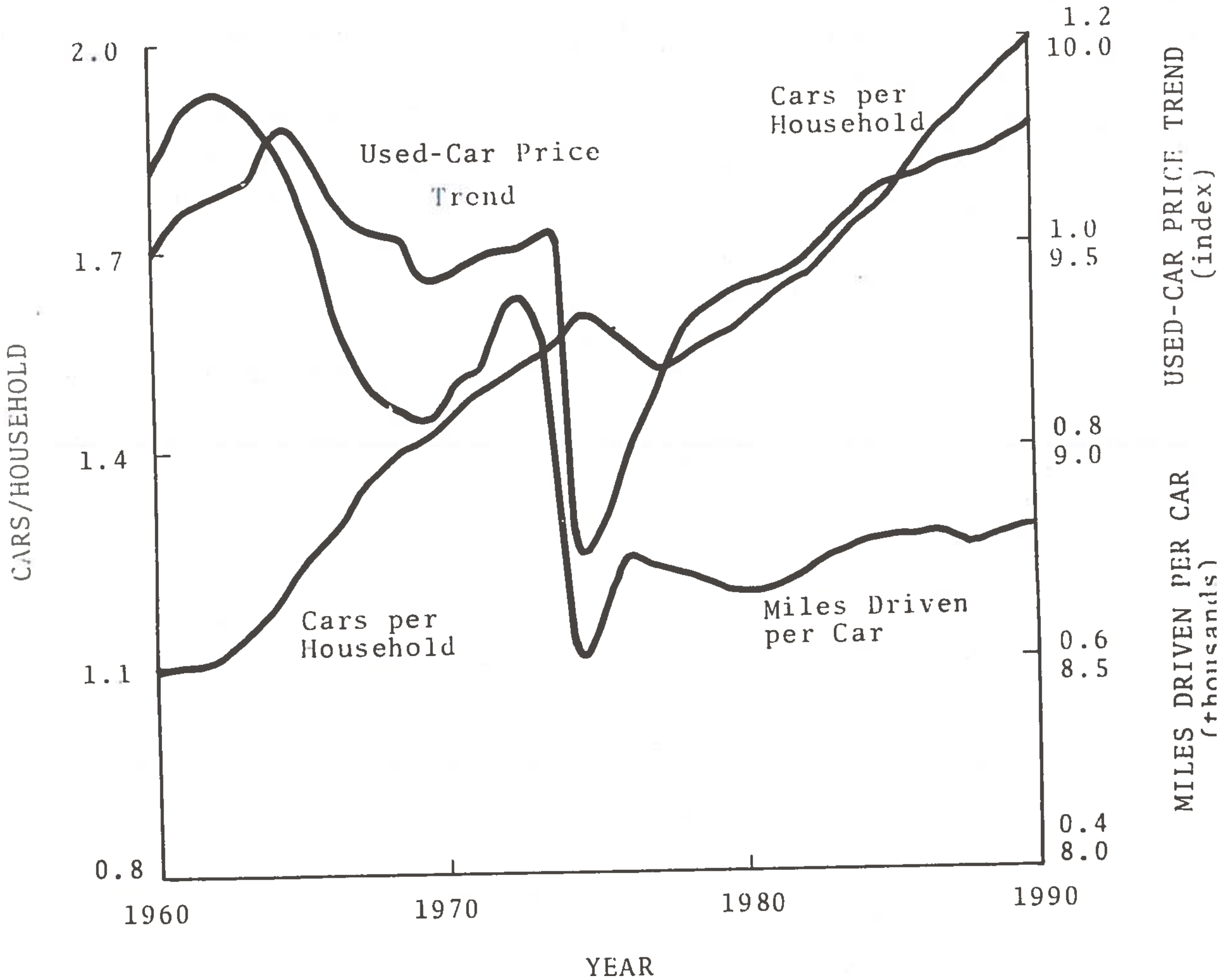

FIGURE 3-2. INTERNAL DYNAMICS, NEW-CAR SALES SPECIFICATION

sales in 1974 and 1975. It is interesting to note, however, the causal mechanisms which bring this behavior about. The precipitous increase in gasoline price in 1974 results in a major drop in used-car price. Lower used-car price in turn greatly reduced new-car sales. Simultaneously, the reduced used-car price stimulates scrappage, which, in reducing fleet size, also reduces cars per household. Fewer cars per household increases used-car price, so that the system immediately begins to recover towards previous levels in spite of continuing high-gas prices. By 1980, new-car sales and scrappage have returned to their historical growth trendline.

Examination of the baseline run, therefore, suggests weaknesses in this specification. First, the positive feedback through fleet size, average miles per vehicle, and scrappage can lead to exacerbation of errors introduced at any point in the simulation. This is particularly true when VMT forecasts are made independent of fleet size. Second, the necessary corrective negative feedback apparently should occur through average miles per vehicle rather than (or in addition to) the number of cars per household as in the RAND model. It seems intuitively correct that as each vehicle is used less the demand for more vehicles will drop. Such a relationship might enter the used-car price equation or the new-car sales equation (as in the TSC model). However, its corrective influence on the system appears to be too important to omit.

Results of the baseline simulation using the alternative fleet-size specification are shown in Table 3-2 and Figure 3-3. As expected, fleet-size projections are quite accurate through 1975. Interestingly, scrappage and new-car sales are also more accurate in this specification than the preceding one. Sales grow somewhat too rapidly between 1965 and 1973, then fail to decrease as dramatically in 1974 and 1975 as actual sales have. Note that sales recover to more than 13 million by 1980 and 15 million in 1985 in spite of the lack of influence of exogenous socioeconomic variables, and conservative estimate of cars demanded per driving-age person.

TABLE 3-2. FLEET-SIZE SPECIFICATION, BASELINE RUN VERSUS HISTORICAL DATA

Year	New-Car Sales (millions) Projected	New-Car Sales (millions) Actual	Scrappage (millions) Projected	Scrappage (millions) Actual	Fleet Size (millions) Projected	Fleet Size (millions) Actual
1960	6.1	6.6	4.0	4.2	58.6	58.6
1965	8.5	9.4	4.8	6.0	70.7	70.8
1970	11.0	8.5	7.3	8.5	84.3	84.5
1975	13.4	-	9.3	-	96.3	-
1980	13.1	-	8.5	-	112.0	-
1985	15.5	-	11.1	-	126.3	-
1990	17.4	-	13.2	-	137.5	-

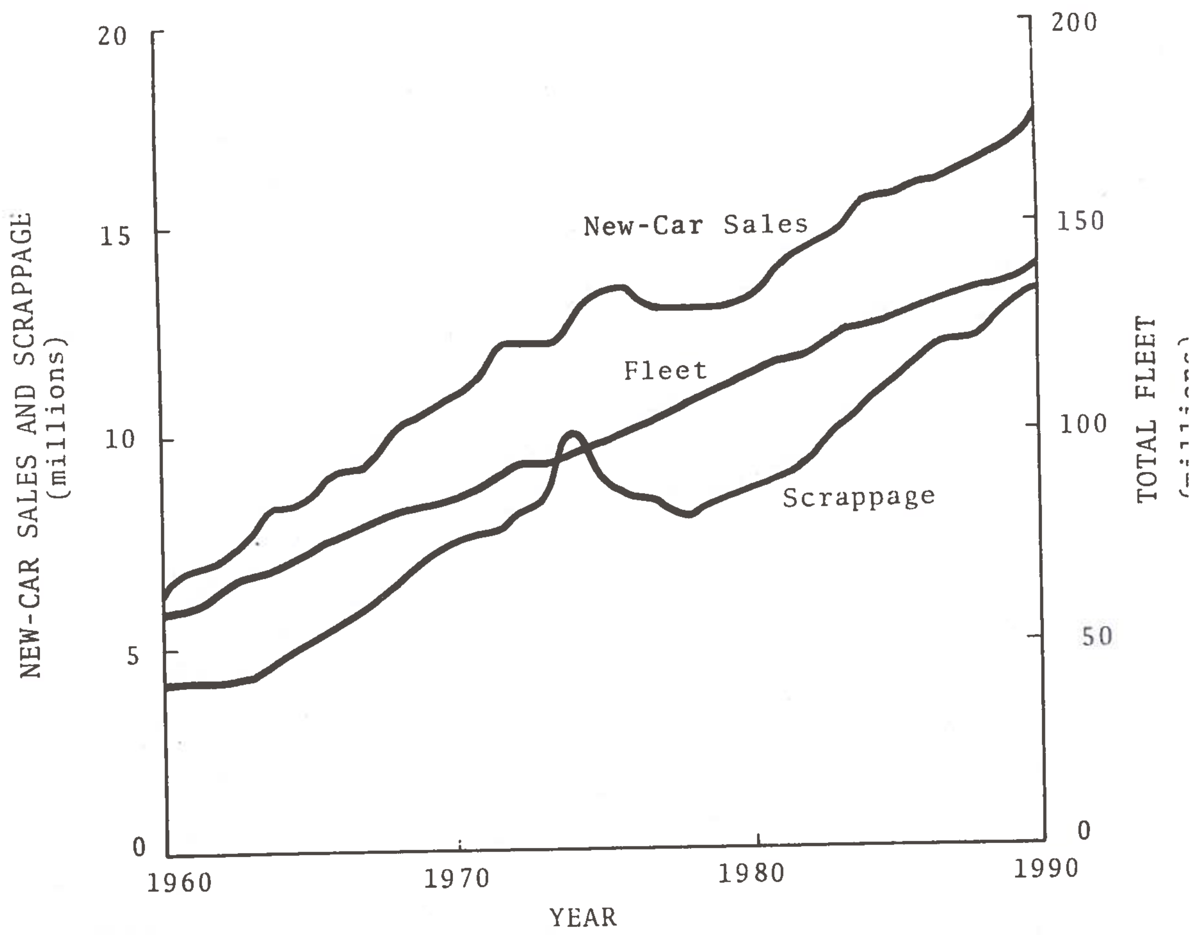

FIGURE 3-3. BASELINE, FLEET-SIZE SPECIFICATION

The greater stability and accuracy of this formulation result largely from the constrained growth in total fleet size. Since VMT remains unaffected, the miles driven per vehicle stays at about the 10,000 mile-per-year level through 1980. Scrappage rates, therefore, reflect more closely the historical pattern, and new-car sales -- a residual of fleet size and scrappage in this formulation -- also follow actual historical trends reasonably well. The principal internal source of errors, positive feedback through fleet size and scrappage, is not encountered, because fleet size is no longer a function of scrappage and new-car sales. The positive loop has been opened, eliminating a major source of instability and error. On the other hand, this specification omits any detailed characterization of the influence of socioeconomic factors and transportation-related policies on new-car sales. This weakness could be eliminated by estimating an econometric model of aggregate auto demand that incorporated the relevant socioeconomic and policy variables.

3.3 SENSITIVITY ANALYSES

A limited number of sensitivity analyses were performed to test the influence of exogenously specified variables and parameters on each specification. The same tests were performed on both model formulations (where possible) to identify differences in response. Reported here are changes in new-car prices, gasoline prices, and aggregate auto demand.

Tables 3-3 and 3-4 display the results of assumed increases in new-car prices after 1975. According to the U.S. Department of Commerce time series, real new-car prices dropped more than 30 percent between 1960 and 1975. In the base run, the price index was held constant at its 1974 value through 1990. For this test, new-car price was specified to rise by some 25 percent from 1975 to 1980, a change that might occur if current plans for regulating exhaust emissions and fuel economy are implemented. Following 1980, the price is again held constant at its new, higher value.

Table 3-3 indicates that new-car sales in fact decrease during the period 1975-1980 in the new-car sales specification.

TABLE 3-3. SENSITIVITY ANALYSIS: HIGH NEW-CAR PRICE, NEW-CAR SALES SPECIFICATION

Year	New-Car Sales (millions)		Scrappage (millions)		Total Fleet (millions)	
	Current	Baseline	Current	Baseline	Current	Baseline
1960	6.6	6.6	4.0	4.0	58.6	58.6
1965	11.5	11.5	4.6	4.6	77.4	77.4
1970	12.3	12.3	6.4	6.4	102.3	102.3
1975	10.8	10.9	9.7	9.7	116.4	116.5
1980	13.7	15.3	8.3	8.4	130.0	133.0
1985	17.4	17.5	10.4	9.9	152.0	159.1
1990	19.9	20.4	12.5	12.0	189.0	189.0

TABLE 3-4. SENSITIVITY ANALYSIS: HIGH NEW-CAR PRICE, FLEET-SIZE SPECIFICATION

Year	New-Car Sales (millions)		Scrappage (millions)		Total Fleet (millions)	
	Current	Baseline	Current	Baseline	Current	Baseline
1960	6.1	6.1	4.0	4.0	58.6	58.6
1965	8.5	8.5	4.8	4.8	70.7	70.7
1970	11.0	11.0	7.3	7.3	84.3	84.3
1975	13.3	13.4	9.0	9.3	96.3	96.3
1980	12.6	13.1	8.3	8.5	112.0	112.0
1985	15.4	15.5	11.1	11.1	126.3	126.3
1980	17.3	17.4	13.3	13.2	137.5	137.5

There is a simultaneous decrease in fleet size, but as this occurs, miles driven per vehicle decrease, and thus scrappage, so that the effect on fleet size is not commensurate with sales reductions. More older cars are simply retained in the fleet. Following 1980, the smaller size of the fleet raises used-car prices, stimulating new-car demand. By 1985, sales have almost recovered fully, and by 1990 fleet size has also returned to the baseline level. Increased prices, therefore, caused some sales reductions over a five-year period, but virtually no change in the longer term as the system tended to return to the same equilibrium growth pattern.

Table 3-4 shows a very similar response in new-car sales for the fleet-size specification. Here, however, higher new-car prices exert their influence through used-car price and scrappage only, and not directly through new-car sales. The scrappage rate decreases slightly due to higher used-car prices. The size of the fleet, however, is independent of new-car price, and therefore remains at baseline values. The net result, then, is that new-car sales decrease by a maximum of 0.5 million between 1975 and 1980, leading to a slight increase in the proportion of older cars in the population. The response is very similar to that of the new-car sales specification.

The two formulations are also similar in their response to gasoline-price increases. In the base run, gasoline price was held constant at its 1975 value of about 38.7¢ per gallon (in 1967 dollars) through 1990. For these tests, the price was trended to 50¢ per gallon by 1990. Results are shown in Tables 3-5 and 3-6.

In the first specification, increased gas prices cause new-car sales declines of 0.5 million in 1980 and 2.1 million in 1990. These decreases are largely the result of lower used-car prices; the net effect on total-fleet size is moderated. The ultimate impact of a gradual 30-percent increase in gasoline price on new-car sales is much more substantial than that of the 20-percent increase in new-car prices over 5 years tested previously.

The fleet-size specification also simulates reduced new-car sales with higher gasoline prices (Table 3-6) although the changes

TABLE 3-5. SENSITIVITY ANALYSIS: HIGH-GAS PRICE, NEW-CAR SALES SPECIFICATION

Year	New-Car Sales (millions)		Scrappage (millions)		Total Fleet (millions)	
	Current	Baseline	Current	Baseline	Current	Baseline
1960	6.6	6.6	4.0	4.0	58.6	58.6
1965	11.5	11.5	4.6	4.6	77.4	77.4
1970	12.3	12.3	6.4	6.4	102.3	102.3
1975	10.9	10.9	9.7	9.7	116.5	116.5
1980	14.8	15.3	8.5	8.4	125.0	133.0
1985	15.8	17.5	9.6	9.9	150.0	159.1
1990	18.3	20.4	10.8	12.0	180.0	189.0

TABLE 3-6. SENSITIVITY ANALYSIS: HIGH-GAS PRICE, FLEET-SIZE SPECIFICATION

Year	New-Car Sales (millions)		Scrappage (millions)		Total Fleet (millions)	
	Current	Baseline	Current	Baseline	Current	Baseline
1960	6.1	6.1	4.0	4.0	58.6	58.6
1965	8.5	8.5	4.8	4.8	70.7	70.7
1970	11.0	11.0	7.3	7.3	84.3	84.3
1975	13.4	13.4	9.3	9.3	96.3	96.3
1980	13.1	13.1	8.3	8.5	112.0	112.0
1985	14.5	15.5	9.9	11.1	126.3	126.3
1990	15.4	17.4	11.3	13.2	137.5	137.5

are more gradual. By 1985, sales are down 1 million, and by 1990 they are down 2 million. This is caused by a decreasing scrappage rate as a result of lower used-car prices. The size of the fleet again remains unaffected. While some variations in fleet size might well be expected as a result of higher-gas prices, our demand specification currently does not represent this sensitivity.

A final set of tests was performed on the fleet-size specification alone in which aggregate auto demand per driving-age person was varied to reasonable extremes. In the baseline run, demand per driver grew from 0.72 cars per driver in 1975 to 0.80 in 1990. For the high-demand case, the value of this parameter was increased to 1.0 cars per driver in 1990. For the low-demand case, it was held constant at 0.72 following 1975. Results are shown in Tables 3-7 and 3-8.

Clearly, changes in fleet size will be exactly proportional to changes in demand per driver. The adjustment mechanisms -- scrappage and new-car sales -- do not react proportionally, however, because of internal feedback. For the high-demand case, the adjustment in fleet size results from a combination of higher sales, and lower scrappage is higher. In both cases, the simulations imply, as one would expect, that changes in demand are distributed rather evenly between new and used cars.

It is interesting to compare these tests with the new-car sales specification and with other researchers' forecasts. Based on Table 3-7, we can see that fleet projections made by the alternative specification, reaching almost 190 million cars by 1990, imply that every driving-aged person in the United States owns, on average, more than one car. At the same time, each of these cars is being driven substantially less on average than at present. Under such conditions, auto demand has little to do with demand for travel; people do not own more than one car to travel more, or even to travel more easily (since each driver can only use one car at a time). So this high demand per person must have to do with status, recreation, or specialized driving desires.

TABLE 3-7. SENSITIVITY ANALYSIS: HIGH-AUTO DEMAND, FLEET-SIZE SPECIFICATION

Year	New-Car Sales (millions) Current	Baseline	Scrappage (millions) Current	Baseline	Total Fleet (millions) Current	Baseline
1960	6.1	6.1	4.0	4.0	58.6	58.6
1965	8.5	8.5	4.8	4.8	70.7	70.8
1970	11.0	11.0	7.3	7.3	84.3	84.3
1975	13.4	13.4	9.3	9.3	96.3	96.3
1980	15.3	13.1	8.2	8.5	120.9	112.0
1985	17.5	15.5	10.2	11.1	148.3	126.3
1990	19.8	17.4	12.4	13.2	173.8	137.5

TABLE 3-8. SENSITIVITY ANALYSIS: LOW-AUTO DEMAND, FLEET-SIZE SPECIFICATION

Year	New-Car Sales (millions) Current	Baseline	Scrappage (millions) Current	Baseline	Total Fleet (millions) Current	Baseline
1960	6.1	6.1	4.0	4.0	58.6	58.6
1965	8.5	8.5	4.8	4.8	70.7	70.7
1970	11.0	11.0	7.3	7.3	84.3	84.3
1975	13.4	13.4	9.3	9.3	96.3	96.3
1980	12.1	13.1	8.7	8.5	107.5	112.0
1985	14.8	15.5	11.4	11.1	115.5	126.3
1990	16.7	17.4	13.6	13.2	122.7	137.5

On the other hand, many recent forecasts have estimated 1985 auto demand at around 13 million cars.[7] Based on Table 3-8, it can be seen that this implies a significant reduction in demand per driver from current levels. If demand for travel is unaf fected, then each car in the fleet will be driven significantly farther as a result. This, in turn, will raise the scrappage rate (unless these 1985 cars are more durable) and thus cause additional replacement demand. If new-car sales continue to be constrained, the cars already in the fleet will be driven still more, etc. Ultimately, of course, new-car sales must adjust upward in the face of expanding demand for travel. It seems unrealistic, in any case, to assume that the demand per driver will decrease between now and 1985, so that a 1985 estimate of roughly 15 million cars is well justified.

These sensitivity analyses, of course, have not fully explored the dynamic behavior of either specification. They do help, however, in establishing the similarily in the responses of the formulations to variations in exogenous inputs and parameters.

4. SUMMARY AND CONCLUSIONS

4.1 MODEL SPECIFICATIONS

Two alternative specifications of a dynamic fleet model were tested in a series of simulations. The first explicitly represents new-car sales and scrappage, with overall fleet size determined as a residual. The second explicitly represents total fleet size and scrappage, while new-car sales are determined as a residual. The two specifications were selected to contrast with TSC's current model, which explicitly represents new-car sales and fleet size, leaving scrappage as the residual.

Results with the new-car sales specification suggest that important instabilities arise from positive feedback through fleet size, average miles driven per car, and scrappage. In simulations, overestimates of new-car sales led to increasingly large errors in fleet-size forecasts because of this feedback. The problem can be corrected by linking VMT to fleet size, and relating miles driven per vehicle directly to either used-car price or new-car sales.

The fleet-size specification exhibited more stable behavior and more accurate forecasts of scrappage and new-car sales. In part, this is the result of omitting the above-mentioned positive feedback loop, so that the source of instabilities and errors is removed. The present version of this specification is overly simplistic in that aggregate auto demand depends only on the driving-age population. This weakness could be remedied by estimating econometrically an aggregate demand equation that incorporates appropriate social, economic, and policy variables.

Sensitivity analyses of the two models suggest several general conclusions. It appears, first, that the auto fleet and its dynamic mechanisms are not very sensitive to disturbances in the long run. Increased gas prices in 1974 provide a good example. The increase caused immediate, large changes in new-car sales, scrappage and used-car prices. However, the combined result -- smaller fleet size relative to growing population -- quickly caused the system to begin to recover, as used-car price grew, stimulating new-car sales. In only a few years, the system had returned to its trendline growth pattern in spite of continued high-gas prices.

This example also demonstrates the importance of exogenously specified factors for system behavior. Ultimately, external variables such as disposable income, demographic characteristics, etc., determine the trendline for the system. That trendline represents, in essence, an equilibrium-growth pattern toward which the system recovers following disturbances. The trendline can be changed only by altering exogenous forecasts, by recalibrating relevant parametric relationships internal to the model, or by making some of the current exogenous variables endogenous.

The final conclusion concerns the overall stability of alternative model specifications. Real socioeconomic systems are inherently stable: if they could not recover from disturbances they would not survive. There are two principal mechanisms through which this stability is achieved. The first is negative feedback, which has been already discussed. The second is the phenomenon of saturation. One weakness of the new-car sales specification is its lack of recognition of any saturation point for either new-car sales or total fleet size, in spite of the fact that growth in sales and fleet size far outstrips population growth. The alternative spe cification proved inherently more stable precisely because both over all fleet size and new-car sales were explicitly linked to an automc bile-market saturation point. It seems worthwhile in future research to devote more effort to identifying and quantifying such saturation points for incorporation in a dynamic fleet model.

4.2 COMPUTER METHODOLOGY

Concerning the efficacy of DYNAMO and the System Dynamics methodology, the following observations are offered. For the current modeling effort, DYNAMO 3 offers a substantial savings in programming time over FORTRAN and similar languages. This is at least partially offset by additional software expenses for the compiler. DYNAMO 2 offers little or no advantage over more standard programming languages. Use of DYNAMO does not require a sacrifice in flexibility or versatility except in the areas of precise integration and output formats, where DYNAMO has fixed subroutines. On balance, then, DYNAMO offers neither significant advantages nor disadvantages, except in instances where programming time is at a premium.

APPENDIX A - MODEL LISTINGS

```
EIC FLEETH MODEL: NEW CAR SALES SPECIFICATION
C T=15
DMNSN SLA(T),SR(T),RANC(T),SLAN(T),ACCMN(T)
DMNSN AMPC(T),ACCM(T),ISR(T),MI(T),WIDYPS(T)
NOTE
FOR SI=2,T
FOR SK=1,14
FOR S=1,T
NOTE
NOTE STOCK AGING SECTOR
NOTE
L SLA.K(1)=SLA.J(1)+(DT)(NCD.J-SR.J(1)-RANC.J(1))
L SLA.K(SI)=SLA.J(SI)+(DT)(RANC.J(SI-1)-SR.J(SI)-RANC.J(SI))
NOTE STOCK LEVEL BY AGE (CARS)
A SR.K(S)=(1/UCPTD.K)(ISR.K(S))(SLA.K(S))
NOTE SCRAPPAGE RATE BY AGE (CARS/YEAR)
A RANC.K(SK)=PULSE((SLA.K(SK)-DT*SR.K(SK))/DT,1960,1)
A RANC.K(15)=0
NOTE
NOTE MILEAGE SECTOR
NOTE
A TVMT.K=VMTPH.K*HSHLD.K
NOTE TOTAL VMT
A VMTPH.K=VC+(MA*DVMT.K)+(MB*DPH.K)+(MC*INCH.K)+(MD*RGP.K/MPG.K)
NOTE VMT PER HOUSEHOLD
C VC=1590
C MA=.6233
C MB=2153
C MC=.3936
C MD=-140580
NOTE
A DVMT.K=SMOOTH(VMTPH.K,1)
NOTE DELAYED VMTPH
N DVMT=10000
NOTE 1959 VMT PER HSHLD
A DPH.K=DRV.K/HSHLD.K
NOTE DRIVERS PER HSHLD
A INCH.K=INC.K/HSHLD.K
NOTE DISP INC PER HSHLD
A AVMTPC.K=TVMT.K/TOTAL.K
NOTE AVG MILES PER YEAR PER CAR
A AMPC.K(S)=AVMTPC.K*MI(S)
NOTE ADDITIONAL MILES PER CAR BY AGE  (MILES/YEAR/CAR)
T MI=1.75/1.61/1.32/1.14/1.18/1.0/1.04/.66/1.09/.81/.65/.65/.65/.65/.65
NOTE MILEAGE INDICES
A ACCM.K(1)=AMPC.K(1)
NOTE ACCUMULATED MILES AGE 1
A ACCM.K(SI)=SMOOTH(ACCM.K(SI-1),1)+AMPC.K(SI)
NOTE ACCUMULATED MILES BY AGE
A ISR.K(S)=TABHL(ISRT,ACCM.K(S),0,140E3,10E3)
NOTE INDIC SCRAPPAGE RATE BY AGE, FRACTION OF STOCK
NOTE INDIC SCRAP RATE TABLE
T ISRT=0/.0003/.0005/.0009/.0023/.004/.008/.017/.043/.092/.167/
X .229/.389/.455/.556
A SCRAP.K=SUMV(SR.K,1,T)
```

```
NOTE TOTAL SCRAPPAGE
NOTE
NOTE PRICE-DEMAND SECTOR
NOTE
A TOTAL.K=SUMV(SLA.K,1,T)
NOTE TOAAL STOCK OF CARS
A LTOT.K=SMOOTH(TOTAL.K,1)
NOTE LAGGED TOTAL
A LTPH.K=LTOT.K/HSHLD.K
NOTE LTOT PER HSHLD
A AVGAGE.K=TOTYRS.K/TOTAL.K
NOTE AVG AGE OF CAR STOCK (YEARS)
A TOTYRS.K=SUMV(WTDYRS.K,1,T)
NOTE TOTAL CAR-YEARS
A WTDYRS.K(S)=SLA.K(S)*S
NOTE WEIGHTED YEARS (CAR-YEARS)
A UCP.K=(UA*AVGAGE.K)+(UB*NCP.K)+(UC*LTPH.K)+(UD*GP.K)+(UE*INCH.K/1000)
NOTE USED CAR PRICE INDEX
C UA=-.15
C UB=1.7268
C UC=-1.4041
C UD=-.87122
C UE=.44809
NOTE
A UCPTD.K=UCP.K/AUCP.K
NOTE USED CAR PRICE TREND
A AUCP.K=SMOOTH(UCP.K,10)
NOTE SMOOTHED UCP
A NCP.K=RPNC.K/100
NOTE NEW CAR PRICE INDEX FOR UCP
A GP.K=RGP.K/.3511
NOTE GAS PRICE INDEX (1958 BASE=1)
A NCDPH.K=NCDC+(NSA*NCP.K)+(NSB*UCP.K)+(NSC*INCH.K/DINCH.K)
NOTE NCD PER HSHLD
C NCDC=-.508
C NSA=-.20869
C NSB=.09318
C NSC=.7305
NOTE CONSTANTS
A DINCH.K=SMOOTH(INCH.K,1)
NOTE DELAYED INCH
A NCD.K=NCDPH.K*HSHLD.K
NOTE NEW CAR DEMAND
NOTE
NOTE INITIAL LEVELS
NOTE
N SLA(S)=SLAN(S)
T SLAN=6577E3/5817E3/4313E3/5966E3/5841E3/6539E3/4352E3/5103E3/2925E3
X /3598E3/3559E3/2042E3/959E3/651E3/326E3
N TIME=1960
N ACCM(S)=ACCMN(S)
NOTE
T ACCMN=0/1.7E4/3.3E4/4.6E4/5.5E4/6.6E4/7.5E4/8.5E4/9.3E4/10.3E4/
X 11.1E4/11.7E4/12.3E4/12.9E4/13.5E4
NOTE EXOGENOUS INPUTS
```

```
NOTE
NOTE FOR NEW CAR SALES
NOTE
A RPNC.K=TABHL(RPNCT,TIME.K,1960,1990,1)
NOTE REAL PRICE OF NEW CARS (1967=100)
T RPNCT=117.87/115.62/114.34/112.72/110.49/106.84/101.86/100.01
X /98.63/95.07/92.52/92.41/88.65/83.52/79.56/80/80/80/80/80/80/80/
X 80/80/80/80/80/80/80/80/80
NOTE NEW CAR PRICE TABLE
NOTE
NOTE EXOGENOUS INPUTS FOR VMT
NOTE
A DRV.K=TABHL(DRVT,TIME.K,1960,1990,1)
NOTE DRIVERS
T DRVT=87361E3/88852E3/90705E3/93695E3/95468E3/98496E3/100959E3/
X 103172E3/105392E3/106295E3/111534E3/114397E3/118414E3/121100E3/
X 123800E3/126500E3/128800E3/131000E3/133300E3/135500E3/137800E3/
X 140200E3/142600E3/145000E3/147400E3/149800E3/152100E3/154400E3/
X 156600E3/158900E3/161200E3
NOTE TABLE FOR DRIVERS
A HSHLD.K=TABHL(HST,TIME.K,1960,1990,1)
NOTE HOUSEHOLDS
T HST=52799E3/53557E3/54764E3/55270E3/56149E3/57436E3/58406E3/59236E3/
X 60813E3/62214E3/63401E3/64778E3/66676E3/68251E3/69859E3/70900E3/
X 72200E3/73400E3/74700E3/76000E3/77300E3/78700E3/80100E3/81400E3/
X 82800E3/84200E3/85400E3/86600E3/87700E3/88900E3/90100E3
  INC.K=TABHL(INCT,TIME.K,1960,1990,1)
NOTE DISP INCOME
T INCT=340.3E9/350.5E9/367.3E9/381.2E9/408.1E9/434.8E9/458.9E9/477.6E9/
X 499.1E9/513.5E9/534.8E9/555.4E9/580.5E9/619.6E9/604.7E9/612.8E9/
X 633.6E9/655.2E9/677.5E9/700.5E9/724.3E9/748.9E9/774.4E9/800.7E9/
X 827.9E9/856.1E9/885.2E9/915.3E9/946.4E9/978.6E9/1011.9E9
NOTE TABLE FOR DISPOSABLE INCOME
A RGP.K=TABHL(GT,TIME.K,1960,1990,1)
NOTE REAL GAS PRICE (1967 $)
T GT=.3512/.3434/.3381/.3315/.3264/.3298/.3298/.3317/.3236/.3168/.3069/
X .3004/.2884/.2992/.3846/.3873/.3873/.3873/.3873/.3873/.3873/.3873/
X .3873/.3873/.3873/.3873/.3873/.3873/.3973/.3873/.3873
NOTE TABLE FOR GAS PRICES
A MPG.K=TABHL(MPGT,TIME.K,1960,1990,1)
NOTE MILES PER GALLON
T MPGT=14.28/14.38/14.37/14.37/14.34/14.15/14.1/14.05/13.91/13.75/13.58/
X 13.73/13.67/13.1/13.2/13.6/14.0/14.4/14.8/15.2/15.6/16.0/16.4/16.6/
X 17.2/17.6/18.0/18.4/18.8/19.2/19.6
NOTE TABLE FOR MPG
SPEC DT=.25,LENGTH=1990,PLTPER=1,PRTPER=1
PLOT NCD=N,SCRAP=S/TOTAL=T/UCP=U,NCP=P/TVMT=V
PLOT AVGAGE=A/LTPM=C/UCPTD=D/AVMTPC=M
PRINT NCD,SCRAP,TOTAL,TVMT,AVMTPC,AVGAGE,UCP,UCPTD,LTPM
PRINT RI
PRINT SLA
PRINT SR
PRINT ISR
PRINT ACCM
RUN BASELINE
```

EIC FLEETC MODEL : **FLEET SIZE SPECIFICATION**

```
C T=15
DMNSN SLA(T),SR(T),RANC(T),SLAM(T),ACCM(T)
DMNSN AMPC(T),ACCM(T),ISR(T),MI(T),MTDYRS(T)
NOTE
FOR SI=2,T
FOR SK=1,14
FOR S=1,T
NOTE
NOTE STOCK AGING SECTION
NOTE
L SLA.K(1)=SLA.J(1)+(DT)(NCD.J-SR.J(1)-RANC.J(1))
L SLA.K(SI)=SLA.J(SI)+(DT)(RANC.J(SI-1)-SR.J(SI)-RANC.J(SI))
NOTE STOCK LEVEL BY AGE (CARS)
A SR.K(S)=(1/UCPTU.K)(ISR.K(S))(SLA.K(S))
NOTE SCRAPPAGE RATE BY AGE (CARS/YEAR)
A RANC.K(SK)=PULSE((SLA.K(SK)-DT*SR.K(SK))/DT,1960,1)
A RANC.K(15)=0
NOTE
NOTE MILEAGE SECTION
NOTE
A TVMT.K=VMTPH.K*HSHLD.K
NOTE TOTAL VMT
A VMTPH.K=VC+(MA*DVMT.K)+(MB*DPH.K)+(MC*INCH.K)+(MD*RGP.K/MPG.K)
NOTE VMT PER HOUSEHOLD
C VC=1590
C MA=.6233
C MB=2153
C MC=.3936
C MD=-140580
NOTE
A DVMT.K=SMOOTH(VMTPH.K,1)
NOTE DELAYED VMTPH
N DVMT=10000
NOTE 1959 VMT PER HSHLD
A DPH.K=DRV.K/HSHLD.K
NOTE DRIVERS PER HSHLD
A INCH.K=INC.K/HSHLD.K
NOTE DISP INC PER HSHLD
A AVMTPC.K=TVMT.K/TOTAL.K
NOTE AVG MILES PER YEAR PER CAR
A AMPC.K(S)=AVMTPC.K*MI(S)
NOTE ADDITIONAL MILES PER CAR BY AGE  (MILES/YEAR/CAR)
T MI=1.75/1.61/1.32/1.14/1.18/1.0/1.04/.86/1.09/.81/.65/.65/.65/.65/.65
NOTE MILEAGE INDICES
A ACCM.K(1)=AMPC.K(1)
NOTE ACCUMULATED MILES AGE 1
A ACCM.K(SI)=SMOOTH(ACCM.K(SI-1),1)+AMPC.K(SI)
NOTE ACCUMULATED MILES BY AGE
A ISR.K(S)=TABHL(ISRT,ACCM.K(S),0,140E3,10E3)
NOTE INDIC SCRAPPAGE RATE BY AGE, FRACTION OF STOCK
  ISRT=0/.0003/.0005/.0009/.0023/.004/.008/.017/.043/.092/
X .167/.229/.389/.455/.556
NOTE INDIC SCRAP RATE TABLE
A SCRAP.K=SUMV(SR.K,1,T)
```

```
NOTE TOTAL SCRAPPAGE
NOTE
NOTE PRICE-DEMAND SECTOR
NOTE
A TOTAL.K=SUMV(SLA.K,1,T)
NOTE TOAAL STOCK OF CARS
A LTOT.K=SMOOTH(TOTAL.K,1)
NOTE LAGGED TOTAL
A LTPH.K=LTOT.K/HSHLD.K
NOTE LTOT PER HSHLD
A AVGAGE.K=TOTYRS.K/TOTAL.K
NOTE AVG AGE OF CAR STOCK (YEARS)
A TOTYRS.K=SUMV(WTDYRS.K,1,T)
NOTE TOTAL CAR-YEARS
A WTDYRS.K(S)=SLA.K(S)*S
NOTE WEIGHTED YEARS (CAR-YEARS)
A UCP.K=(UA*AVGAGE.K)+(UB*NCP.K)+(UC*LTPH.K)+(UD*GP.K)+(UE*INCH.K/1000)
NOTE USED CAR PRICE INDEX
C UA=-.15
C UB=1.7268
C UC=-1.4041
C UD=-.87122
C.UE=.44809
NOTE
A UCPTD.K=UCP.K/AUCP.K
NOTE USED CAR PRICE TREND
A AUCP.K=SMOOTH(UCP.K,10)
 OTE SMOOTHED UCP
A NCP.K=RPNC.K/100
NOTE NEW CAR PRICE INDEX FOR UCP
A GP.K=RGP.K/.3511
NOTE GAS PRICE INDEX (1959 BASE=1)
A TDEM.K=DPD.K*DRIVA.K
NOTE TOTAL DEMAND (CARS)
A DPD.K=TABHL(DPDT,TIME.K,1960,1990,3)
NOTE DEMAND PER DRIVER
T DPDT=.54/.58/.63/.67/.7/.72/.74/.76/.78/.79/.8
NOTE
A NCD.K=TDEM.K-TOTAL.K
NOTE NEW CAR DEMAND
NOTE
NOTE INITIAL LEVELS
NOTE
N SLA(S)=SLAN(S)
T SLAN=6577E3/5817E3/4313E3/5966E3/5641E3/6539E3/4352E3/5103E3/2925E3
X /3598E3/3559E3/2042E3/959E3/661E3/326E3
N TIME=1960
N ACCM(S)=ACCMN(S)
T ACCMN=0/1.7E4/3.3E4/4.6E4/5.5E4/6.6E4/7.5E4/8.5E4/9.3E4/
X 10.3E4/11.1E4/11.7E4/12.3E4/12.9E4/13.5E4
NOTE
NOTE EXOGENOUS INPUTS
 OTE
NOTE FOR NEW CAR SALES
NOTE
```

```
A RPNC.K=TABHL(RPNCT,TIME.K,1960,1990,1)
NOTE REAL PRICE OF NEW CARS (1967=100)
T RPNCT=117.07/116.62/114.54/112.72/110.99/106.84/101.86/100.01
X 99.63/95.47/92.52/92.41/88.65/83.52/79.56/80/80/80/80/80/80/80/
X 80/80/80/80/80/80/80/80
NOTE NEW CAR PRICE TABLE
A DRIVA.K=TABHL(DRIVAT,TIME.K,1960,1990,1)
NOTE DRIVING AGE POPULATION
T DRIVAT=1.1575E8/1.2134E8/1.2293E8/1.2515E8/1.2722E8/1.2924E8/
X 1.3118E8/1.3332E8/1.3550E8/1.3784E8/1.4016E8/1.4260E8/1.4578E8/
X 1.4826E8/1.5083E8/
X 1.5244E8/1.5523E8/1.5781E8/1.6051E8/1.634E8/1.662E8/1.6921E8/1.7222E8/
X 1.7501E8/1.7802E8/1.8103E8/
X 1.8351E8/1.8619E8/1.8858E8/1.9114E8/1.9372E8
NOTE TABLE FOR DRIVING AGE POPULATION
NOTE
NOTE EXOGENOUS INPUTS FOR VMT
NOTE
A DRV.K=TABHL(DRVT,TIME.K,1960,1990,1)
NOTE DRIVERS
T DRVT=87361E3/88852E3/90705E3/93695E3/95466E3/98496E3/100959E3/
X 103172E3/105392E3/108295E3/111534E3/114397E3/118414E3/121100E3/
X 123800E3/126500E3/128800E3/131000E3/133300E3/135500E3/137800E3/
X 140200E3/142600E3/145000E3/147400E3/149800E3/152100E3/154400E3/
X 156600E3/158900E3/161200E3
NOTE TABLE FOR DRIVERS
A HSHLD.K=TABHL(HST,TIME.K,1960,1990,1)
NOTE HOUSEHOLDS
T HST=52799E3/53557E3/54764E3/55270E3/56149E3/57436E3/58406E3/59236E3/
X 60813E3/62214E3/63401E3/64776E3/66676E3/68251E3/69859E3/70900E3/
X 72200E3/73400E3/74700E3/76000E3/77300E3/78700E3/80100E3/81400E3/
X 82800E3/84200E3/85400E3/86500E3/87700E3/88900E3/90100E3
A INC.K=TABHL(INCT,TIME.K,1960,1990,1)
NOTE DISP INCOME
T INCT=340.3E9/350.5E9/367.3E9/381.2E9/408.1E9/434.8E9/458.9E9/477.6E9/
X 499.1E9/513.5E9/534.6E9/555.4E9/580.5E9/619.6E9/604.7E9/612.8E9/
X 633.6E9/655.2E9/677.5E9/700.5E9/724.3E9/748.9E9/774.4E9/800.7E9/
X 827.9E9/856.1E9/885.2E9/915.3E9/946.4E9/978.6E9/1011.9E9
NOTE TABLE FOR DISPOSABLE INCOME
A RGP.K=TABHL(GT,TIME.K,1960,1990,1)
NOTE REAL GAS PRICE (1967 $)
T GT=.3512/.3434/.3381/.3315/.3264/.3298/.3293/.3317/.3236/.3168/.3069/
X .3004/.2884/.2992/.3846/.3873/.3873/.3873/.3873/.3873/.3873/.3873/
X .3873/.3873/.3873/.3873/.3873/.3873/.3873/.3873/.3873
NOTE TABLE FOR GAS PRICES
A MPG.K=TABHL(MPGT,TIME.K,1960,1990,1)
NOTE MILES PER GALLON
T MPGT=14.28/14.38/14.37/14.37/14.34/14.15/14.1/14.05/13.91/13.75/13.58/
X 13.73/13.67/13.1/13.2/13.6/14.0/14.4/14.8/15.2/15.6/16.0/16.4/16.8/
X 17.2/17.6/18.0/18.4/18.8/19.2/19.6
NOTE TABLE FOR MPG
SPEC DT=.25,LENGTH=1990,PLTPER=1,PRTPER=1
PLOT NCD=N,SCRAP=S/TOTAL=T/UCP=U,NCP=P/TVMT=V
PLOT AVGAGE=A/LTPH=C/UCPTD=D/AVMTPC=M
PRINT NCD,SCRAP,TOTAL,TVMT,AVMTPC,AVGAGE,UCP,UCPTD,LTPH

PRINT SLA
PRINT SR
PRINT ISR
PRINT ACCM
PRINT R1
RUN BASELINE
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APPENDIX B - REPORT OF INVENTIONS

After diligent investigation, no new inventions resulted from the research presented in this report. However, the integration of relationships derived from previous studies into this single model does suggest certain areas of future research in dynamic auto fleet models.

APPENDIX C - REFERENCES

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