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A Procedure for Estimating Automobile Fuel Consumption on Congested Urban Roads

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Final Report

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Urban Mass Transportation Administration
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U. S. DEPARTMENT OF COMMERCE, Frederick B. Dent, Secretary
NATIONAL BUREAU OF STANDARDS, Richard W. Roberts, Director

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ABSTRACT

Energy consumption is an important measure of the performance of a transportation system. To be able to accurately measure associated automobile fuel consumption will improve the evaluation of urban transportation alternatives. An estimation procedure is proposed that is designed to be particularly sensitive to automobile fuel consumption in congested, peak hour traffic. This procedure is based upon vehicle attributes and roadway operating conditions which were determined through an extensive review of the auto fuel consumption literature. Vehicle attributes include characteristics of the automobile that affect fuel consumption. Roadway operating conditions comprise the types of driving to which the automobiles are subjected. Vehicles are classified by weight and model year. The proposed roadway classifications are expressway, arterial, and local street. For each vehicle type category, base fuel consumption rates are determined. These base consumption rates are then modified by adjustment factors which reflect the roadway operating conditions. The rates are multiplied by the vehicle miles of each vehicle category and summed over all categories to compute the total fuel consumption on the road under analysis. An example application of the procedure including sensitivity analyses is presented. The base fuel consumption rates can be obtained from EPA emissions test data. Research is required to determine the adjustment factors, particularly under conditions of extreme roadway congestion.

1. INTRODUCTION

1.1 DISCUSSION OF THE PROBLEM

The conservation of automobile fuel is an important benefit of mass transportation, and an essential statistic of each transit alternative should be the estimated saving in automobile gasoline. Most transit improvements focus upon peak period traffic conditions; however, present techniques for estimating auto gasoline consumption do not adequately account for this rush hour operating environment of the vehicle (roadway design characteristics, volume, capacity, etc.) or the characteristics of the vehicles which make up today's traffic volume flows (engines, weight, age, etc.).

When the volume of vehicles on a roadway approaches capacity, congestion occurs. One effect of congestion is that vehicles, because of frequent needs for deceleration, are not able to maintain their attempted speeds. This causes an increase in fuel consumption. Thus, if congestion is not considered, auto gasoline consumption is understated.

Estimation problems are also caused by the obsolescence of the available data. Vehicle characteristics have changed considerably since 1967. Most are heavier, and all are fitted with emissions control devices. Since each of these changes affects gasoline consumption, estimation procedures developed using pre-1967 data will produce inaccurate results.

1.2 PURPOSE

The ultimate requirement of this and related research is to provide procedures for estimating automobile fuel consumption that may be used by transportation planners in evaluating alternative transportation strategies in congested urban corridors. The purpose of this report is to summarize the existing literature and research in progress to develop a statement of current knowledge of automobile fuel consumption, to identify inadequacies in existing techniques that lead to inaccurate estimations of consumption, and to recommend approaches for the elimination of the inadequacies.

1.3 ORGANIZATION

The report is divided into five sections. A discussion of the problem of estimating fuel consumption is found in this section. Section 2 reviews the existing literature and research in progress on automobile fuel consumption. The third section presents an analysis of deficiencies of existing estimation procedures, including a discussion of the factors affecting fuel consumption. Section 4 proposes a procedure for estimating automobile fuel consumption based upon the analysis in Section 3. The fifth and final section recommends a data collection procedure for input to the proposed estimation procedure and recommends areas for further research.

2. REVIEW OF LITERATURE AND RESEARCH IN PROGRESS

The estimation of automobile fuel consumption has been the subject of research in various areas of the automobile industry and transportation field for several years. Recently, added importance has been attached to fuel consumption estimation as a factor in the evaluation of urban transportation alternatives. The purpose of this section is to review both the related literature and research to determine the state-of-the-art and discover any inadequacies which might exist in present methods for estimating auto fuel consumption.

2.1 LITERATURE

The rate at which an automobile consumes gasoline is influenced by the environmental conditions in which it operates as well as by the design of the automobile. Thus, a procedure for estimating fuel consumption should consider the characteristics of both the automobiles and the environmental conditions of the roadway on which they operate. This section reviews the related literature and research to determine the degree to which auto fuel estimation procedures account for diversity of both the automobiles and the operating conditions which are likely to be encountered.

The great majority of the published research concerning automobile fuel consumption has been produced or sponsored by either: 1) the automobile industry, 2) the Environmental Protection Agency, or 3) the transportation planning profession. While each is responsible for a substantial amount of research in the field of automobile fuel consumption, each source offers a different perspective on automobile fuel consumption and the analysis of factors affecting the rate at which fuel is consumed.

1. Automobile Industry

The automotive industry, in papers published by the Society of Automotive Engineers (SAE), generally considers the problem of fuel consumption from the point of view of the individual vehicle. (2,4) These papers are similar in that they contain discussions of the effects of changes in vehicle design characteristics upon fuel consumption. Such characteristics as size, weight, engine design and axle ratio were examined, and the relationship between each characteristic and fuel consumption was isolated and quantified. The majority of the tests in these studies used constant driving cycles.[1] Therefore, data on vehicle fuel consumption for different traffic volume and type of roadway combinations have not been produced by these industry studies.

A typical paper from the automotive industry was written by G. J. Huebner, Jr., of the Chrysler Corporation entitled "Energy and the Automobile -- General Factors Affecting Vehicle Fuel Consumption." (2) A 3600 lb vehicle was used, and the effects of engine efficiency and displacement, compression ratio, torque converter, transmission type, axle ratio, aerodynamic drag, tires, accessories, vehicle weight, and emissions control system upon fuel consumption were investigated for both a 70 mph cruise and an urban driving cycle.[2] Huebner concluded that since 1968, vehicle weight increases and emissions controls had reduced fuel economy substantially, while the other factors had had little effect on fuel economy. The effects of road conditions were not investigated for either case.

2. Environmental Protection Agency

The Environmental Protection Agency's (EPA) investigations of automobile fuel consumption have been conducted along with the agency's tests of automobile emissions controls. Federal certification is required for all new cars sold in the United States, and fuel consumption data are a tangential output of these tests. The data are generated on a chassis dynamometer which simulates,[3] in a controlled environment, an urban driving cycle of 7.5 miles in length with attendant changes in speed and rates of acceleration and deceleration. Fuel consumption is not measured directly, but is computed using the carbon balance method. This method computes consumption by measuring the amount of carbon in the engine exhaust and comparing it with the amount in the gasoline burned. The carbon balance method has been found to be within an average of 4.5 percent of fuel consumption when measured directly. (3)

[1] A constant driving cycle is one where the same pattern of accelerations, deceleration, and constant speeds are repeated for each vehicle.

[2] An urban driving cycle simulates the accelerations, decelerations, stops, and speed changes most frequently encountered when driving in urban areas. This typically includes many starts and stops, and maximum speeds under 40 mph.

[3] A chassis dynamometer is a machine which allows a vehicle to be operated in a laboratory environment. It allows the wheels to turn and simulates the inertia of the vehicle, but since the vehicle remains stationary, rolling resistance and air resistance are not simulated.

Since the consumption data has been collected by model year and vehicle model type, the data include considerable information about the change in consumption by model year and vehicle weight. However, as with research by the automotive industry, the effects of traffic volume and roadway conditions have not been investigated. Thus, data on vehicle performance under variable roadway conditions have not been produced.

3. Transportation Planning

In the discussions on automobile fuel consumption, the transportation planning literature considers the effect of roadway operating conditions (as opposed to vehicle characteristics) upon fuel consumption. The primary focus is the effect of such characteristics of the operating environment as grade, curvature, volume, speed, and traffic signals. Paul Claffey, in NCHRP 111, has produced one of the most comprehensive studies to date from the transportation planning profession. (5) Auto gasoline consumption was measured for varying operating conditions, including road type, grade, curvature, speed, surface condition, speed changes, and traffic volume. NCHRP 111 provides tables of fuel consumption rates as functions of the roadway operating environment. These rates are based upon a standard size car, as represented by a 4400 lb. 1964 Chevrolet sedan. The report also includes measurements of consumption for smaller automobiles in the appendices, but the measurements do not reflect all of the roadway operating conditions. Claffey's work is typical of the other literature in transportation planning in that it does not account for the variation in fuel consumption as a function of vehicle characteristics, the analysis being performed on the "typical", or most-used vehicle.

2.2 RESEARCH IN PROGRESS

Research on gasoline consumption for use in transportation planning is currently concentrated in the Transportation Systems Center (TSC) of the Department of Transportation. A recent effort for the Federal Energy Administration (FEA) involves the collecting of data on automobile fuel consumption for use in several computer models which test the energy impacts of alternative national policies affecting transportation. These data are being gathered by a firm that specializes in developing vehicle operating cost data for large private fleet owners. Fuel consumption data are being collected for model years 1965-1974 for 14 U. S. automobiles and 4 foreign models. The autos are divided into four size classes: subcompact, compact, standard, and full size. General operating conditions are divided into three classes: mostly urban driving, mostly suburban driving, and mostly interstate driving. The data are also stratified by climatic conditions into three ambient temperature ranges. Although stratified explicitly by vehicle type, the data do not directly reflect specific urban operating conditions of road type and traffic volume, as these are imbedded in the three general operating categories.

Another study currently underway at TSC is a computer simulation of an automobile to investigate the effects of various parameters upon fuel consumption. Vehicle characteristics such as weight or operating conditions such as speed may be varied to determine the effect upon the fuel consumption rate of the simulated vehicle. This simulation model is also being used to investigate the trade-offs in fuel consumption among vehicle design options, e.g., adding weight to the vehicle without changing engine size or adding weight but maintaining performance by increasing engine displacement.

Also underway at TSC is a study to investigate alternative procedures for measuring fuel consumption. In the event that the Government requires auto manufacturers to label their cars with respect to fuel economy, a uniform measurement procedure will be required, and answers are being sought for such questions as how to instrument the test vehicle and how to test it for fuel consumption.

In summary, the existing work on estimating automobile fuel consumption has concentrated either on the individual vehicle or the roadway environment. Some have analyzed the attributes of the vehicle to determine their effects upon consumption. Other studies have examined the operating environment of the vehicle to determine its effect upon consumption. However, accurate estimations of the fuel consumption of auto volumes require a knowledge of the joint effect of vehicular attributes and roadway operating conditions, and, to date, there has not been a synthesis of those two areas of research. Section 4 will introduce an estimation procedure that incorporates both vehicle characteristics and operating conditions in order to more accurately estimate fuel consumption under a number of cases which are likely to be encountered during peak periods in urban areas.

3. FACTORS WHICH AFFECT AUTO FUEL CONSUMPTION

The variables or factors which affect fuel consumption will be divided into two categories: vehicle attributes and characteristics of the roadway operating environment. Vehicle attributes are those characteristics of the automobile that directly affect the amount of gasoline consumed by that vehicle and include weight, engine size and design, shape, rolling resistance, and accessories. Characteristics of the roadway operating environment are other factors which affect consumption and include temperature, road type, traffic volume, speed, number of traffic signals, grade, curvature, and the condition of the pavement. While all attributes and roadway operating conditions affect fuel consumption to some degree, the analysis reported in this document will be limited to those attributes and conditions which have the largest effect on automobile fuel consumption in the urban area. These are automobile weight and design, traffic volume, and road type.

3.1 VEHICLE ATTRIBUTES

Weight has been found to be the single most important vehicle attribute affecting fuel consumption (1,2). In general, a car with inertia weight of 5000 lbs will consume twice as much gasoline as a car weighing 2500 lbs (under the same operating conditions) because the engine must perform more work to propel a heavy vehicle than a light vehicle. Another study found that vehicle weight was correlated with fuel consumption with a simple correlation coefficient of 0.93. (3)

Data published by the Environmental Protection Agency (EPA) indicates that fuel consumption varies with changes in vehicle model year. (1,3) Model year is actually a surrogate which reflects automotive design and performance changes which affect fuel consumption. Major changes have recently been caused by the need to meet Federal emissions standards and include spark retardation and exhaust gas recirculation. The effects of these changes on fuel consumption are not readily apparent. There has been a trend of increasing fuel consumption from 1967 to the present for vehicles weighing more than 3500 lbs and of slightly decreasing fuel consumption for vehicles under 3500 lbs. A 4500 lb 1973 model automobile had nearly a 13 percent greater fuel consumption rate than a similar 1967 model of the same weight. (3)

Automobile accessories, such as power steering, power brakes, automatic transmissions, and air conditioning affect fuel consumption. Of these, air conditioning and automatic transmission have been found to affect fuel consumption most. (1,2) Also, both are increasingly prevalent accessories with 72.6 percent of 1973 American-made cars being sold with air conditioning and 93.4 percent with automatic transmissions. (9)

Air conditioning has a two-fold effect upon consumption: first, the added weight of about 100 lbs for the unit results in a 1 to 2 percent fuel consumption penalty. (Smaller cars are affected more by the added weight than are larger cars.) Second, a much larger penalty is associated with the operation of air conditioning, as the compressor consumes energy. The effect upon consumption depends upon the environment of the roadway, driving speed, and the ambient temperature. The average increase in consumption has been found to be approximately nine percent with a maximum up to 20 percent. (1) Another study measured a 14 percent increase in fuel consumption with the operation of the air conditioning of a 3600 lb car during an urban driving cycle. (2) Automatic transmissions do not have as great an effect upon fuel consumption as air conditioning, with an average penalty of only about two percent. (1) Lighter weight cars with smaller engines, however, show up to a six percent penalty. (4)

3.2 ROADWAY OPERATING CONDITIONS

The two most important characteristics of the roadway operating environment, road type and traffic volume, are interrelated in their effect upon automobile fuel consumption. Roads have been categorized into three types for fuel consumption analysis: expressways, arterials, and local streets in downtown areas (referred to hereafter as Central Business District (CBD) streets). In free flowing traffic conditions, the road type does not have an effect upon fuel consumption at a given speed; however, if there is congestion, vehicle fuel consumption will vary with road type.

Traffic volume is related to road type in as much as the volume of traffic that constitutes congestion varies according to the type of road and the number of lanes on that road. The Claffey study determined that increases in volume can increase fuel consumption by as much as 9 percent on an expressway and by as much as 21 percent on a CBD street. Since these statistics do not include fuel consumption rates under extreme traffic congestion, service levels E and F (Table 1), they understate the potential effect of congestion on fuel consumption.

Speed is another factor that has a direct effect upon automobile fuel consumption. Much has been written on the effect of speed upon fuel consumption on the open road; many also present fuel consumption rates as functions of speeds which can be maintained on the open road. However, an average speed that could be maintained in free flowing traffic on the open road might differ substantially from a similar one attained during congested peak period traffic. This is due to the interaction of an individual vehicle with other vehicles and traffic control devices. This interaction requires that speed be considered in conjunction with traffic density and road type. The Claffey study showed that the dimension of speed that is important when related to traffic volume is the attempted speed of the automobile.[4] The study showed that fuel consumption at attempted speeds of 45 mph and 60 mph on an expressway (under the same traffic conditions - Level of Service D) can differ by as much as 8.5 percent. On an urban arterial the difference between 30 mph and 40 mph was 12 percent (Level of Service D). Again, these values do not include extreme traffic congestion.

The prediction or estimation of fuel consumption on a road is dependent upon the attributes of the vehicles in the traffic stream and the roadway operating conditions. The most important vehicle attributes affecting fuel consumption are vehicle weight and vehicle model year. The most important roadway operating conditions are road type, traffic volume, and attempted speed. The problem is that, to date, no method nor data are available so that all of these factors can be simultaneously taken into account.

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[4]Attempted speed is the speed at which the driver of a vehicle would like to travel but might not be able to due to slower vehicles in a heavy traffic stream which block his path. It can be approximated by the posted speed limit of the road.

Table 1

LEVEL OF SERVICE

LEVEL OF SERVICE	DESCRIPTION
A	Free flow with low volumes and high speeds.
B	Stable flow with operating speeds beginning to be restricted somewhat by traffic conditions.
C	Stable flow but speeds and maneuverability are more closely controlled by the higher volumes.
D	Approaching unstable flow with tolerable operating speeds being maintained though considerably affected by changes in operating conditions.
E	Flow is unstable with volumes at or near capacity of the road.
F	Forced flow operation at low speeds where volumes are below capacity. Speeds are reduced substantially and stoppages may occur for short or long periods of time because of downstream congestion.

Source: "Highway Capacity Manual", Special Report 87, Highway Research Board, Washington, D. C., 1965

4. A PROCEDURE FOR ESTIMATING AUTOMOBILE FUEL CONSUMPTION

This section discusses a proposed procedure for estimating automobile fuel consumption. This procedure will require weight, model year and accessory (primarily air conditioning) information about vehicles in the flow of traffic; and road type, traffic volume, and attempted speed information about the roadway operating environment.

Ideally, total automobile fuel consumption can be computed by multiplying vehicle miles traveled by appropriate consumption rates (expressed in gallons per mile) which are functions of the five previously discussed variables:

$$C = \sum_{I} VM_I CR_I$$

where:

I = indices for vehicle type, traffic volume, road type, speed, and accessory usage

VM = vehicle miles

CR = consumption rate

The critical question, of course, is how to specify the function CR.

4.1 THE PROCEDURE

Present procedures are inadequate for estimating the fuel consumption of autos traveling over either of the three road types under high traffic volumes. Data and procedures for correcting the deficiency are discussed in the remainder of this document.

The preceding discussions have presented factors to be considered in the estimation of automobile fuel consumption with a specific flow of traffic.[5] Paragraph 4.1 presents a computational procedure which follows the approach presented in NCHRP 111. The idea is to develop base auto consumption rates and to modify these base rates with adjustment factors which reflect the operating environment of the roadway. The product of the base rates and the adjustment factors will constitute a gasoline consumption rate function which incorporates both vehicle and roadway operating conditions. Estimated gasoline consumption will be given by:

(2)
$$C = \sum (BC_{w,my} \cdot A_{w,my,r,t,s,a})\,(VM_{w,my,r,t,s,a})$$
$$= \sum (CR_{w,my,r,t,s,a})\,(VM_{w,my,r,t,s,a})$$

[5]This estimation procedure was developed for automobiles but could be generalized to include trucks as well.

where:

C = total fuel consumption (gallons)

CR = consumption rate for each combination of weight and model year category, road type, traffic volume, attempted speed, and accessory usage

BC = base fuel consumption rate in gallons per mile for each weight and model year category

VM,A = vehicle miles and adjustment factors for each combination of weight and model year category, road type, traffic volume, attempted speed, and accessory usage

a = accessory usage

w = vehicle weight category

r = road type

my = vehicle model year category

t = traffic volume

s = attempted speed

4.2 AGGREGATION OF VARIABLES

A preliminary investigation was undertaken to determine a potential stratification of the variables and the sensitivity of the estimation procedure to different stratifications.

1. Vehicle Attributes

The stratification of consumption rates by vehicle weight and model year was based upon consumption data presented by Hellman and Austin of EPA. (3) The data were stratified by model year from 1957 to 1974, and by weight from 1750 to 5550 lbs. The consumption data were presented by individual model year and by weight intervals of 250 lbs from 1750 to to 3000 lbs and by 500 lb intervals from 3000 to 5500 lbs, a total of 18 model year categories and 11 weight class categories. (The entire data set is presented in Table 2).

Further examination of the EPA data revealed that the greatest changes in fuel consumption occurred between the 2750 and 3000 lbs categories and the 4000 and 4500 lbs categories. Therefore the weight classes have been aggregated into three new categories: less than 3000 lbs, between 3000 and 4000 lbs, and greater than 4000 lbs. Analyzing the model year stratification in the same manner, the largest changes occurred between 1967 and 1968, 1970 and 1971, and between 1973 and 1974. Austin and Hellman aggregated the 1957-1967 data in their analysis because these were the model years that had no Federal emissions requirements to be met.

Retaining this aggregation as one category, the new categories for model year are: up to and including 1967, 1968 through 1970, 1971 through 1973, and finally 1974. Therefore, the number of vehicle weight model year categories has been reduced from 198 to 12.

The sensitivity of the estimation procedure to a further aggregation of the vehicle attribute data was also briefly investigated. The methodology employed in this sensitivity analysis involved using the estimation procedure with the aggregate data set (the 12 data points) and aggregating the weight categories while maintaining the weight stratification. In each case, the estimates of total fuel consumption were compared with the estimate produced during the full aggregate data set. It was found that aggregating the weight categories into a single 4500 lb class (standard size automobile) while maintaining model year stratification resulted in a 20.3 percent higher estimate of total fuel consumption than when all 12 data points were used. By contrast, aggregating model year into a single year, 1969, resulted in only a 2.0 percent lower estimate of total consumption than was obtained using the full aggregate data set.

2. Roadway Operating Conditions

The only study to date that has collected and analyzed fuel consumption data for a broad range of roadway operating conditions is presented in NCHRP 111. (5) The analysis of the sensitivity of fuel consumption estimation to roadway operating conditions is based upon this work.

The fuel consumption data in NCHRP 111 are stratified by three road types: six lane expressway, six lane urban arterial with no curb parking, and a six lane CBD street with parking in both curb lanes. The data are further stratified by traffic volume, attempted speed, and number of traffic control signals per mile.

a. The volumes on each road type produce conditions that range from Level of Service A through Level of Service D. Data are not available for Service Levels E and F. (Refer to Table 1, page 6.)

b. The attempted speeds are given on each road type in the ranges appropriate for that particular type of facility, i.e., 45-60 mph on expressways; 30-40 mph on the urban arterial; and 25 mph on the CBD street.

c. The number of traffic control signals per mile are grouped according to the road type, with none on the expressway; between 0 and 2 on the urban arterial; and between 0 and 10 on the CBD street.

The sensitivity of the estimation procedure to stratification of road type may be investigated by examining the data for a given Level of Service, speed, and number of signals per mile to ascertain the differences in consumption. The reported data showed a potential difference of 53 percent between the urban arterial and the CBD street for equal level of service and speed. The effect of traffic volume was examined for each road type by comparing per mile consumption rate at service levels A and D and at the same attempted speed. For the expressway a 7 percent increase was observed as increased volumes pushed the service level down from A to D; no difference was observed on the arterials; and a 21 percent increase was observed on the CBD street.

An increase in the attempted speed on an expressway from 45 mph to 60 mph produced 9 percent higher fuel consumption while an increase from 30 mph to 40 mph on an urban arterial resulted in a 39 percent increase in fuel consumption (both at Level of Service D).

Finally, an increase in the number of traffic control signals per mile from 0 to 2 produced a 58 percent increase in consumption on an urban arterial, and an 180 percent increase in consumption for an increase of from 0 to 10 signals per mile on a CBD street.

The tentative conclusions that may be reached about the necessary stratification of roadway operating conditions suggest that road type should be differentiated, and the three types presented in NCHRP 111 (expressway, urban arterial, and CBD street) will be retained in this study. The effect of traffic volume is not as clear as the effect of road types; however, Claffey did not gather data for Levels of Service E and F which intuitively would seem to have a more pronounced effect upon consumption than Levels of Service A through D. Further investigation of traffic volume effects seems necessary and will be discussed in Section 5.

TABLE 2

FUEL ECONOMY IN MILES PER GALLON FOR VARIOUS MODEL YEARS AND INERTIA WEIGHT CATEGORIES (--INDICATES NO DATA)

	INERTIA WEIGHT										
MODEL YEAR	1750	2000	2250	2500	2750	3000	3500	4000	4500	5000	5500
57	--	26.4	--	--	--	--	14.7	13.0	--	--	12.5
58	--	25.3	18.2	--	13.2	--	13.6	15.2	12.5	8.6	--
59	--	28.6	--	--	--	15.2	15.0	13.2	12.7	13.8	--
60	--	20.4	--	22.3	24.5	--	15.7	12.4	10.8	10.9	--
61	--	29.4	--	20.9	16.3	17.2	11.4	14.0	10.5	10.6	--
62	--	25.8	--	--	18.0	16.3	13.0	13.8	12.6	10.8	--
63	--	23.2	19.5	--	16.1	14.7	12.6	12.0	11.1	10.6	--
64	--	22.8	--	--	17.3	16.2	13.7	12.9	11.4	11.0	--
65	--	23.8	--	--	18.3	15.2	13.7	12.3	11.7	10.3	--
66	--	20.9	--	12.7	14.9	14.6	13.9	12.3	12.1	11.3	9.3
67	--	22.6	25.7	--	18.7	15.9	13.1	12.1	11.6	11.2	10.3
68	--	19.3	20.5	18.5	19.7	15.6	13.3	12.0	11.3	9.5	--
69	--	22.2	20.3	18.8	--	15.4	13.3	11.9	11.3	9.1	10.8
70	--	23.4	19.3	17.5	18.5	15.9	13.3	12.0	10.9	10.1	9.9
71	27.2	22.6	21.4	19.3	18.3	14.8	12.2	11.7	10.7	9.6	10.9
72	--	23.0	21.9	19.6	20.0	14.4	13.3	11.1	10.7	9.6	9.3
73	24.8	23.8	21.9	19.7	17.5	15.6	13.9	10.8	10.1	9.3	8.6
74	--	24.1	21.4	18.7	17.7	14.8	13.7	10.8	9.6	9.1	8.2
75	--	--	20.1	17.4	16.6	--	14.3	--	10.1	9.6	8.4
57-67 Aver.	--	23.2	21.7	19.1	17.1	15.4	13.5	12.6	11.7	10.9	10.5

Source: "A Report on Automobile Fuel Economy", United States Environmental Protection Agency, Office of Air and Water Programs, Office of Mobile Source Air Pollution Control, October 1973.

4.3 SUMMARY OF PROCEDURE AND EXAMPLE

A prototype of the auto fuel consumption estimation procedure advocated in paragraph 4.2 was developed; it is based upon two vehicle attributes and three roadway operating conditions. The prototype estimation procedure uses base consumption rates for various combinations of vehicle weight and model year and adjustment factors for combinations of road type, traffic volume, and attempted speed. However, available data did not allow for the detailed disaggregate computations described previously: Vehicle Miles ($VM_{w,my,r,t,s,a}$) was approximated by the product of $P_{w,my}$, a distribution for weight and model year categories; $M_{r,t,s}$, the length of a roadway of type r in miles with a volume per hour of t autos and a speed limit of s mph; and T_r, the total number of automobiles on the roadway during the time period under study. The influence of accessory usage was not included. The formulation of the procedure is:

(3) $$C_r = T_r \sum_{t,s} M_{r,t,s} \sum_{w,my} \cdot P_{w,my} \; BC_{w,my} \cdot A_{w,my,r,t,s}$$

T_r = total number of vehicles on road type r

$P_{w,my}$ = percentage of vehicles in class w,my

$M_{r,t,s}$ = number of miles of travel on road type r with t vehicles per hour and speed limit of s mph

$BC_{w,my}$ = base consumption rate in free-flowing traffic for vehicle in class w and my (gallons per mile)

$A_{w,my,r,t,s}$ = adjustment factor for vehicle class w,my on road type r with traffic volume t and attempted speed s

A simple example may be used to illustrate the estimation procedure.[6] Assume that an estimate of total automobile fuel consumption on a six lane expressway during the AM peak period is desired. The hypothetical situation is as follows:

speed limit:	55 mph
length of expressway:	7.4 miles
inbound peak hour traffic volume:	4900 vehicles per hour (VPH) (Level of Service C)
total AM peak period (2.5 hours) traffic:	12,000 autos[7]

Vehicle Model Year and Weight Distribution

in Freeway Traffic Stream[8]

	1955-1967	1968-1970	1971-1973	1974
<3000 lbs	.068	.088	.065	.030
3000-4000 lbs	.124	.161	.120	.055
>4000 lbs	.078	.101	.075	.035

Base Consumption Rate Matrix [gallons per vehicle-mile (gpvm)]

	1955-1967	1968-1970	1971-1973	1974
<3000 lbs	.050	.050	.051	.051
3000-4000 lbs	.074	.077	.079	.068
>4000 lbs	.087	.093	.103	.106

[6]The example is for illustrative purposes only. Results are based upon data from NCHRP 111 and therefore should only be used to estimate auto fuel consumption under conditions corresponding to service levels A through D

[7]While the estimation procedure can theoretically be applied to any time period, it is envisioned that the adjustment factors will be based on hourly flows. Therefore, the peak period may be divided into smaller time periods, where different volumes prevail; and hence, different adjustment factors are required. This example assumes that the same set of adjustment factors apply to the entire peak period.

[8]If research determines that model year and weight are independent variables, this joint distribution can be replaced by two separate distributions, one each for vehicle weight and model year.

Values of Adjustment Factors for six lane expressway with attempted speed 55 mph and 4900 VPH (Level of Service C) (ignoring accessory usage.)

	1955-1967	1968-1970	1971-1973	1974
<3000 lbs	1.04	1.05	1.05	1.06
3000-4000 lbs	1.05	1.05	1.06	1.06
>4000 lbs	1.05	1.05	1.06	1.06

The estimation procedure is divided into three steps:

Step 1: Determine Vehicle Miles Traveled for Each Vehicle Type

vehicle miles traveled = (total vehicles) (%in w,my class) (road length)

for my = 1967 and w<3000 lbs

vehicle miles = (12,000) (.068) (7.4) = 5994

Similar calculations are performed for each w and my pair.

Step 2: Compute Base Fuel Consumption

base fuel consumption = (base consumption rate) (vehicle miles)

for my = 1967 and w < 3000 lbs

from the Base Consumption Rate Matrix, BC = .050

from vehicle miles computed in step one, V_m = 5994

base fuel consumption = (.050) (5994) = 299.7 ≈ 300 gallons

Base Fuel Consumption Matrix (gallons)

	1955-1967	1968-1971	1971-1973	1974
<3000 lbs	300	389	294	136
3000-4000 lbs	816	1101	839	333
>4000 lbs	605	838	690	328

Step 3: Compute Adjusted Fuel Consumption

Each value in the base consumption matrix is multiplied by its corresponding adjustment factor:

for my = 1967 and w<3000: 300 (1.04) = 312 gallons

Adjusted Fuel Consumption Matrix (gallons)

	1955-1967	1968-1971	1971-1973	1974
<3000 lbs	312	408	309	144
3000-4000 lbs	857	1156	889	353
>4000 lbs	635	880	731	348

And then summing the values in the Adjusted Fuel Consumption Matrix, the total consumption for inbound automobiles during the AM peak period is: C = 7022 gallons

5. RECOMMENDED APPROACH TO DATA COLLECTION

The rate at which gasoline is consumed by a particular auto during a peak period (as shown in Section 4.2) can be approximated by the product of the base (free flow) rate of consumption (BC) for that auto and an adjustment factor (A) which represents the effect of roadway operating conditions on gasoline consumption. Thus, R = BC x A.

Currently, only the base consumption rates can be obtained for a wide range of model year and vehicle weight categories. Adjustment factors to account for varying roadway operating conditions are only available for a single model year-weight category and three roadway types. The adjustment factors which are available were developed for a 1964 automobile and more recent data on changes in vehicle weight and operating characteristics are not available. In addition, adjustment factors (nor the data for their development) are not available for the estimation of fuel consumption under extreme traffic congestion (Service Levels E and F). The effect of these deficiencies is to understate peak period gasoline consumption and to generally make transportation planning less sensitive to fuel consumption impacts.

Since current base fuel consumption rates can be derived from the EPA data which are provided annually, a desirable approach would be one which combines the EPA rates with adjustment factors to be computed at regular intervals (e.g., three or four year intervals). Adjustment factors would be developed to link EPA measurements with various roadway operating conditions.

Before the estimation procedure is implemented, a pilot study should be undertaken to compare the results obtained using the proposed procedure and those obtained from small but detailed field data collections. If a satisfactory correspondence between predicted and observed consumption is observed, appropriate field data collections should be scheduled to obtain the gasoline consumption data necessary for implementing the proposed procedure.

To implement the proposed or a comparable procedure for estimating auto fuel consumption, certain data (including the EPA data) must be assembled. These data should allow for the estimation of consumption under: 1) frequently encountered conditions of extreme traffic congestion; 2) high usage of accessories, primarily air conditioners; and 3) various automobile mixes. Such a data set should allow for stratification by:

1. Roadway type (freeway, arterial, or local street)
2. Attempted speed (or speed limit)
3. Stops per mile (signal lights or stop signs)
4. Roadway volume or Level of Service (especially volumes approaching roadway capacity)
5. Gasoline consumption (gallons per mile)
6. Vehicle weight
7. Vehicle model year characteristics (design changes affecting consumption)
8. Accessory usage

The data in the initial collection should be analyzed to minimize the future collection of non-essential information and to strengthen the mechanics of the collection procedure. With respect to the mechanics of the data collections, particular attention should be focused on the choice of time intervals between data collections and sample size. At the present time, it appears that minimum data requirements for computing the adjustment factors should include fuel consumption data on at least one vehicle from each vehicle weight and model year category for operations on each type of roadway. For freeways, the data would consist of consumption rates for a set of volume and attempted speed combinations. For arterials and local streets the data would consist of consumption rates for combinations of volume, attempted speed, and traffic control conditions. Whether or not the data should be collected for more than one vehicle would be decided only after a detailed study design was completed.

In order to minimize the amount of fuel consumption data that needs to be collected, an investigation of the response of the vehicle types to various operating conditions should be conducted. This would determine if an adjustment factor is required for each combination of road type, traffic volume, attempted speed, accessory usage, vehicle weight and model year or if a smaller set may be compiled (e.g., one for each road type). Any reduction in the number of variables considered would substantially reduce the data requirements of the procedure.

If implemented, this approach to estimating gasoline consumption will allow planners to more accurately predict the energy impacts of transportation alternatives. The range of policy alternatives for which fuel consumption can be estimated will be broadened considerably, including 1) alternative auto size ownership policies, 2) alternative auto driver diversion approaches, and 3) alternative traffic control policies. The costs incurred will only be those associated with the generation of adjustment factors, and through a systematic sensitivity analysis, these costs may even be reduced.

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15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

Energy consumption is an important measure of the performance of a transportation system. To be able to accurately measure associated automobile fuel consumption will improve the evaluation of urban transportation alternatives. An estimated procedure is proposed that is designed to be particularly sensitive to automobile fuel consumption in congested, peak hour traffic. This procedure is based upon vehicle attributes and roadway operating conditions which were determined through an extensive review of the auto fuel consumption literature. Vehicle attributes include characteristics of the automobile that affect fuel consumption. Roadway operating conditions comprise the types of driving to which the automobiles are subjected. Vehicles are classified by weight and model year. The proposed roadway classifications are expressway, arterial, and local street. For each vehicle type category, base fuel consumption rates are determined. These base consumption rates are then modified by adjustment factors which reflect the roadway operating conditions. The rates are multiplied by the vehicle miles of each vehicle category and summed over all categories to compute the total fueld consumption on the road under analysis. An example application of the procedure including sensitivity analyses is presented. The base fuel consumption rates can be obtained from EPA emissions test data. Research is required to determine the adjustment factors, particularly under conditions of extreme roadway congestion.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

automobile fuel consumption; congestion; energy conservation; fuel consumption; impact assessment; roadway operating environment; urban roads; vehicle characteristics

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