REPORT NO DOT-TSC-OST-76-51

AGGREGATE AUTO TRAVEL FORECASTING: STATE OF THE ART AND SUGGESTIONS FOR FUTURE RESEARCH

SAMPLE

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DECEMBER 1976

FINAL REPORT

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INFORMATION SERVICE, SPRINGFIELD,
VIRGINIA 22161

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
Office of the Secretary
Office of the Assistant Secretary for
Systems Development and Technology
Washington DC 20590

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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT-TSC-OST-76- 51		

4. Title and Subtitle	5. Report Date
AGGREGATE AUTO TRAVEL FORECASTING: STATE OF THE ART AND SUGGESTIONS FOR FUTURE RESEARCH	December 1976
	6. Performing Organization Code
7. Author(s) Robert E. Mellman	8. Performing Organization Report No. DOT-TSC-OST-76-51
9. Performing Organization Name and Address U.S. Department of Transportation Transportation Systems Center Kendall Square Cambridge MA 02142	10. Work Unit No. (TRAIS) OS714/R7508 11. Contract or Grant No.
12. Sponsoring Agency Name and Address U.S. Department of Transportation Office of the Secretary Office of the Asst. Sec. for Sys. Dev. & Tech. Washington DC 20590	13. Type of Report and Period Covered Final Report May 1976 - June 1976 14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

This report reviews existing forecasting models of auto vehicle miles of travel (VMT), and presents evidence that such models incorrectly omit time cost and spatial form variables. The omission of these variables biases parameter estimates in existing VMT models. More accurate parameter estimates are made, and suggestions are made for improving VMT models.

Accurate VMT models are important because VMT is a primary determinant of auto fuel use, pollution, and traffic fatalities; because the federal government is considering regulations to lower the levels of these externalities; and because future levels of the externalities must be measured in order to calculate the benefits to be derived from such federal regulation.

17. Key Words	18. Distribution Statement
Auto Travel Forecast VMT Model	DOCUMENT IS AVAILABLE TO THE U.S. PUBLIC THROUGH THE NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD, VIRGINIA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	46	

Form DOT F 1700.7 (8-72)

Reproduction of completed page authorized

PREFACE

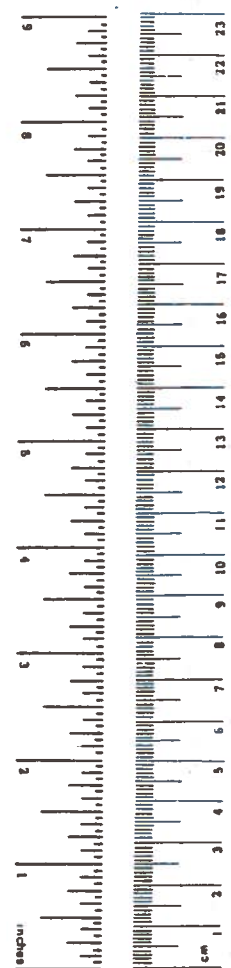
This report was prepared under PPA OS-614, Industry Economics Subproject of the Automotive Energy Efficiency Program, sponsored by the Office of the Assistant Secretary for Systems Development and Technology, TST. This report reviews existing forecasting models of auto vehicle miles of travel (VMT), and presents evidence that such models incorrectly omit time cost and spatial form variables. The omission of these variables biases parameter estimates in existing VMT models. More accurate parameter estimates are made, and suggestions are made for improving VMT models.

Accurate VMT models are important because VMT is a primary determinant of auto fuel use, pollution, and traffic fatalities, because the federal government is considering regulations to lower the levels of these externalities, and because future levels of the externalities must be measured in order to calculate the benefits to be derived from such federal regulation.

METRIC CONVERSION FACTORS

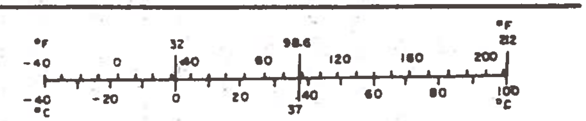
Approximate Conversions to Metric Measures

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

The report critically reviews existing forecasting models of highway vehicle miles of travel (VMT) for the United States, most of which emphasize demographic, income, and fuel price explanatory variables. The report presents evidence that explanatory variables not included in existing models are also primary determinants of VMT in the United States. These other variables are the adequacy of highway and transit facilities, and the effect of this existing transport infrastructure on spatial form. It is argued that these variables are critical to VMT analysis because they influence the relative time cost of highway travel. It is the time cost of travel, rather than the money cost of travel or perhaps even available income, that is the most important determinant of the number of miles people choose to travel per year. Finally, the implications of this finding for related research topics are discussed. Because VMT is a primary determinant of fuel consumption, ambient air quality, and traffic fatalities in the United States, a reliable procedure for forecasting VMT is fundamental to policy analysis in those vital and controversial areas. It is necessary to estimate accurately the magnitude of future energy shortage, pollution, and traffic accident problems in order to measure the value of proposed preventative policies.

2. BACKGROUND

2.1 GENERAL

The reliability of existing studies of the determinants of VMT is limited by the quality of existing VMT data. There are no direct measurements of actual annual VMT in the United States at any level of aggregation. Therefore, VMT analysis must rest on estimates of VMT. There are three sources of estimates of VMT, but each has major limitations. The three sources are the annual FHWA estimates published in Highway Statistics, the Nationwide Personal Transportation Survey (NPTS) conducted by the Bureau of the Census for FHWA in 1969-70, and studies of particular metropolitan areas produced for the purposes of transportation planning.

2.2 ANNUAL FHWA VMT ESTIMATES

Nearly all published VMT models are based on annual estimates of national VMT compiled by the Federal Highway Administration. These figures are taken from state estimates which are based on fuel consumption records. Because gasoline and diesel fuel sales are taxed, careful accounts of fuel sales are kept by each state. By multiplying these records of fuel sales by estimates of motor vehicle fleet fuel economy (miles per gallon) the states arrive at the total number of miles driven per year. The FHWA aggregates these state estimates to a national basis, separating auto VMT from truck, bus, and cycle VMT. Investigators have used this nationally aggregated auto VMT series for time series estimation of VMT models.

There are three major inadequacies with the data. The first is that the VMT estimates rely on imprecise estimates of fleet fuel economy, and for some states the fleet fuel economy figures might be inaccurate. A second source of bias is that incentives exist for states to report inaccurate VMT estimates. For instance, high VMT estimates improve a state's safety image by reducing traffic fatalities per vehicle mile. High VMT estimates also increase any federal highway appropriations that are distributed on a vehicle-mile basis. Under contract to FHWA Paul J. Claffey constructed careful estimates of actual VMT from fuel consumption estimates for eight states.[1] Claffey found that three of the eight state VMT estimates were more than ten percent higher than his estimates (the largest difference being 14.2%), and that the average state estimate was 6.5% higher than the Claffey estimate.

The third limitation of the FHWA VMT estimates is that the automobile travel data is aggregated on a national basis so that there is only one VMT data point for each year. The high level of aggregation of the data presents the chief difficulty in statistically separating the determinants of VMT. In general, statistical explanation is most powerful when there is considerable variation in the values of both the independent and dependent variables over the sample period. However, on an aggregate basis for the past twenty years, U.S. VMT has been a time-trend variable with little variation in the regular growth pattern. The recent period of no VMT growth was marked by greatly increased fuel costs, doubts about fuel availability, public sentiment against driving, and the worst of the post-war recessions. It is difficult to identify the relative strengths of these factors based on one no-growth data point.

The statistical problems caused by relatively steady growth in VMT over time are magnified by similar monotonic growth in some of the explanatory variables. Growth in VMT has been accompanied by growth in population, auto stock, income, wealth, and road quality; and, very nearly, a monotonic decline in fuel price and real car price until 1974. The fact that the explanatory variables have tended to move together until 1974, makes separation of their individual impacts on VMT treacherous.

This problem of multicollinearity is enormous. With no good method of testing to find the real explanation, any combination of two or more independent variables can explain roughly 99% of the variance in VMT. The problem is not that it is too hard to explain VMT growth, but rather that it is too easy. Any variable that has grown fairly regularly over time correlates well with VMT, as measured on an annual and national aggregated basis. But, leaving just any variable in the explanatory equation underspecifies the equations and causes biased parameter estimates.

An additional difficulty in explaining VMT on an annual national basis is that some plausible explanatory variables cannot be adequately measured at a national level. For instance, it seems sensible that population density, quality of alternative transit, urbanization, and spatial form influence driving patterns at the local level, but no good aggregate national measure of these variables exists. The increase in the number of miles of high-speed limited-access highway, and even the widening of other roads over the last decades have certainly improved traffic flow and encouraged driving, but, again, these changes are hard to quantify on an annual national basis. Even were these variables to be properly quantified and aggregated, the high degree of correlation existing among plausible urbanization, highway supply, and economic growth variables as measured over time intensifies the multicollinearity problems already discussed. Investigators using aggregate time series data have been forced to include only two or three explanatory variables in their VMT equations, eliminating possibly important independent variables and creating possible bias in parameter estimates.

2.3 NATIONWIDE PERSONAL TRANSPORTATION SURVEY VMT ESTIMATES

The only national alternative to the FHWA data base is a cross-section survey, the Nationwide Personal Transportation Survey, conducted in 1969-70 by the Bureau of the Census for the Federal Highway Administration. Approximately 6000 households were interviewed, and information was obtained on general socio-economic characteristics indlucing car ownership, typical household travel patterns to school, work, and shopping, and specific travel trips for a designated day. Of relevance to aggregate VMT considerations, the respondents were asked how many miles their household had driven in the previous year. This microscale data might be used to overcome many of the impediments caused by the national level of aggregation of the FHWA data. However, the NPTS VMT estimates have major problems of their own which make them inappropriate for serious econometric work.

a. The VMT data is based on guesses of annual travel by individuals rather than on actual odometer readings. Nobody knows how well individuals can estimate their actual household VMT, but the supposition must be that many of the observations have large errors. Aggregated nationally, these NPTS VMT estimates are 20% above the FHWA estimates for national VMT. There is no reason to believe the NPTS data is more accurate than the FHWA annual data.

b. The NPTS data tapes and reports were designed to mask the residential locations of the respondents. The region of the country is available for each observation, but the individual city of residence is not. Moreover, no data were collected on prevailing gasoline prices facing each respondent. Therefore, it is impossible to systematically relate annual VMT per household to the road network characteristics or other spatial characteristics of the city of residence, or to gasoline cost in the city of residence.

While investigators at Charles River Associates[2] have managed to match somewhat less than 1000 respondents from 43 SMSA's to residence locations, the task of applying their work to the concerns of this paper is time-consuming and tedious. Moreover, even if this work were carried out, it is likely that the relatively small number of observations scattered over many SMSA's would not lead to a reliable VMT model. The NPTS gives no information on specific respondent residence within the SMSA, information detail which might help compensate for the relatively small sample size within any SMSA.

c. Long-range forecasts of future VMT rely largely on estimates of how expected future increases in real income will influence the amount of driving people choose to do. Using a cross-section sample to study the problem would require a large sample of high-income households, households representative of American households in the year 1990 or 2000 after 15-25 years of assumed exponential income growth. Unfortunately, the NPTS contains a very small sample of upper-middle income and upper income households.

The sample is not weighted toward the projected income distribution of the future. For this reason, use of the NPTS sample gives little evidence as to how increasing incomes will influence VMT. Serious questions arise as to the applicability of the NPTS cross-section survey for time-trend forecasting.

d. Since experience has shown it to be cumbersome to exercise the NPTS data tapes, the researcher is tempted to make inferences about income elasticity from the NPTS summary booklets. By combining information in the volume on auto travel per vehicle by income class with information in the volume on auto ownership by income class one is able to calculate an estimated VMT per household elasticity with respect to income of approximately one.

However, this cursory inspection omits the effect of household family size (or number of drivers) on VMT per household. Income is directly correlated with family size and part (if not most) of the observed correlation between VMT and income is really due to family size. Single person households tend to be either very young or very old and have low income and low one-person VMT. Young marrieds generally have higher incomes and higher two-person household VMT. By the time a family has driving-age children, the parents are close to peak earning power, and the high family income is associated with, but not a cause of, the extensive driving done by the three or more driver household. Higher numbers of drivers in a household cause high VMT per household; higher numbers are also associated with higher income. But, it is wrong to impute the higher VMT associated with large families exclusively to the higher income of larger households. Economists project higher household incomes in the future, but not larger households. Serious VMT analysis must isolate the impact of larger households on VMT from the impact of higher income on VMT.

In support of the assertion that higher income families have more drivers, figures from the NPTS volume #11 report indicate that in the NPTS sample:

88.1% of 0 driver households earn less than $7,500, as do
66.1% of 1 driver households,

33.4% of 2 driver households,

21.6% of 3 driver households, and

19.8% of 4 or more driver households.

Clearly, the higher household VMT associated with higher household income can not be causally linked entirely to income; it is partly due to the number of drivers per household.

2.4 METROPOLITAN TRAVEL STUDY VMT ESTIMATES

A third possible source of data on automobile VMT consists of metropolitan travel studies. Nearly every metropolitan area occasionally surveys driving habits for the purpose of transportation planning. However, the data collected is usually not aggregated or put in form suitable for the analysis discussed in this paper. The individual studies usually count trips rather than measure miles of travel, and, in any case, it would be a tremendous effort to attempt to combine the different formats and different measures taken in different locations into an analysis of national travel. In light of the problems inherent in combining raw data from different surveys, investigators have been reluctant to try to test hypotheses about aggregate VMT from individual metropolitan studies.

3. REVIEW OF EXISTING VMT MODELS

3.1 GENERAL

Despite the severe limitations inherent in the use of the FHWA national aggregate VMT estimates as a data base for VMT analysis, limitations of other data are even more severe, and the FHWA annual time series has been used almost exclusively in constructing VMT models. The VMT analyses were concentrated in the period during and shortly after the Arab oil embargo, when the federal government enlisted the aid of researchers in forecasting future auto consumption of gasoline and necessity vehicle miles of travel. Previous to the embargo, VMT forecasting had been based on simple extrapolation. Because of the sense of urgency associated with work related to the "energy crisis," the VMT analyses' efforts were marked by quick reaction studies oriented to time-series forecasting. Because the federal government was most interested in understanding the effects of proposed fuel taxes on VMT and fuel consumption, these studies focused on determining the elasticity of VMT with respect to fuel price. Because the FHWA annual VMT figures are a time series and are easily related to socio-economic variables including fuel costs, FHWA VMT estimates were used for the analysis. VMT models are reviewed below.

3.2 CHASE ECONOMETRICS MODEL

The Chase Econometrics model[3] is part of a system of equations structured to estimate the effect of tax incentives and disincentives on car sales and fuel consumption. The VMT equation is:

$$VMT = 3416.1 + \underset{(9.2)}{78.5A} - \underset{(2.5)}{3944.5P}$$

$$+ \underset{(2.3)}{5181\ \Delta PCI} + \underset{(2.1)}{7841\ V_{-2}} + \underset{(2.2)}{8.81\ \Delta YW} \quad (R^2 = .99)$$

where

A = automobile stock

P = relative price of gas and oil

ΔPCI = change in consumer price index

V_{-2} = average price of new cars (2 year lag) - current dollars

ΔYW = change in wages and salaries - current dollars.

The Chase Econometrics model has VMT as a function of auto stock, gas price, lagged car price, and cyclical variables reflecting changes in nominal income and in the inflation rate. The forecasting equation has several major drawbacks to use in long-run studies. The cost of driving is represented by the price of gas and oil, but the fuel efficiency of the auto fleet is omitted. Because the fuel cost of driving is the dividend of gas price and fuel efficiency, this model does not incorporate the effects of projected substantial increases in auto fleet fuel efficiency. Some analysts predict that technological advances will more than offset increased fuel cost, so that, in the next ten to twenty years, fuel cost per mile will actually decline. Since the model would predict lower VMT due to higher fuel price but not include the offset of higher fuel economy, this VMT model is seriously flawed in the specification of the cost of driving term and would give unreliable forecasts for that reason.

Moreover, there is little theoretical justification for other terms in a long-run model. There appears to be no reason to include the average price of new cars two years ago as one of only five determining variables. If economic conditions induced people to want to take long auto trips, people might purchase more new cars than otherwise. However, this decision would be reflected in the quantity rather than the price of new cars and would be reflected in current behavior and not the behavior of two years before.

The equation finds a positive relationship between VMT and the rate of inflation in the consumer price index. Inasmuch as there does exist a Phillips curve, and the rate of inflation can be said to correspond to a rate of unemployment, the inclusion of this term makes sense. However, recent history has shattered belief in the existence of a stable Phillips curve. Therefore, while the rate of inflation could indicate income pressure toward higher VMT in a specific business cycle, it has little use in a long-run forecasting model applicable to times when basic structural change might have pushed the Phillips trade-off away from its position held during the period for which the model was estimated. In addition, as a practical matter, predicting the rate of inflation for future decades is required for using the model to forecast long-run trends in VMT, and that prediction is very difficult. The equation emphasizes cyclical inflation which is difficult to forecast, when, in reality, it is secular real influences which determine long-run trends in VMT growth.

This same criticism can be applied to the ΔYW term. While it is clearly real income which influences VMT secularly, the ΔYW term reflects wage and salary increases in money terms. This term of the equation is geared to a short-run cyclical forecasting model, and has little justification for inclusion in an analysis of policy based on long-run considerations of energy and resource depletion.

3.3 ENERGY AND ENVIRONMENTAL ANALYSIS, INC. MODEL

Energy and Environmental Analysis, Inc.[4] has constructed an estimating equation for national VMT which overcomes some of the misguided reasoning inherent in the Chase Econometrics equation:

$$\text{VMT} = \underset{(5.4)}{834} + \underset{(22)}{1.39}\ \text{DI} - \underset{(1.8)}{3267}\ \text{CV (new)}$$

$$- \underset{(3.2)}{8615}\ \text{CV (lagged stock)} \quad (R^2 = .99)$$

where

DI = real disposable income

CV (new) = average cost per VMT of new cars

CV (lagged stock) = cost per VMT of previous year's fleet.

This equation correctly includes a real income variable and measures the marginal cost of driving rather than just the price of gas. Although the cost variable should perhaps be a single cost term, weighting auto VMT by vintage, the equation presents two terms which supply a reasonable approximation.

However, the equation omits a term to represent the number of cars in the auto stock. The model is estimated over a period when much of the growth of VMT per capita was doubtless due to the increase in rates of car ownership, and is used to forecast over a period during which auto stock per capita will presumably be asymptotically approaching a limit. The income term picks up income relationships to VMT which are both dependent on and independent of the growth in auto stock per capita. This income term is used to forecast over a period when the influence of income will largely be independent of the growth in stock of cars, and when the percentage of the population that has auto availability cannot increase substantially from already high levels. For this reason, the equation would probably overestimate future growth in VMT.

While the EEA study discusses cylical influences on the economy, none is in the equation. Disposable income rarely falls, even in recessionary times, and, thus, is a poor indicator of economic conditions. Either the unemployment rate or the divergence from time trend growth in disposable income should be included to incorporate cyclical effects. While cyclical changes are expected to be unimportant to long-run forecasting, omission of a cyclical variable causes under-specification of the equation and possible bias in the parameters which are included.

A third criticism of the EEA model, which is applicable to other models as well, is that travel cost is considered to consist only of the fuel cost of travel. The time cost of travel is also very important to drivers, yet is omitted from the model. The population may have changed driving habits in response to changes in the fuel cost of travel, but the population certainly has also changed driving habits over the last twenty-five years in response to the interstate highway system, urban freeways, improved auto reliability, and other structural changes which have improved average auto speed and lowered the time cost of travel. The effect of improved road networks on suburbanization, and the effect of suburbanization trends on aggregate VMT are often mentioned in discussions of auto use and spatial form,[5] but are omitted from this and other VMT models.

3.4 JACK FAUCETT, INC. MODEL

Jack Faucett, Inc.[6] constructed the following model for the inter-agency federal government report on Motor Vehicle Goals Beyond 1980:

$$\frac{VMT}{HHLD} = \underset{(-3.7)}{-52979.8} + \underset{(3.52}{15087} \text{ LOG} \left(\frac{DI}{HHLD}\right)$$

$$+ \underset{(2.75)}{6337.7} \left(\frac{AUTOS}{HHLD}\right) - \underset{(-2.78)}{2204.24} \text{ CPM } (R^2 = .98)$$

where

$\frac{VMT}{HHLD}$ = Annual VMT per household

$\frac{DI}{HHLD}$ = Real disposable income per household (1967 $)

$\frac{AUTOS}{HHLD}$ = Total cars in use per household

CMP = Index of real fuel cost per mile.

This model has the good features of including income along with auto stock, and measuring fuel cost per mile as the dividend of fuel cost and fuel efficiency. Population growth is included by estimating the equation on a per household basis. However, due to the low number of observations available for use in an annual model, the equation omits cyclical variables and omits a variable to measure change in the time cost of travel.

3.5 FEDERAL ENERGY ADMINISTRATION MODEL

A similar model was estimated by a group working for the Federal Energy Administration:[7]

$$VMAUTO = N*EXP\left(\underset{(12.7)}{.81}*LOG\left(VMAUTO(-1)/N(-1)\right)\right)$$

$$+ \underset{(12.1)}{6.52} - \underset{(-1.8)}{.36}*LOG(COSTPM)$$

$$+ \underset{(11.2)}{.98}*LOG(YD58\%N) + \underset{(.94)}{.003} *RU$$

$$- .81*\left(6.51 - \left(.36\ LOG*COSTPM(-1)\right)\right)$$
$$+ .98*LOG\left(YD58\%N(-1) + .033*RU(-1)\right)$$
$$\bar{R}^2 = .996$$

where

VMAUTO = Total vehicle-miles of passenger cars

N = Total population

COSTPM = Cost per mile of auto driving

YD58%N = Disposable income per person, $58

RU = Unemployment rate.

The FEA model correctly includes cost per mile, disposable income, and the cyclical unemployment variable. It does not include variables representing the time cost of travel or the auto stock. Much of the variance in VMT over time in this equation is explained by the previous year's VMT. It is certainly true that lagged VMT is a good predictor of current VMT. Residential and work location, recreational habits, and other elements of national lifestyles change slowly over time. VMT in any year should be within a few percentage points of VMT in the previous year. However, the forecaster interested in long-term trends must know the structural determinants of VMT, for it can be expected that as the time horizon of the forecast period expands, lagged VMT will be a less reliable predictor of the future. Including lagged VMT in the estimated equation improves the value of the R^2 statistic, but does little to help the researcher in understanding the determinants of VMT in the long-run.

3.6 RAND CORPORATION MODEL

A RAND Corporation study[8] analyzed the determinants of U.S. fuel consumption in a system of seven equations, one of which is a VMT equation. Because of multicollinearity problems and the relatively low number of degrees of freedom, the equation was estimated including gas price but not fuel efficiency as an independent variable. A derived form is then calculated in which the elasticity of VMT with respect to fleet fuel efficiency is assumed to be equal to, though of opposite sign than, the elasticity with respect to gasoline price. The estimated equation is:

$$\text{Log}(VMT/H) = \underset{(752)}{9.19} + \underset{(13.4)}{.84}*\text{Log}(A/H) - \underset{(3.52)}{.37}*\text{Log } P + \underset{(2.31)}{.025}*D$$

and the derived form is:

$$\text{Log}(VMT/H) = 8.0 + .86*\text{Log}(A/H) - .44*\text{Log}(P) + .44*\text{Log}(E) + .04*D$$

where:

VMT/H = Auto VMT per household

A/H = Auto stock per household

P = CPI index of real gasoline price

E = Fleet miles per gallon

D = Dummy variable for Federal safety-emission regulations.

This equation has many of the qualities of the models already reviewed. However, the reader should note that in the RAND system of equations, VMT is assumed to depend on the demand for autos; and that the income term does not appear in the equation. In the long run, it makes more sense to assume that autos are derived from the demand for travel. If cars are driven more miles per year on average, they will wear out more quickly, and annual replacement demand for cars will be higher. If cars on average are driven fewer miles per year, they will wear out more slowly, and auto replacement demand will be less. Clearly, auto demand depends on VMT. It should also be noted that the RAND model system is recursive rather than simultaneous due to the low number of degrees of freedom. If less highly aggregated data were available, the equations could be specified in a theoretically correct manner, and the parameter estimates would be more reliable.

3.7 TRANSPORTATION SYSTEMS CENTER MODEL

A TSC model,[9] developed for the Automotive Energy Efficiency Program, estimates VMT as a function of explanatory variables to be:

$$VMT/H = \underset{(1.06)}{1590} + \underset{(6.21)}{0.634}\ (VMT/H)_{-1}$$

$$+ \underset{(2.07)}{2153}\ (D/H) + \underset{(2.57)}{.394}\ (R/H) - \underset{(5.75)}{140{,}580}\ (P/E)$$

$$(R^2 = .99)$$

where:

VMT/H = VMT per household

D/H = Number of drivers per household

R/H = Real disposable income per household

P/E = Gasoline price divided by fleet fuel economy.

The presence of the lagged dependent variable in the model specification makes it possible to calculate short and long run VMT elasticities with respect to the independent variables. The underlying assumption of the specification is that actual VMT adjusts only partially to changes in desired VMT in any year induced by changes in exogenous variables. For instance, it is assumed that a sharp escalation of fuel prices will bring about a lower desired VMT, but the population will take more than one year to adjust. The adjustment processes including basic changes in lifestyles such as moving residences closer to work places and to schools, concentration of commerical activities, and planning of fewer recreational auto trips. Short-term elasticities produced by the model for demand for VMT are .27 with respect to the number of drivers, .24 with respect to disposable income, and -.22 with respect to the cost of travel. Long-run (equilibrium) elasticities are .71 with respect to the number of drivers, .63 with respect to disposable income, and -.57 with respect to the cost of travel.

However, the assertion that long-run VMT changes in response to exogenous shocks are larger than short-run changes is only an assertion. It is equally possible that, in the long run, persons adjust car fuel efficiency or car size in response to changes in exogenous variables but alter their driving habits very little. In the long-run, must of the population may find that it is much easier to adjust the kind of car they drive than to adjust how much the car is driven. If this were true, short-run VMT elasticities (before auto change is made) would be larger in value than the long-run VMT elasticity.

A rigorous VMT analysis should distinguish between these two view of the time structure of VMT adjustment to changes in exogenous variables. However, the small number of degrees of freedom and the lack of extensive historical experience of VMT growth diverging from trend make it impossible to choose the "correct" adjustment structure. Therefore, until microscale data over time on VMT is available, acceptance or rejection of the stock-adjustment VMT specification must rest on the personal judgment of the individual researcher.

Another methodological criticism of the TSC model is that the number of drivers should not be treated as an exogenous variable. Structural changes that influence the number of miles people drive also influence the number of people who choose to obtain drivers' licenses. It would be preferable to substitute "driving-age" population" for "number of drivers" in the estimated equation. The model also fails to model explicitly the effects of approaching auto-stock saturation which were discussed above.

3.8 EIC CORPORATION MODEL

Researchers at EIC Corporation[10] revised the TSC model taking into consideration criticisms of the model that had arisen. The lagged dependent variable term was removed from the equation and the equation was reestimated using first differences. A policy variable relating VMT to mass transit availability was added. The driving age population is dropped from the equation, and the model was no longer based on a per household denominator.

The EIC equation takes the form:

(1) $VMT = VMT(-1) + \Delta VMT$

(2)
$$\Delta VMT = \underset{(3.2)}{11.3\ \Delta HH} + \underset{(4.8)}{.86\ \Delta Y} - \underset{(-5.2)}{8273\ \Delta COST} - \underset{(-1.4)}{45\ \Delta TRANS} \qquad (R^2 = .86)$$

where:

VMT = Nationwide VMT

VMT(-1) = VMT lagged one year

HH = Number of households

Y = Real disposable income

COST = Price of gas divided by fleet fuel efficiency

TRANS = The total supply of transit, measured in vehicle miles.

The VMT elasticities at 1974 variable values are .80 with respect to households, .57 with respect to income, -.24 with respect to the cost of driving, and -.90 with respect to transit supplied. The EIC equation is one of the best of the VMT models. However, it fails to deal with the question of auto stock saturation and the effect of income on VMT independent of its effect on auto stock. Moreover, the TRANS variable should properly be viewed as a jointly endogenous variable rather than as an exogenour variable. Relative total price shifts and income shifts which influence the transit decision also influence the driving alternative. Inclusion of transit supply would be defensible, but inclusion of transit use creates some simultaneous equation bias as the VMT equation is specified. Unfortunately, the aggregated nature of the model makes estimation of the theoretically correct form impossible due to multicollinearily problems.

4. ADEQUACY OF EXISTING VMT MODELS

The previous discussion demonstrates that valid criticisms cam be applied to each of the existing VMT models. Even combining the best features of each estimated equation produces a model which gives inadequate attention to 1) the time cost of auto travel and to 2) relative time and money costs of competing travel modes in determining aggregate auto VMT. Existing models are based almost exclusively on the effects of income and the fuel cost per mile on per capita VMT. It is important to ask whether these included variables adequately capture the determinants of national VMT. The word "adequately" is used because additional variables would almost certainly add some explanatory power to the VMT equations. The question is whether the increase in explanatory power is worth the substantial data collection cost of model expansion.

VMT forecasts are of fundamental importance in judging the wisdom of government policies related to fuel conservation, air quality, and traffic safety. The high quality of VMT forecasts is an important research priority. However, development of a micro-scale data base is relatively expensive and time-consuming. In evaluating existing models, it is necessary not only to mention the omission of seemingly determining variables, but also to demonstrate 1) that these variables are quantitatively important relative to the included income and money price of driving variables, and 2) that their inclusion justifies the development of a new data base.

A casual inspection of available analysis offers convincing evidence that the time cost of travel is important in determining VMT. At least, time cost is more important than the fuel cost of travel. A 1970 study by Thomas and Thompson of the Stanford Research Institute[11] places the value of time for commuting motorists at $2.82 per person per hour. Another study mentioned in the same volume[12] gives the value of $2.50. Because the value of the 1976 dollar is considerably less than that of the 1970 dollar and because average car occupancy rates are higher than 1.0, $3.00 per hour is a conservative assessment of the time cost of auto travel in 1976. Therefore, in travelling one hour, auto travel costs are at least $3.00 in time while the fuel cost is likely to be less than half of $3.00. (A 15 mile per gallon car using 60¢ per gallon fuel averaging 30 miles per hour uses $1.20 per hour in fuel.) As substantiation of the importance of time in relation to fuel cost the reader may note that many drivers purchase gasoline at convenient stations where the price is 10% higher than at the low-cost station one-half mile out of the way, but that very few drivers fail to give careful attention to shaving seconds from their work trip however indirect the route.

A similar type of casual inspection argues for the importance of mass transit and highway supply, omitted variables in conventional VMT models, in influencing VMT. 1972 total VMT per capita is less than 6000 miles per capita in states which have large cities with the best rapid transit systems - Massachusetts, New York, Pennsylvania, and Illinois. In contrast, states with the best supply of interstate highway per capita, states of the Southwest and Rockey Mountain regions, universally logged more than 6000 miles per capita.[13] An <u>a priori</u> case exists for supposing that existing VMT models should be amended to include auto travel cost and other determining variables not now included. This assertion implies that the parameter estimates of existing, under-specified equations cannot be presumed to be unbiased.

5. SUGGESTED VMT MODEL SPECIFICATIONS

If data availability considerations are ignored, it is relatively easy to specify a VMT model for any region of given spatial form as a standard consumer demand model. Auto travel VMT per capita can be assumed to depend on income levels, the time cost of auto travel, the money cost of auto travel, the time cost of travel by competing modes, and the money cost of travel by competing modes. VMT per capita can also be expected to vary regularly with the density of spatial form. In a dense area, destinations tend to be relatively close, congestion high, and VMT relatively low; in a less dense area, destinations tend to be further away, congestion less, and, other things being equal, VMT relatively high. The model sketched in this section contains elements of the models of VMT already in existence (population, income, and fuel cost of travel) but contains other variables as well. These other variables were omitted from existing models either because it is difficult to find a data series to represent the concept (time cost of competing modes) or because of multicollinearity difficulties. This paper will now test the importance of these omitted variables.

Analysis of the pattern of national VMT over time is difficult due to the strong time trend in the data series, small variation from that trend, and small variations in the values of some explanatory variables. Analysis of the variance in international VMT figures is difficult because of possibly great differences in culture and custom, to say nothing of the difficulties inherent in evaluating socio-economic variables across countries. This paper will approach the VMT problem by comparing VMT in states within the United States. While data series cannot be found to precisely measure the true explanatory concepts, the independent variables entered here are sensible and offer a reasonable alternative to the simple income-fuel price models.

The dependent variable of the equations to be estimated is VMT per capita. These is no data available, however, on auto VMT by state. The VMT term measures truck and auto VMT. This variable can be defended by arguing that a large majority of trucks are small trucks, that small trucks have fuel consumption, emissions, and safety characteristics similar to cars, and that the car-truck distinction in the literature is arbitrary. However, the real reason auto and truck VMT are combined on the left hand side of the estimated equation is that the FHWA state estimates do not separate car and truck VMT. All data are 1972 values.

The income term is 1972 money income per capita by state. There is no variable which adequately measures the average time cost of auto travel, or network speed, in a state. The number of miles of interstate highway per capita in the state is used as a proxy for network speed. More miles of highway not only allow more rapid speeds on the highway, but reduce congestion on other roads. While miles of highway does not exactly measure the average speed of the average auto trip in a state, it may be a good proxy variable. Fuel cost is measured by the average 1972 gasoline line price in each state. Since the same array of automobiles with the same array of fuel economies were available for use in each state, this variable attempts to measure the effect of fuel price on VMT allowing the fuel efficiency of the auto stock to vary. (A proper test would include gas price data from several years. The estimated equation implicitly assumes that gas prices in different states did not change relative to each other in the years prior to 1972.) The time and money costs of competing modes of travel are very difficult to measure. Attempting to calculate the time and money costs of air and rail travel and their differences across states would probably prove futile. Attempting to measure the time and money cost of public local transit facing the average citizen of each state would probably also prove futile. Because in most states auto and truck VMT is so large relative to public transit VMT, the benefits to be gained from such measurements are probably small. In the estimated equations, miles of urban rail transit per capita in each state acts as a proxy for the "quality," or relative real price, of public transit. The differences, if any, in relative real prices of air and intercity rail transit across states are left out of the equation.

Atuo travel in any region also depends on the spatial form of the region, particularly the density. As a recent paper by Harrison and Kain[14] points out, older cities built before auto travel was dominant tend to be concentrated. They were built to conserve travel at a time when travel was more expensive than today, and, because of the durability of buildings and roads, they remain spatially structured as they were when built. Newer cities and the newer rings of older cities were physically constructed at a time when auto travel was dominant and travel relatively inexpensive. Newer cities tend to be less densely populated. Two variables are included in the equation to measure the effect of spatial form on VMT. These are the state population in 1950 divided by the state population in 1970, intended to measure the age of the physical structure of the region, and the percentage of families living in single-family homes, used as a proxy for density that is independent of already included variables and as a measure of the rural qualities of a state. The reader should note that the observations should ideally be geographic divisions other than states, which are generally heterogeneous, but that states are the only level at which consistent VMT estimates are available. Observations are used from the 48 continental states and the District of Columbia.

One minor adjustment to VMT data is made. As previously discussed, Claffey[15] analyzed fuel consumption in eight states and arrived at VMT estimates somewhat different from the FHWA estimates. Rather than ignore these more careful estimates, the FHWA estimates for eight states were adjusted to reflect the Claffey estimates. The FHWA VMT estimates were adjusted to coincide with the Claffey estimates after these were normalized so that their average divergence from the FHWA estimates was zero. The largest adjustment is for the State of Pennsylvania, where the 1972 VMT estimate is lowered by 7.6%.

The following abbreviations for variables are used in the discussion of regression results:

VMTPC = Vehicle Miles of Travel per Capita (1000's)

YPC = Money Income per Capita (1000's of Dollars)

GASP = Average Gas Price, Cents per Gallon

TIP = Total Miles of Interstate Highway per Hundred Thousand People

RTRAPC = Miles of Rapid Rail Transit per Thousand People

OLD = 1950 State Population Divided by 1970 State Population

HOUSE = Percentage of Population Living in Single-Family Homes.

6. ESTIMATION AND RESULTS USING EXISTING MODELS

A first test of the reliability of the existing population-income-fuel price models is to run a regression of VMT per capita using only gas price and income per capita as explanatory variables. Validation of the model would occur through high calculated T-statistics, negative for gas price and positive for income, and a high F-statistic. Neither of the two T-statistics nor the F-statistic proves significantly different from 0 at the 95% confidence level. The equation explains less than 12% of the interstate variation in VMT.

$$\underset{}{VMTPC} = \underset{(3.67)}{12.06} - \underset{(1.83)}{.65\ YPC} - \underset{(1.01)}{.10\ GASP}$$

R^2 = .115 T-statistics in parentheses

F = 3.00

It should be noted that the income term has a negative coefficient. The lack of a positive and significant income coefficant income coefficient can be explained. States with high income per capita tend to have cities with high densities and hence low VMT (N.Y., Conn., D.C.) while states with low per capita income often have few large and dense cities and for that reason high VMT (S.C., Ky., N.M.). The density differences are associated with differences in existing highway supply per capita (low for large dense cities), transit supply per capita (existing only in the large dense cities as measured), and with the time period during which the physical area developed. Because the simple income - gas price model performed so poorly, a more complete VMT equation is estimated.

$$VMTPC = \underset{(1.38)}{4.09} + \underset{(7.74)}{.014*TIPH}$$

$$- \underset{(2.71)}{77.13*RTRAPC} - \underset{(4.09)}{.025*OLD}$$

$$+ \underset{(2.83)}{.036*HOUSE} + \underset{(0.85)}{.045*GASP}$$

$$- \quad .057*YPC$$
$$(0.18)$$

$$R^2 = .78$$

The estimated parameters of the equation clearly indicate that transportation infrastructure and spatial form are the most important explanatory determinants of interstate differences in VMT. Both the income and gas price variables are statistically insignificant influences on VMT and both estimated coefficients are of the wrong sign. It might be expected that gas price would show an insignificant effect on VMT because the lowest gas price is only twenty percent below the highest gas price by state in 1972, and forty of the forty-nine observations had gas price within four cents of each other. The income coefficient is statistically insignificant; independent of the income effect associated with population growth, single unit household residence propensity, and highway and transit supply per capita. It may well be that income does have some real effect on VMT, but the regression estimates offer evidence that it is small, relative to that of spatial form influences.

Apparently, much of the VMT growth that has paralleled income growth should be accounted for by the improvement of the road system and accompanying changes in spatial form. This explains why existing VMT models with underspecified equations lead to unrealistically high VMT estimates for the coming decades. For instance, the preliminary version of one of the models reviewed in this paper predicted that by the year 2000, VMT per driver would average over seventy-five miles per day. This was judged an unreasonable forecast.

The gas price coefficient of the estimated equation turned out to be of the wrong sign. The equation is reestimated using prior information (estimates from other studies) of gas price elasticity indicating that it is about -.15. Assuming that the gas price elasticity is -.15, the following parameter estimates are calculated for the other coefficients. This process hardly changes other coefficient estimates.

$$
\begin{aligned}
VMPTC = {} & \underset{(3.63)}{7.17} + \underset{(7.54)}{.013*TIPH} \\
& - \underset{(2.65)}{76.5*RTRAPC} - \underset{(4.15)}{.026*OLD} \\
& + \underset{(2.54)}{.032*HOUSE} - \underset{(0.26)}{.081*YPC} \\
& - .028*GASP \qquad (R^2 = .77)
\end{aligned}
$$

Other explanatory variables were included in the equation with little success. The percentage of the population of prime driving age (18-65) was included, but proved insignificant. There is too little variation among states in the value of this variable. States with a relatively high percentage of their population over 65 (Florida and Arizona) are compensated by a low percentage of the population under 18. The failure of this variable to be a significant determining factor in a cross-section study, however, is little evidence that the age structure of the population will be unimportant in influencing future VMT.

The literature review criticized time-series VMT studies for not including auto stock along with the income variable so that income elasticity independent of auto stock could be estimated. This is important so that VMT forecasting into the future can be made, under the assumption that auto stock saturation is occurring, and that future increases in the auto stock cannot match past increases. Because the equation estimated is for observations at one time when auto stock was already relatively close to saturation, in comparison to the early 1950's when most time-series analysis begins observations, it was felt safe to omit an auto stock variable. Alternatively, the reader may think of auto stock as being a function of all included variables, (which is more sensible than being a function of only income and gas price), and of auto stock being implicitly in the model as it stands.

An unemployment rate variable proved to be statistically insignificant. It is not known whether this is because there was, in reality, little cyclical difference among states in 1972, or because the total overall unemployment rate is a poor measure of cyclical variation. Variables representing the percentage of each state "urban" and the percentage of each state in SMSA's of more than 500,000 people also proves insignificant. Apparently, the effects of these variables are picked up by the already included variables.

The inclusion of both traditional demand and of road supply variables is also tested on observations over time. This test confirms the importance of inclusion of road supply factors in an aggregate VMT model. In the time growth analysis, the elasticity of VMT with respect to income does prove significant but substantially lower than the value of unity found by other researchers. Unfortunately, because the level of aggregation is statewide, because imperfect proxies exist for included variables, and because change is measured between two points rather than continually over time, it is felt that the simple regression is only of heuristic importance and that it should not be considered a usable VMT model.

While the cross-section regression above explains levels of VMT, this regression will seek to explain the growth rate of VMT by state between 1763-72. The three determining variables tested are growth rate of income, growth rate of auto stock, and growth rate of divided highway. The testing of other explanatory variables for significance proved to be severely hampered by multicollinearity problems and lack of variance in some variables across states.

The most striking difficulty in the analysis is that no estimates exist for VMT by state for the years before 1967. To get data on VMT over a decade, we have to assume that using gasoline consumption as a proxy for VMT does not bias the parameter estimates. (Alternately, the reader may want to look at a "gasoline demand" model.) Assuming that relative fleet fuel efficiencies across states did not vary during the decade, and the author believes that they did not vary much, the equation can be thought of as explaining growth rates in VMT. A second problem is the familiar one that no good proxy exists for road quality or network speed by state. For change in road network quality over time, the change in miles of divided 4 or more lane highway is used. Both gasoline and highway mileage numbers are taken from the 1963 and

1972 editions of Highway Statistics. The car registration stocks are taken from Ward's Automotive Yearbook. Income is taken from Department of Commerce estimates published in the Survey of Current Business.

The endogenous variable in the regression is 1972 gasoline sales per capita divided by 1963 gasoline consumption per capita. Values range from 124.4 in Delaware to 172.3 in Mississippi. The first explanatory variable is 1972 divided highway per capita divided by 1963 divided highway per capita. Values range from 93.1 in Delaware to 390.8 in Montana. The second explanatory variable is 1972 personal income per capita divided by 1963 personal income per capita. Values range from 153.3 in Delaware to 222.1 in Mississippi. The final explanatory variable is 1972 auto stock per capita divided by 1963 auto stock per capita. Values range from 93 in Delaware in 164 in Mississippi. (All values have been multiplied by 100.)

In the regression results the following abbreviations are used:

DGPC = 1972/1963 gasoline consumption per capita

LDHPC = Log (1972/1963 divided highway per capita)

DIPC = 1972/1963 disposable income per capita

DAPC = 1972/1963 auto stock per capita.

The regression results are:

$$DGPC = -\underset{(0.62)}{9.11} + \underset{(3.38)}{8.47}*LDHPC + \underset{(6.21)}{.40}*DIPC + \underset{(3.70)}{.26}*DAPC$$

(T-statistics in parentheses) ($R^2 = .78$)

Because the variables represent changes in state variables between 1963 and 1972, the coefficients are elasticity estimates. The regression yields an income per capita elasticity of .40 and an auto stock elasticity of .26. The highway quality term is in log form, and since the relationship between highway miles and network speed is so poorly defined in this simple equation no highway supply elasticity is calculated. In general, this regression supports the findings of the previous regression.

7. A PROPERLY SPECIFIED SIMUTANEOUS SYSTEM

The regressions presented above should not be taken as acceptable forecasting models for two basic reasons. The first is that the underlying data is or poor quality for model construction. The VMT numbers are based on estimates rather than actual odometer readings. They are aggregated at state levels rather than at reasonable regional levels. There is no empirical investigation into how transit and highway investments affect spatial form, and no study of what measure of road quality most highly correlates with network speed. The second basic problem with the "models" presented is that they oversimplify the real VMT-determining process. A proper specification would, at a minimum, include the relationships expressed in Figure 1. Arrows represent directions of causation which could act immediately or with lags of months or years. Estimation of such a model is currently impractical due to data inadequacies and, perhaps, inherent multicollinearily problems.

While much progress has been made in structuring the top half of the diagram, regional land economists are still far from understanding the bottom half. It is clear on both theoretical[16] and empirical[17] grounds that population-serving institutions follow changes in residential patterns, but other businesses and institutions are still often located exogenously in metropolitan models.[18] Because residential patterns depend on employment location as well as the transportation infrastructure, employment-generating institutional location must be understood as a precondition of spatial form modeling; even if spatial form were given, there is, at present, very little evidence empirically linking spatial form to VMT generation.

These inadequacies emphasize the need for micro-scale data based on actual odometer readings and coming from a variety of regional types. Without data on VMT patterns by income and demographic group by region type, it is impossible to separate accurately the effects of income, demography, and spatial form on auto VMT. This report has shown that separation to be important.

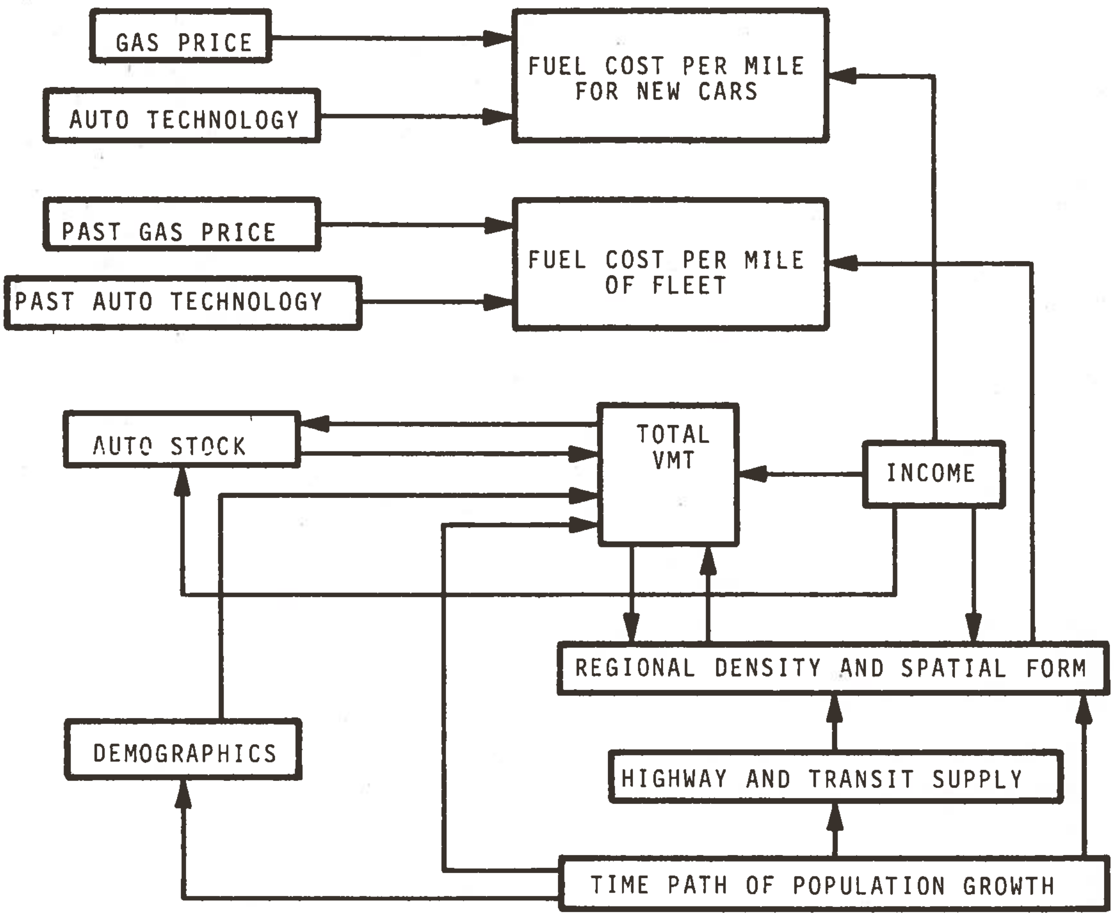

FIGURE 1. MODEL OF VMT DETERMINATION

Therefore, much more of the econometric structure of Figure 1 must be filled in by researchers before VMT models will be able to forecast accurately.

8. IMPLICATIONS OF VMT MODEL RESULTS

While this critique of VMT studies has emphasized the unreliability of aggregate VMT forecasting models, it would be wrong for policy analysts to act as if there were nothing known about future VMT. Enough work has been done so that we can confidently state that the elasticity of VMT with respect to gas price is low. Elasticities from zero to -.3 have been estimated, and -.15 can be considered a reasonable consensus estimate. Similarly, enough work has been done so that we can say with some confidence that early naive estimates putting the VMT elasticity with respect to real income above 1.0 were exaggerated. Later estimates put the income elasticity between .25 and .50; .40 seems to be a good long-run consensus estimate.

Because the gas price elasticity is low, because income is not a relevant policy variable, and because other behavioral incentives have proved ineffective in affecting aggregate VMT, most knowledgeable analysts have emphasized the role of technology in ameliorating the diseconomies currently associated with VMT.[19] Equipping cars to be more fuel efficient, emit lower concentrations of pollutants, and be of safer construction is preferable to limiting VMT as a strategy in reducing the adverse effects of VMT.

For long run planning purposes, however, other aspects of society which change slowly and are not considered relevant policy instruments must be considered VMT-influencing variables. Residential and commercial structures and transportation infrastructure are extremely durable, and lifestyles within the framework of existing regions are difficult to change. But, the VMT regression estimates in this report indicate that government policies which influence highway construction, public transit construction, and residential location do influence levels of VMT. In fact, in the very long run, it may be governmental policies toward highways, public transit, and residential location that are most important in determining growth rates of VMT.

Clearly, therefore, an important step in refining models of fuel consumption, pollution, and safety for use in evaluating public policy toward the automobile is the generation of more reliable VMT models which must include spatial form and highway and transit availability variables. The construction of such models depends on the collection of micro-scale VMT data based on actual odometer readings which are geographically identified. When such data becomes available, it will be relatively easy to estimate a properly specified VMT model.

After VMT forecasting is suitably understood, further refinement of the analysis will lie in work related to the linking of fuel consumption, pollution, and traffic accidents to spatial form as well as to VMT. Measuring these externalities on a per-mile basis and multiplying by a good estimate of VMT improves current policy analysis, which has given great attention to per-mile levels of externalities but little attention to VMT projections. But, it should be recognized that levels of these externalities do not depend only on VMT, but also on where VMT occurs. Areas with a large amount of high-speed, divided, uncongested highways will have relatively large VMT generation, but adverse effect on VMT per mile driven will be low. Steady-state, 55 mile-per-hour driving burns less fuel per mile than stop and start city driving and also causes less pollution. Similarly, extended transit would tend to lower VMT per capita in a given area, but also would influence spatial form in such a way that roads become more congested, fuel economy becomes worse, and air pollution becomes more highly concentrated. Rather than becoming involved in a review of the literature concerning spatial form, transport-generated externalities, and optimum city design, it is merely noted that at the present state of knowledge researchers are still far from understanding how spatial form influences these externalities, either in total or on a per-mile basis. However, the assumption must be made that the externalities are closely correlated with VMT, (since driving patterns are somewhat similar across regions) and that factors which raise VMT will also unambiguously raise the level of the externalities.

However, because the links between spatial structure and transportation-related externalities have not been thoroughly investigated, it is premature to use residential building incentives or other land use policies as public policies toward motor vehicle externalities. The current emphasis on auto technology rather than on a major restructuring of living patterns or life-styles is justified due to the uncertainties involved in treating spatial form variables as policy instruments. However, since they apparently do influence driving habits, spatial form and time cost of travel should begin to be incorporated into VMT forecasting models. Long-range research planning should include studies of the effect of spatial form on fuel economy, pollution, and auto safety.

9. CONCLUSIONS AND RESEARCH RECOMMENDATIONS

In recent years, the estimation of future trends of automobile and truck vehicle miles of travel has become important. This importance is due to national programs to lessen fuel consumption, air pollution, and traffic accidents, and the necessity for inclusion of VMT forecasts in calculating the cost-effectiveness of proposed governmental regulations.

Because of data restriction, existing VMT forecasting models are based on time series estimation of nationally aggregated data. The regressions and discussion presented in this paper have shown that the time cost of travel, existing transport infrastructure, and regional spatial form, which have been omitted from existing VMT models are important determinants of per capita VMT. Inclusion of these variables is necessary to estimate properly the parameters of a nationally aggregated VMT mode. Reliable VMT forecasts are required in evaluating cost trade-offs of policy directed toward fuel conservation, pollution abatement, traffic safety, and cost minimization by the Federal government.

Because the effects of federal policy toward the automobile are measured in the billions of dollars, because reliable VMT forecasts are needed for policy evaluation, and because non-existent micro-scale VMT data is required to produce accurate VMT forecasts, the Transportation Systems Center under the Auto Energy Efficiency Program is currently planning to have a contractor evaluate existing VMT data to lead to better data estimates and forecasts. Such research will greatly improve the government's ability to forecast VMT, and also fuel consumption, pollution emissions, and traffic fatalities. The proposed contract may also result in regional VMT models.

The next major research task will be to relate fuel consumption, pollution emissions, and accident damage per vehicle mile to regional spatial form. With such knowledge, the Federal Department of Transportation and all other parties interested in public policy toward energy conservation, air quality, and traffic safety could more accurately ascertain the magnitude of future energy use, pollution generation, and accident damage by the auto sector. From this information they could more accurately calculate the value of policies intended to lessen these adverse externalities caused by auto travel.

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