

Vehicle Kilometers Traveled: Evaluation of Existing Data Sources

Leon M. Rudman, Research and Special Programs Administration, Transportation Systems Center, U.S. Department of Transportation, Cambridge, Massachusetts

Vehicle kilometers traveled is the total kilometers traveled by motor vehicles on the highway system during a given period of time. Vehicle kilometers traveled by passenger automobile is an important variable in the analysis of fuel efficiency, fuel consumption, environmental quality, and highway safety. Changing patterns of future vehicle kilometers traveled have significant applications for energy conservation and economic stability. This report evaluates existing data sources for vehicle kilometers traveled and gasoline consumption. Collection, reporting, consolidation, and estimation procedures are addressed. Since direct measurement of vehicle kilometers traveled has never been made, the available information consists of indirect estimates based on various sets of assumptions. The type of assumptions and the reliability of the data determine the models and types of hypotheses that can be meaningfully tested. Historically, the importance of vehicle kilometers traveled accumulation has been directed toward highway planning and included such areas as traffic density, highway safety, and other non-energy-related areas. For these nonenergy endeavors, the traffic-counting methodology has been the procedure used most widely by the individual states to estimate vehicle kilometers traveled. However, since the 1973 energy crisis, the Federal Highway Administration has requested that the states estimate vehicle kilometers traveled based on average fuel efficiency rated for different vehicle classifications. This alternative methodology may be a more appropriate way in which to solve energy-related issues because energy efficiency is one of the predetermined variables. However, fuel-consumption rates involve many heterogeneous inputs, and it has been difficult to arrive at a meaningful state average for fuel economy. The Federal Highway Administration has not developed and selected one specific methodology to estimate vehicle kilometers traveled. No single procedure has been established to collect, report, and consolidate vehicle kilometers traveled data. Each state and every region within a state selects its own process for gathering these data. Therefore, an accurate and reliable estimate of vehicle kilometers traveled from heterogeneous inputs cannot be obtained.

Vehicle kilometers traveled is the total kilometers traveled by motor vehicles on the highway system during a given period of time. Vehicle kilometers traveled by passenger automobile is an important variable in the analysis of fuel efficiency, fuel consumption, environmental quality, and highway safety. Unless otherwise specified, vehicle kilometers traveled henceforth will refer to passenger automobile vehicle kilometers traveled. Changing patterns of future vehicle kilometers traveled have significant implications for energy conservation and economic stability (1). The transportation sector uses 53 percent of the total petroleum consumed in the United States, and the passenger automobile accounts for 53 percent of all transportation energy as well as 69 percent of the highway energy (2).

This report evaluates the existing data sources for vehicle kilometers traveled and gasoline consumption. Collection, reporting, consolidation, and estimation procedures are addressed. No direct measurement of vehicle kilometers traveled has ever been made; the available information consists of estimates based on various assumptions. The assumptions and the reliability of the data determine the models and types of hypotheses that can be tested.

Historically, the importance of vehicle kilometers traveled accumulation has been directed toward highway planning and included such areas as traffic density, highway safety, and other non-energy-related areas. Since 1973, attempts have been made to use vehicle kilometers traveled statistics to address problems of fuel efficiency,

fuel consumption, and energy conservation. Accordingly, many states are currently evaluating their methodologies and are considering changes in their estimating procedures for travel distances in order to reflect more properly these energy-related problems.

GENERAL METHODOLOGIES OF TRAVEL-DISTANCE ESTIMATION

The quality of existing travel-distance data limits the reliability of future studies on fuel consumption. Mellman indicates (3), "There are no direct measurements of actual annual VMT [vehicle miles traveled] 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 limitations."

Only two national sources of information on automobile travel currently exist. The Federal Highway Administration (FHWA) publishes an annual report, Highway Statistics (4). In conjunction with the 1970 census, FHWA also sponsored the Nationwide Personal Transportation Study (NPTS), in which a sample of households were questioned about their travel behavior.

Nearly all current data on annual estimates of national travel distances are compiled by the FHWA. Highway Statistics, from which Table 1 of this study was derived, is the most widely cited of the travel distance data. It forms the empirical basis for highway planning and is now being used for fuel-efficiency studies. These statistics are taken from state estimates, which are based on gasoline-consumption records. By multiplying fuel sales by estimates of fleet fuel economy (L/km), the states compute vehicle kilometers traveled per year.

While gasoline consumption is accurately known from tax data, estimates of liters per kilometer are a major source of error. What liters per kilometer actually depend on, and whether these factors can be empirically measured, are complex problems. In principle, average fuel economy in a state depends on

1. The drive cycle (drive schedule, meteorology, and topography),
2. Spatial distribution of travel (urban versus rural travel) in each state, and
3. The mix of automobiles by age and weight.

However, Rabe states (5):

It is theoretically possible, then, to start with independent information of fuel economy by weight class and age of vehicle and develop a composite weighted average fuel economy that accounts for the type of vehicle driven, driving cycles, and physical factors. Unfortunately, the precise influence of driving cycle, climate, and topography on fuel economy is not known, so that even the most careful estimates would introduce some error.

In practice, the situation is much worse. Each state produces its own vehicle kilometers traveled estimate by using any procedure it wishes. The procedures fall into three broad categories:

Table 1. Estimated motor-vehicle travel in the United States and related data.

Item	Passenger Vehicles										All Motor Vehicles	
	Personal Passenger Vehicles				Buses				Cargo Vehicles			
	Year	Passenger Automobiles ^a	Motorcycles ^b	All	Commercial	School and Other Nonrevenue	All	All	Single-Unit Trucks	Combinations		All
Motor vehicle travel (vehicle-km 000 000s)												
Main rural roads	1975			529 555	1 493	1 497	2 990	532 546	145 501	71 321	216 822	749 368
Local rural roads	1974			504 857	1 553	1 481	3 034	507 891	138 504	71 716	210 219	718 110
All rural roads	1975			180 002	129	1 641	1 770	181 772	33 333	2 150	35 483	217 255
Urban streets	1974			182 831	145	1 625	1 770	184 602	34 068	2 232	36 300	220 902
	1975			709 558	1 622	3 138	4 760	714 318	178 834	73 472	252 305	966 623
	1974			687 688	1 698	3 106	4 804	692 492	172 572	73 948	246 520	939 012
	1975			981 016	2 639	885	3 525	984 541	173 443	15 944	189 386	1 173 927
	1974			942 690	2 502	837	3 339	964 029	167 741	16 270	184 011	1 130 040
Total	1975	1 654 603	35 970	1 690 573	4 262	4 023	8 285	1 698 858	352 276	89 415	441 692	2 140 550
	1974	1 594 413	35 964	1 630 377	4 200	3 943	8 143	1 638 520	340 312	90 218	430 531	2 069 051
Number of vehicles registered (000s)	1975	106 712.6	4 966.8	111 679.4	93.8	368.3	462.1	112 141.5	24 644.7	1 131.0	25 775.7	137 917.2
	1974	104 856.3	4 966.4	109 822.7	90.1	356.9	447.0	110 269.7	23 545.2	1 085.0	24 630.2	134 899.9
Average distance traveled per vehicle (km)	1975	15 504	7 242	15 137	45 432	10 924	17 928	15 149	14 294	79 059	17 136	15 520
	1974	15 205	7 242	14 846	46 620	11 048	18 218	14 859	14 453	83 150	17 479	15 337
Fuel consumed (L 000 000s)	1975	287 729	1 692	289 421	2 093	1 295	3 388	292 809	82 779	36 960	119 740	412 474
	1974	279 250	1 692	280 942	1 987	1 260	3 247	284 189	79 967	38 236	118 203	412 549
Average fuel consumed per vehicle (L)	1975	2 695	341	2 593	22 319	3 517	7 332	2 612	3 358	32 679	4 645	2 990
	1974	2 665	341	2 559	22 058	3 532	7 264	2 578	3 396	35 242	4 800	2 983
Average distance traveled per liter of fuel consumed (km/L)	1975	5.75	21.26	5.84	2.04	3.11	2.44	5.80	4.26	2.40	3.69	5.19
	1974	5.71	21.26	5.80	2.11	3.13	2.51	5.76	4.26	2.36	3.64	5.14

Notes: 1 km = 0.62 mile; 1 L = 0.26 gal; 1 km/L = 2.35 mile/gal.

Cells may not add due to rounding.

^a For the 50 states and the District of Columbia.^b Separate estimates of passenger automobile and motorcycle travel are not available by highway category.

1. Simple trend extrapolation based on socioeconomic changes;

2. Extrapolation of traffic counts, based on number of vehicles per kilometer of roadway; and

3. Some variant of the procedure outlined above, usually based on a very rough estimate of average fuel economy.

In short, the FHWA data represent the only time series currently available. Their accuracy is questionable because of nonuniform estimation procedures. Yet they are frequently cited since some data are better than none. FHWA has undertaken some new studies in order to improve the quality of existing information in this critical area.

STATE APPROACHES

An area in need of further study is the state inputs to the FHWA annual travel-distance statistics. An understanding of the ways in which travel-distance statistics are currently being compiled by individual states is needed.

The Transportation and Economic Research Association (TERA) surveyed all 50 states for the methodology each used to prepare annual estimates of travel distance (6). Basically, TERA found that there are two methods used by states in compiling travel-distance data—the vehicle-count method and the fuel-consumption method. These methods are used individually or in conjunction with each other.

Although vehicle counts offer a good alternative to the fuel-efficiency method, there is need for improvement. There is substantial diversity in the counting methodology with respect to persons responsible for the counting programs, how the programs are administered, and how the results are processed.

The second method used by the states to compute vehicle travel distances is the fuel-consumption method. Since the 1973 energy crisis, FHWA has requested that the states use the fuel-consumption method to estimate vehicle kilometers traveled. Unfortunately, most of the

state estimates assume an existing fuel efficiency and thus lack usefulness for estimating the fuel efficiency of the national fleet. Estimates of vehicle kilometers traveled prior to 1973 have been directed mainly toward highway planning and have included such areas as traffic density, highway safety, and other non-energy-related areas.

All states cannot employ one single methodology to determine fuel-efficiency rates. Because drive cycles and drive schedules are heterogeneous, there is no simple solution. The Claffey model attempted to estimate vehicle kilometers traveled by using the fuel-consumption method without the problems inherent in that model.

Vehicle Counts

The most widely used technique for estimating vehicle kilometers traveled is the traffic-count procedure. This procedure assumes that the vehicle kilometers traveled in a state during a year can be estimated by counting the traffic on representative sections of roadway (links) during short periods of time and expanding these results to statewide totals.

The total vehicle kilometers traveled in a state during a year is then:

$$VKMT = \sum C_{ij} L_i w_i t_{ij} \quad (1)$$

where

VKMT = vehicle kilometers traveled,

C_{ij} = traffic volume (count) passing location i during period j ,

L_i = length of the link (km) on which location i is located,

w_i = assigned weight (or expansion factor) to equate with L_i with the total set of links it represents, and

t_{ij} = assigned weight (or expansion factor) to equate the count during period j with the total annual count at location i .

A link is a section of roadway that has homogeneous traffic volume. It usually encompasses a section of roadway between two major intersections. Links on local streets range from 0.40 to 0.80 km (0.25 to 0.5 mile), arterials from 0.80 to 1.61 km (0.5 to 1.0 mile), and freeways from 1.61 to 3.22 km (1 to 2 miles) (7, p. iv).

No one standard procedure is used to estimate vehicle kilometers traveled. Each state and city traffic-counting program is, in essence, a different sampling procedure. As FHWA has indicated (7, p. 2),

The most reliable method of developing vehicle-mile and traffic volume information is to count each location continuously throughout the entire year. These long-term counts—in both a spatial and temporal sense—would provide an accurate picture of the entire population of counts—since there would be no sampling errors. However, such a procedure is difficult and costly to achieve in practice. Consequently, a great variety of sampling methods have been employed.

All road systems are classified according to FHWA guidelines and broken down into section lengths that are then monitored, either manually or by a selection of automatic devices, for traffic volume. The reliability of this monitoring is based on equipment used, as well as on the location and on the frequency of the counts. Equipment is extremely costly to use on an extensive network of local roads that carry relatively light truck volumes.

There are three types of traffic counts: (a) a permanent or continuous traffic volume; (b) a seasonal-sample type of traffic count, which is a special count done either to indicate a seasonal variation or to represent a percentage of the state's roadways that can be expanded to represent the total; and (c) complete system coverage that may involve only one road classification or all road classifications in a state. In any case, the system is broken into section length. Complete coverage means that every kilometer of the system is included in the count and the vehicle kilometers traveled is actual rather than expanded from a sample.

The sampling procedures are designed to estimate link-volume counts in 24-h, 48-h, or 5-day periods. In some states, both a complete coverage over multiple-year cycles and sample counting over selected links are undertaken and the results of both are adjusted to reflect seasonal variations. Because the costs of undertaking complete or permanent counts of each kilometer of roadway are prohibitive, traffic sampling is necessary.

Permanent counting is necessary to verify traffic volume on local roads, which account for approximately 70 percent of roadways but for only 12 percent of total highway travel. In most states, the number of these monitoring stations is insufficient. Any extensive expansion of additional stations for local rural or urban roads would be too expensive for most states to undertake.

However, only at continuous (permanent or complete counts) monitoring stations and under perfect conditions can true average daily traffic (ADT) be determined with absolute accuracy. This assumes that there are no mechanical failures and that correct vehicle classification data are available when axle counts are converted to vehicles. Any count of less than one year must be regarded as a sample.

Every state has its own problems concerning traffic-volume information. There is no single procedure that will solve all problems. Nevertheless, there is a methodology that will produce appropriate answers concerning the location and number of stations, length and frequency of counts, and the accuracy of the results. Therefore, it is necessary to consider separately the counting and the estimation of traffic volumes on rural roads and urban streets.

The procedure that is presented for high-volume rural roads can be divided into three major steps (8, pp. 2-5):

1. Grouping continuous-count stations into similar patterns of monthly traffic volume variation,
2. Assigning road sections to groups of similar patterns of monthly variation, and
3. Locating and operating traffic-counting stations.

The major premise for high-volume rural roads, which carry approximately 500 ADT or more, is that it is possible to establish a series of consecutive continuous road sections that have similar patterns or monthly traffic volume variation and to assign road sections to groups of similar patterns of monthly variations. Stations of the same group usually fall along continuous routes. Thus, two fundamental assumptions of traffic volume measurement are that the pattern of monthly variations of traffic volume persist over long stretches of highway and over long periods of time.

After all road sections have been allocated to groups of similar monthly patterns of traffic variation, it may be possible to eliminate or relocate some of the continuous-count stations. This decision, however, should be made only after careful determination of all purposes served by these stations. These considerations should include (7, pp. 14-15)

1. Continuous-count stations, in addition to providing adjustment factors for expansion of coverage counts, may be needed for long-range determination of traffic trends at a particular point;
2. Determination of accurate peak-hour counts at a particular station may be desirable;
3. Other local information may be used;
4. The road sections for which records are not available should be studied (either permanent or seasonal control stations should be located on these sections in future years to enable the proper classification of these road sections by groups; if seasonal count stations are operated, each count should be for a one-week duration);
5. Retention of continuous-count-station locations may be desirable to determine the rates of change of travel; and
6. In general, a minimum of six continuous-counting stations should be located in each group of road sections with an independent set of monthly factors.

Rural roads that carry less than 500 ADT must be treated differently from roads that have higher traffic volumes. Past studies have shown that the standard error of estimate increases at a much greater rate when the traffic volume ranges from 25 to 500 ADT (7, p. 16).

A total of 4111 continuous permanent counting locations have been established nationwide. The number of automatic-traffic-recorder (ATR) locations varies by state. For example, Alaska has only 32 ATRs, but each 1.6 billion VKMT (1 billion vehicle miles traveled) is covered by 11.7 counters. On the other hand, Texas has the largest number of ATRs at 255; yet each 1.6 billion VKMT is based on 2.9 ATRs.

Urban ATR locations account for only one-third of all continuous counts, yet represent 55 percent of nationwide vehicle kilometers traveled. The remaining two-thirds of the counters are located in rural areas, which account for 45 percent of all vehicle kilometers traveled on 83 percent of total highway roadway (9). Since the number of urban ATRs in proportion to urban vehicle kilometers traveled is small and the larger number of rural ATRs are distributed over an extensive rural highway system, the possibility exists that significant

changes in traffic could take place and not be detected.

Vehicle monitoring is only as good as the traffic-counting equipment. Unfortunately, some of this equipment is too expensive for state and local governments. Some, such as the ultrasonic overhead detector, are very accurate; but their disadvantages must be weighed against their positive features. The main assets are freedom from deterioration caused by traffic wear, snow, and ice and ability to provide accurate counts of vehicle by lanes. The main parallel lanes of automobiles pass simultaneously on multilane roads, which causes biases in distinguishing individual lane volumes and overcounting when a vehicle changes lanes. The best and the most accurate counter appears to be overhead measures, but these have a very high initial cost.

Fuel-Consumption Method

The fuel-consumption method is the second procedure that the states use to compile vehicle kilometers traveled data. This method assumes that vehicle kilometers traveled in a state during a year is a function of the fuel-consumption rate and the number of liters of motor fuel consumed by vehicles in one year.

$$VKMT_s = (km/L_s) (FC_s) \quad (2)$$

where FC = gasoline consumed, s = state, and km/L_s = average fuel efficiency. It has been assumed that the fuel-efficiency rate for each state is determined independently from the national fuel-consumption rate. According to TERA (6, p. 50)

The source for fuel consumption data is most often the fuel tax receipts, and the average mile per gallon figure is either suggested by FHWA and adjusted by the state based on judgment, or generated from state studies in the past which enables calculation of trend values for the current year.

Table 2 is a state-by-state summary, compiled by TERA, that is used to estimate vehicle kilometers traveled every year (15, p. 52). A combination of traffic counts and fuel-consumption estimates are used by 23 states. Only 12 have made an independent empirical investigation of kilometers per liter, 4 use FHWA guidelines, and 7 use an unspecified method. FHWA guidelines imply that the states may use the computed national figure for kilometers per liter to determine the individual state vehicle kilometers traveled. Indeed, causality becomes a major issue because

Table 2. Comparative summary of state practices to estimate travel distance.

State	Traffic-Count Method				Fuel-Consumption Method						
	Permanent Station ^a	Seasonal Sample ^b	Complete System Coverage ^c	Manual or Automatic ^c	Fuel-Consumption Estimate				Estimate (km/L)		
					Tax Records	Ratio to National	Whole-sale Figures	Other	Empirical Study	FHWA Guideline	Other
Alabama	X	X		A							
Alaska	X	X	X		X				X		
Arizona		X		A				X		X	
Arkansas	X	X	X	A							
California	X	X		A	X						X
Colorado	X	X		A							
Connecticut			X	A				X			
Delaware		X		A							
Florida	X	X		A							
Georgia	X	X	X	A							
Hawaii	X	X		A	X				X		X
Idaho		X		A	X						
Illinois	X	X		A	X					X	
Indiana	X	X		A	X					X	
Iowa	X	X	X	A							
Kansas		X	X	A							
Kentucky	X	X		A	X				X		
Louisiana	X	X	X	A							
Maine		X	X	A	X					X	
Maryland		X	X	A							
Massachusetts	X	X		A							
Michigan					X				X		
Minnesota	X	X	X	A							
Mississippi		X	X	A				X			X
Missouri	X	X	X	M,A				X			X
Montana	X	X		A	X				X		
Nebraska	X	X	X	M,A				X			X
Nevada	X	X		A							
New Hampshire	X	X		A	X						X
New Jersey	X	X	X	M,A	X				X		
New Mexico	X	X	X	A							
New York								X			
North Carolina		X		A				X			
North Dakota	X	X		M,A							
Ohio	X	X		A	X				X		
Oklahoma	X	X		A	X				X		
Oregon		X	X	A				X	X		
Pennsylvania		X	X	A		X			X		
Rhode Island		X		M,A							
South Carolina		X			X				X		
South Dakota	X		X	A							
Tennessee	X			A	X				X		
Texas	X	X		A							
Utah	X	X	X	A							
Vermont		X	X	A							
Virginia		X	X	A				X			X
Washington	X	X		A							
West Virginia		X	X	A							
Wisconsin		X		A	X				X		
Wyoming	X	X		M,A							
District of Columbia	X	X		M,A							

^aA permanent counting station is placed at one location for a year and continuously monitors traffic volume.

^bThe seasonal-sample type of traffic count is a special count done either to indicate a seasonal variation or to represent a percentage of the state's roadway that can be expanded to represent the total.

^cComplete system coverage traffic counts may involve only one road classification or all in a state. In either case, the system is broken into section lengths, each of which is monitored and for which an ADT is calculated.

Complete coverage means that every kilometer of the system is included in the count and the vehicle distance traveled is actual rather than expanded from a sample.

^dThere are two ways to perform an actual count, either manually (M) or by automatic traffic recorders (A).

FHWA then uses national vehicle kilometers traveled data to compute national fuel consumption.

$$\text{km/L}_n = \text{VKMT}_n / \text{FC}_n \quad (3)$$

$$\sum_{i=1}^{50} \text{VKMT}_i = \text{VKMT}_n \quad (4)$$

where n = nation. Surprisingly, no one state has been using only the fuel-consumption method to estimate vehicle kilometers traveled. The Claffey method (10, p. 3), an improvement in the fuel-consumption method, has been used in New York, is being considered by Michigan, and has been used to verify the results of Oklahoma's methods. The remaining states used some form of traffic counting.

All states cannot employ one single methodology to determine fuel-efficiency rates. Because drive cycles and drive schedules are heterogeneous, there is no simple solution. Also, other variables, including automobile accessories, tires, and vehicle weight, add to the complexity of the problem. If every state in the United States were identical, many of these problems that are critical to this study would be eliminated.

For example, meteorology and topography, which have an impact on the drive cycle, have widely different characteristics. Maximum fuel economy is achieved at 21°C (70°F). For the full city and highway cycle, the fuel economy penalty ranges from 8 to 16 percent for -7°C (20°F) operation and from 0 to 5 percent for 38°C (100°F) operation (11, p. 29). Hills cause increased fuel consumption: The steeper the hills, the greater the increase in fuel consumption and the greater the rate of increase. This is true for both urban and highway cycles and for large and small automobiles. On a national basis, urban fuel consumption is increased by 6.6 percent and the highway fuel consumption is increased by 5.5 percent.

Furthermore, the drive schedule presents varying trip characteristics and behavioral differences to include origin and destination of trip, road design, traffic congestion, and stop-and-go frequency. For operation at an ambient of 21°C, an automobile is warmed up to the point where it will give 95 percent of its fully warmed-up fuel economy after a trip of about 6-8 km (4-5 miles). However, for that trip, the average fuel economy is only 70 percent of its warmed-up potential. Trips shorter than 8 km constitute 64 percent of all trips and consume 31 percent of all fuel, yet account for only 15 percent of vehicle kilometers traveled, as can be seen in Table 3, which is summarized below (1 km = 0.62 mile).

Trip Length (km)	Trips (%)	Fuel (%)	Vehicle Kilometers Traveled (%)
0-8	64	31	15
8-16	22	17	17
0-16	86	48	32

Disaggregation by purpose or location of trip is appropriate, because these travel characteristics influence other facets of analysis and because these travel sensitivities could vary with the type of trip (e.g., work versus leisure and urban versus rural or suburban). More than half of all workers (52 percent) live 8 km or less from the job; and 20 percent travel longer distances of 24 km (15 miles) or more from work. The average home-to-work trip length by automobile is 15.1 km (9.4 miles). Trip lengths are generally longer in unincorporated areas [17.9 km (11.1 miles)] and incorporated places of 1 million and larger [22.7 km (14.1 miles)]. In the latter

areas, 53 percent of all home-to-work vehicle kilometers of travel is generated by workers who commute more than 33 km (21 miles) to work. The automobile accounts for three-fourths of all home-to-work travel (12).

Finally, stop-and-go frequencies account for such variables as speed, accelerations, decelerations, idle, and cruise. In short, fuel-efficiency rates are so heterogeneous that is misleading for FHWA to use one estimate for kilometers per liter throughout the nation. State and regional variations do occur and their inputs are required to determine the true fuel-economy values.

In sum, no test-procedure drive schedule was found to have been adequately correlated with actual in-use driving (13, p. 5-4). EPA test errors are possible through a number of variability factors. The EPA drive schedules, determined by dynamometer fuel-economy testing, do not accurately present urban and rural highway driving. Recent field studies that have attempted to determine in-use vehicle drive schedules have not had a favorable outcome. Since several variables affect a drive schedule for a particular trip, specific values for each may not be duplicated for other trips.

FHWA METHOD OF ESTIMATING VEHICLE TRAVEL DISTANCES

The purpose of this section is to develop an understanding of the way in which FHWA estimates vehicle kilometers traveled. There are two major data sources. The first is the average fuel economy (km/L), and the second is the vehicle count. In each state the fuel economy depends on

1. The share of automobiles by age and weight,
2. The spatial distribution of travel, and
3. The drive cycle (climate, topography, and drive schedule).

The exact influence of the drive cycle on the fuel-consumption rate is assumed. The vehicle count is determined by a sampling of the number of vehicles per kilometer of road.

Table 1 stresses the fuel-efficiency approach and is derived from data principally submitted by state transportation departments. Average kilometers traveled per liter of fuel consumed is computed by dividing vehicle kilometers traveled by fuel consumed. Average kilometers traveled per vehicle is calculated by dividing vehicle kilometers traveled by vehicle registrations.

Several caveats should be noted. First, the approach used to prepare Table 1 is slightly different each year, depending on the data available and the analyst. The development and documentation of standardized procedure has not been accomplished by FHWA. Some intermittent values are developed by analyzing trends, but in other years empirical derivations are used. Thus, a precise explanation for the development of Table 1 is very difficult. The most complete description of these procedures is documented in the TERA reports and in an FHWA document dated January 5, 1978.

Second, the inputs used by FHWA to compute the data in Table 1 are often compiled by more than one source. For example, there is a recurring discrepancy between FHWA registration data compiled on a full calendar year approach and R. L. Polk estimates of vehicles in use on July 1 of each year (14). As Table 4 reveals, the percentage difference can range from 7.6 to 13.4 percent. Over the past 10 years, the average difference between FHWA and Polk estimates has been 11.2 percent.

The FHWA data are based principally on reports from state highway departments. States are instructed to

Table 3. Effect of trip length on fuel economy.

Trip Length (km)	Trips (%)	Vehicle Distance Traveled (%)	City Driving Warm-Up City Fuel Economy (%)	Incremental Fuel Economy (%)
1.6	17	1.5	47	47
3.2	16.5	2.8	61	75
4.8	13	3.5	69	85
6.4	10	3.6	74	89
8.0	7.5	3.7	77	89
Subtotal	64	15.1		
9.7	6.5	3.5	80	95
11.3	5.0	3.4	83	100
12.9	4.0	3.3	85	99
14.5	3.5	3.2	86	
16.1	3.0	3.1	88	
Subtotal	22	16.5		
Total	86.0	31.6		

Note: 1 km = 0.62 mile.

Table 4. Comparison of alternate estimates of automobile travel per year.

Year	FHWA Registrations (calendar year)	Polk Automobiles in Use (in use July 1)	Percentage Difference ^a	Vehicle Travel (km/year)	
				FHWA	Polk ^b
1960	61.7	57.1	8.1	15 202	16 433
1961	63.4	58.9	7.6	15 232	16 390
1962	66.1	60.9	8.5	15 184	16 475
1963	69.0	63.5	8.7	15 092	16 406
1964	72.0	66.1	8.9	15 155	16 504
1965	75.3	68.9	9.3	15 107	16 512
1966	78.1	71.3	9.5	15 297	16 750
1967	80.4	73.0	10.1	15 421	16 979
1968	83.6	75.4	10.9	15 493	17 181
1969	86.9	78.5	10.7	15 743	17 428
1970	89.3	80.4	11.1	16 058	17 841
1971	92.7	83.1	11.6	16 288	18 178
1972	97.1	86.4	12.4	16 390	18 422
1973	101.8	89.8	13.4	16 081	18 234
1974	104.9	92.6	13.3	15 279	17 312
1975	107.4	95.2	12.8	15 535 ^c	17 523

Note: 1 km = 0.62 mile.

^a Computed as [(FHWA data - Polk data)/Polk data] × 100.^b Computed as [(FHWA VKMT/year) × (1 + (percentage difference/100))].^c Jack Faucett Associates estimate based on 1974-VKMT growth of 4.1 percent, reflective of traffic growth by all highway vehicles, as reported in Traffic Volume Trends.

eliminate from their totals any vehicles that have been reregistered during the year. Because of differences in registration plate transfer practices and state record-keeping procedures, some states may not remove all reregistrations, such as those attributable to interstate transfer of registration or those due to resale and reregistration of a vehicle. Adjustments are made by FHWA to correct for omissions of this sort.

The key difference between the sources is their conception. FHWA includes all vehicles that have operated on the roads during a calendar year, including vehicles that are retired during the year. Polk counts the vehicles that are registered to operate at one point in time. Polk data reflect adjustments for reregistered and scrapped vehicles. Consequently, the Polk estimate for registrations appears to be more accurate and should be a better measure for computation of the annual distance traveled per vehicle.

Next, although total vehicle kilometers traveled for all motor vehicles is submitted annually by each state according to a uniform reporting format, there is no single methodology applied by all states to derive and compile vehicle kilometers traveled data. FHWA is currently developing a uniform computational procedure based primarily on the analysis done by Claffey in 1972 for FHWA (10). The procedure is a computerized algorithm for use in estimating travel on non-federal-aid roads where vehicle counts are not available. Factors that affect motor vehicle fuel-consumption rates are incorporated into the analysis. These include roadway design, terrain, and meteorological conditions as well

as vital distributions by highway system and vehicle type.

Once these individual state vehicle travel distances have been totaled into a nationwide figure for all motor vehicle travel, FHWA uses a variety of procedures to derive travel by vehicle type (15). Although the FHWA procedure appears to indicate that total vehicle kilometers traveled for passenger automobiles reported by FHWA is a residual figure obtained by successive deductions from the total highway vehicle kilometers traveled data reported by state transportation departments, the final estimate for passenger automobiles is checked by FHWA against data compiled and published by other sources.

In addition, the FHWA data on motor-fuel consumption are compiled from statistics provided by each state, based on motor-fuel tax receipts. The gross fuel consumption reported gasoline used for both highway and nonhighway purposes. Data on nonhighway uses of gasoline are not recorded in the same way in all states. In fact, except for Arizona, it is necessary to estimate a portion of all of the nonhighway use. FHWA adjusts nonhighway motor-fuel consumption from total use. The lack of reliability of nonhighway statistics is overshadowed by the fact that they constitute only a small fraction (3.2 percent in 1975) of the total gasoline consumption throughout the nation. Thus, the total highway fuel consumption given in Table 1 is fairly accurate. However, this type of data is very unreliable for select farm states.

The most significant off-highway use is agriculture (50 percent in 1975); next is marine use (23 percent). Since gasoline taxes were designed as a user tax collected to support the highway system, farmers may apply for refunds when gasoline is used solely for farming. The five states that had the highest percentage of agricultural gasoline use in 1975 were North Dakota (28 percent), South Dakota (18 percent), Iowa (11 percent), Wyoming (9 percent), and Nebraska (8 percent). Although the total farm use of gasoline is approximately 3 percent nationwide (which is insignificant) inclusion of these data for the above five states can give misleading results.

Finally, the process of arriving at a national fuel-efficiency rate is not a strict case of only dividing vehicle kilometers traveled by the number of liters of fuel consumed:

$$\text{km/L}_n = \text{VKMT}_n / \text{FC}_n \quad (3)$$

The fuel economy by vehicle class is based on the subjective evaluation and judgment of the respective analyst for a particular year (16, p. 27). The procedure for determining kilometers per liter figures in Table 1 seems to maintain the status quo; only small incremental adjustments are necessary to account for the year changes in vehicle registrations, fuel consumption, and vehicle kilometers traveled. Only when new information, such as an update of a major survey, becomes available are major changes made in the annual fuel economy figures.

However, state vehicle kilometers traveled estimates are based on an assumed knowledge of individual state fuel economy:

$$\text{VKMT}_s = (\text{km/L}_s)(\text{FC}_s) \quad (2)$$

$$\text{VKMT}_n = \sum_1^{50} \text{VKMT}_s \quad (4)$$

It has been theorized that the fuel-efficiency rate for each state is determined independently from the national fuel-consumption rate safety average. Nevertheless, for the 17 states that now use the fuel-consumption

method in combination with the traffic counts, only 12 have made an independent empirical investigation of kilometers per liter; 4 use FHWA guidelines. Empirical investigations do not have a standard methodology and are made infrequently. FHWA guidelines imply that the states may use the computed national figure for fuel economy to determine the individual state vehicle kilometers traveled. Indeed, in this circumstance, causality is a major issue.

NPTS DATA

The major alternative for a national study of vehicle kilometers traveled is the NPTS. This is a cross-section study of 6000 households in 1969-1970. This study gained insight into the relation between demographic and economic characteristics and automobile travel. Some of the variables examined that were relevant to aggregate vehicle kilometers traveled considerations included the number of automobiles per household, origin and destination of trip, urban versus rural travel, discretionary versus necessary travel, age of automobile, income and vehicle kilometers traveled correlations, and annual kilometers of automobile travel. These microscale data might be used to overcome many of the impediments caused by the national level of aggregation of FHWA data.

Some comparisons of travel characteristics were done for urban and rural households. Within the urban trip classification, trip lengths tend to increase with urban size. For example, in cities that have a population of 25 000-49 000, 59 percent of all trips were less than 8 km (5 miles); in those cities that have more than 1 million people, only 44 percent of all trips were less than 8 km (12). Furthermore, the data showed that rural households consume more personal transportation and take longer and more frequent trips than do their urban counterparts.

Yet, there are many limitations to using NPTS statistics as a major source of information for vehicle kilometers of travel. First, vehicle kilometers traveled data are based on guesses of annual travel by individuals rather than on actual odometer readings. Nobody knows how accurately individuals can estimate their vehicle kilometers traveled, but these observations are bound to have large errors. NPTS estimates are 15 percent greater than those of FHWA for national vehicle kilometers traveled.

Second, no data were collected on existing fuel prices for the consumers. Hence, only approximate measures of the cost of travel can be developed. In addition, this survey was made several years before fuel prices increased to their existing high levels. Accordingly, individual responsiveness to magnitudes of price increases may be somewhat different.

A third drawback is the purely cross-sectional character of the statistics. The data represent a picture of the situation existing at the time of the study, 1970. The implications of this static picture are dubious. Are the data characteristic of past years? Do they represent short-term or long-term responses?

Also, the published NPTS report does not reveal geographic locations of the respondents. Therefore, it is impossible to relate annual vehicle kilometers traveled per household to the spatial characteristics of the region or the city of residence and the average cost of gasoline.

Finally, long-range forecasts of vehicle kilometers traveled rely largely on estimates or how anticipated changes in real income affect the individual's driving habits. Unfortunately, the NPTS has a very small sample of upper-middle-income and upper-income households. It is not weighted toward the projected income

distribution of the future. Thus, there is little evidence as to how increasing income influences vehicle kilometers traveled.

The impact of household family size (or number of drivers) on vehicle kilometers traveled per household is not discussed. It is wrong to impute the higher vehicle kilometers traveled associated with larger families exclusively to the higher average income of larger households. For the future, some economists are projecting higher household income but not larger households. Vehicle kilometers traveled analysis must isolate the impact of larger households on vehicle kilometers traveled from the impact of higher income on vehicle kilometers traveled.

Conversely, the greatest value of the NPTS data lie in their microlevel of disaggregation (3, p. 4). The national data of FHWA may be easier to use but they hide important behavioral relations of the individual consumer found at the microlevel. The NPTS household response represents a good, consistent base of socioeconomic information related to vehicle kilometers traveled and automobile ownership.

Another difference between the NPTS data and FHWA occurs in the annual kilometers traveled. Observed annual vehicle kilometers traveled are obtained from home interviews; however, the kilometers per vehicle value in Table 1 is a calculated value found by dividing total automobile travel by the number of registered vehicles. Since all registered vehicles are not operated by households during the entire year, the number of automobiles registered should be substantially greater than the number resulting from expanding the number in the sample households. In another case, a household would be classified as a two-automobile household if that were the number owned at the time of the interview for the NPTS. However, if both automobiles were scrapped and replaced during the year, that particular household would account for four registered vehicles in the FHWA computations. Double counting is not totally eliminated in the latter study.

Perhaps the new NPTS report, which is now in progress, will rectify some of the past inadequacies. The sample size, consisting of 20 000 interviews, will be much improved. The gasoline price is included in the questionnaire and regional information may be available in the analysis. Tapes are expected to be available in late 1978 and some analytical work should be released in late 1979. In the future, these cross-section studies may be undertaken at five-year intervals. Therefore, as the data collection for vehicle kilometers of travel improves, better estimates of the fuel efficiency of the automobile fleet will become available.

PROBLEMS AND IMPROVEMENTS

FHWA has undertaken many recent studies to improve the accumulation of vehicle kilometers traveled statistics. First, the Claffey report, which developed fuel-consumption rates for each state by vehicle type and highway system is the basis for the algorithm of RDTRAV (17). This computerized program uses an adjusted Claffey model. For example, RDTRAV employs 13 highway systems; Claffey has 6. RDTRAV used 10 vehicle classes; Claffey has 4.

Estimates of vehicle travel for the various highway systems are reported annually by each state in a report to the FHWA. These data are generally accurate for heavily traveled (high-level) road systems, where they are determined by traffic counts. However, they are often questionable for local (low-level) roads, where full coverage by traffic counts is impractical.

The need for accurate travel statistics led to a con-

sideration of the use of fuel-consumption rates, known vehicle travel on high-level roads, and total statewide fuel consumption for determining travel figures for a low-level highway system. This approach has been implemented in the computer program RDTRAV (18).

The top-level logic of RDTRAV is straightforward. Known vehicle-travel figures for high-level roads (specified for the state as a whole or on a subarea basis) and estimates of average fuel-consumption rates for these road systems are used in subareas. These fuel-consumption figures are summed over all subareas and the result is subtracted from total fuel consumed statewide to produce fuel consumed on low-level roads throughout the state. This result, together with the fuel consumed on low-level systems, yields the desired travel figures for low-level roads.

A key element of this approach is the accurate estimation of average fuel-consumption rates. Vehicle fuel consumption on the various highway systems is affected by a variety of highway design features, vehicle characteristics, environmental conditions, and traffic-flow characteristics. A search of the literature reveals the lack of available engineering models for computing the effect of these parameters on fuel usage. However, extensive work has been accomplished in the past in the area of experimental tests to produce empirical estimates of fuel usage under a variety of operating conditions. Winfrey (19) and Claffey (20) did the initial work in this area. To this was added the work in vehicle mix and population of the Transportation Systems Center in Cambridge, Massachusetts, and also by Claffey (10), who developed fuel-consumption rates for each state by vehicle type and highway system, taking into account the motor vehicle population and design features on each system. These and other empirical studies are the basis for the inner algorithm of RDTRAV, which contains logic to compute average fuel-consumption rates for high- and low-level road systems (both individually and collectively) for a geographical area.

The basic user inputs required by this inner logic are baseline fuel-use rates for various operating conditions, distributions of travel among these operating conditions (see below), and fuel-rate adjustment factors supplied on a statewide basis or on a subarea basis; up to 99 subareas are allowed.

Baseline fuel rates for each subarea may be specified at any of six levels of detail, depending on which parameters and operating conditions are implicitly accounted for in the available fuel-use data. At one extreme, the user simply specifies average fuel-use rates for high- and low-level roads in the subarea. These rates must account for all highway, vehicle, traffic, and environmental characteristics that affect fuel use in the subarea. At the other extreme, the user supplies fuel-use statistics for each road system, vehicle category, traffic flow condition, and range of road gradient in the subarea. An example of such input would be the average fuel-use rate by small passenger automobiles in congested traffic on local rural roadways in rolling terrain at 0-2 percent range of road gradient. Four levels of data, which fall between these two extremes, are also allowed. Empirical data, extracted from the above referenced studies and included in the program documentation, may be used in the absence of other information.

Parameter adjustment tables may be supplied for operating conditions not accounted for in the baseline rates. Examples of such adjustments include

1. Travel in subfreezing temperatures,
2. Travel on snow- and ice-covered pavements,

3. Vehicle stops and slowdowns,
4. Operation of vehicle air conditioners,
5. Vehicle power-accessory equipment (e.g., power steering and power brakes), and
6. Recent changes in engine design for the control of emissions.

Empirical data for a variety of parameters are listed in the literature and in the program documentation.

Travel distributions are used to integrate (average) the corrected fuel rates to produce average fuel-consumption rate on high- and low-level road systems (both individually and collectively) in the subarea. The types of distributions required depend on the form of fuel-use data supplied. These distributions include

1. Distributions of travel among road systems,
2. Percentage of travel on each road system that is congested,
3. Distributions of travel among vehicle categories for each road system,
4. Distributions of travel among vehicle terrain types for each road system, and
5. Distributions of travel among ranges of highway gradient for each road system and terrain type.

Sources for this information are described in the program documentation.

A variety of options are accommodated in specifying the required input to the program. Different versions of a data table may be specified for different geographical areas, and a particular version may apply to more than one area. Sets of operating conditions for which fuel-use data are supplied (road, vehicle, traffic, terrain, and grade categories) may assume any fixed meanings the user desires for an area, so long as the category definitions remain consistent for all data supplied for that area. In a similar fashion, parameter-adjustment tables may represent any operating characteristic whose effect on fuel usage can be validly specified as a percentage increase or decrease in average fuel rate.

The program output from RDTRAV consists of a printed list of input error and warning messages and, assuming no fatal input errors, two printed tables of fuel-consumption, travel, and fuel-use statistics. The input editor messages contain the sequential number of the card image containing the error. The first statistical table contains fuel consumed, vehicle kilometers traveled, and average fuel-consumption rates for each road system in each subarea. The second table presents similar statistics for high-level roads, low-level roads, and all road systems (collectively) for each subarea and for the state as a whole.

In a second effort to improve the current methodology, FHWA is testing the vehicle kilometers traveled procedures in six cities. The preliminary manual (7) contains a technique for estimating daily average vehicle kilometers traveled based on a stratified random sample of street links (sections of roadway with homogeneous traffic volume). The primary objective of this study is to test the practicality of the methodology in the revised manual and to discover how to integrate the vehicle kilometers traveled estimation program into the traffic-counting program. Figure development includes sampling procedures that are required to subdivide the area vehicle kilometers traveled estimate into the various vehicle classifications (21).

Hamburg and Associates (22) will work in one of the six test cities. Their work program consists of four tasks. Task 1 includes the assembly of historical

traffic-count data and estimation procedures for vehicle kilometers traveled. In task 2, the sampling procedure will be determined, the sample selected, and the specific links determined. In task 3, the actual collection of data will be undertaken. Task 4 will produce estimates of vehicle kilometers traveled for the subregion and measure the accuracy achieved. As part of this task the FHWA procedure (7) will be evaluated with respect to its statistical reliability and applicability.

For another project in May 1977, Hamburg and Associates submitted a proposal to study improved methods for vehicle counting and determining travel distance (23). The problem is one of organizing and integrating numerous specialized programs, which are sponsored by local, regional, and state agencies into one program designed for statewide application but having provision for disaggregating by system type and geography. A survey of current traffic-counting techniques will be undertaken to include design of plan, administration, interagency coordination, collection, processing, and analysis. Next, Hamburg will produce a cost-effective highway-traffic-volume information program. Furthermore, the ability of the improved traffic-volume method to compute vehicle kilometers traveled will be compared to other procedures, such as the fuel-consumption method.

In another study, Rabe (5) concluded that, although many problems in vehicle kilometers traveled modeling can be traced to scarce data, the available information could be used more judiciously than it has been in prior attempts. More complex and realistic hypotheses should be tested before oversimplified models are accepted. Although available data may support some of these tests, a federally sponsored data-collection program could substantiate greater strides in vehicle kilometers traveled forecasting accuracy by eliminating misspecified models.

In addition to the studies that have been detailed, other contracts and projects are being planned and have been undertaken. The studies being carried out are in response to legislative requirements, deficiencies in state and local planning methodology, and policy analysis needs for federal program evaluations. The changing nature of the planning process results in a flexible mixture of projects that vary according to needs in the planning methodology. The two federal agencies that are the principal sponsors for this research effort are the U.S. Department of Transportation and the U.S. Department of Energy.

FINDINGS AND OBSERVATIONS

This paper has evaluated the existing data sources for vehicle kilometers traveled. FHWA has not developed and selected one specific methodology to estimate vehicle kilometers traveled. No single procedure has been established to collect, report, and consolidate vehicle kilometers traveled data. Each state, and every region within a state, selects its own process for gathering these data. Therefore, FHWA cannot obtain an accurate and reliable estimate of vehicle kilometers traveled from such heterogeneous inputs.

Historically, the importance of the accumulation of vehicle kilometers traveled has been directed toward highway planning and included such areas as traffic density, highway safety, and other non-energy-related areas. For these nonenergy endeavors, the traffic-counting methodology has been the procedure used most widely by the individual states to estimate vehicle kilometers traveled. However, since the 1973 energy crisis, FHWA has requested that the states estimate vehicle kilometers traveled based on average fuel-efficiency rates for different vehicle classifications. This alternative method-

ology may be a more appropriate way in which to solve energy-related issues because energy efficiency is one of the predetermined variables.

State departments of transportation have been unable to furnish accurate traffic counts on non-federal-aid highway systems (local, rural, and urban roads). In order to better estimate vehicle kilometers traveled on the non-federal-aid systems, FHWA has been developing the RDTRAV computer program. The RDTRAV algorithm contains logic to compute average fuel-efficiency rates for high- and low-level road systems for a geographical area. The basic inputs required by this inner logic are baseline fuel use rates for various operating conditions, distributions of travel among the operating conditions, and fuel rate adjustment factors for parameters not incorporated in the baseline data.

Today, it is assumed that the fuel-efficiency rate for each state is determined independently from the national fuel-consumption rate. Nevertheless, for the 17 states that now use the fuel-consumption method in combination with the traffic counts, only 10 have made an independent empirical investigation of fuel economy and the other 7 use FHWA guidelines. Empirical investigations do not have a standard methodology and are made infrequently. FHWA guidelines imply that the states may use the computed national figure for kilometers per liter to determine the individual state vehicle kilometers traveled. Indeed, causality is a major issue.

Fuel consumption rates involve many heterogeneous inputs, and it has been difficult to arrive at a meaningful state average. In each state, fuel efficiency depends on

1. The share of automobiles by age and weight,
2. The spatial distribution of travel, and
3. The drive cycle (climate, topography, and drive schedule).

At the current time, such important characteristics as the drive cycle and drive schedule have not been fully evaluated. The drive cycle includes the physical environment in which the vehicle operates. This is comprised of meteorology, topography, and the drive schedule. The latter embraces such key factors as trip information (e.g., origin, destination, purpose, and length), demographic patterns, road type, congestion, and stop-and-go traffic. In addition, other factors that affect fuel consumption and efficiency, such as automobile accessories and vehicle registration classifications, must be considered. The values of these factors should be determined from trip and travel statistics and are the major factors in determining a vehicle's fuel economy.

Although the vehicle count approach offers a good alternative to the fuel-efficiency method, there is need for improvement. First, there is substantial diversity in the counting methodology. Second, the methodology used to expand the counts is not grounded in standard statistical procedures. Third, higher-volume roads are better represented in the counting methodology than the lower-volume facilities. Finally, more statistical evaluation should be inferred from the count program.

To sum up, the scope and accuracy of vehicle kilometers traveled data leave much to be desired. New methodologies (such as the RDTRAV algorithm) must be established and then substantiated through empirical testing in order to achieve the National Highway Traffic Safety Administration's (NHTSA's) objectives. NHTSA is interested in vehicle kilometers traveled and gasoline consumption by vehicle classification and geographic region in order to arrive at the estimate of the fuel efficiency of the passenger automobile fleet.

Some form of standardization is a necessity for computing vehicle kilometers traveled. Experimental pro-

grams being undertaken by FHWA are principally directed toward the establishment of average statewide fuel-consumption rates for the individual states. Traffic counts are expensive, sampling techniques can be subjective, and equipment use varies from one state to another.

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