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Projected Vehicle Characteristics Through 1995

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The U.S. Department of Transportation has established fuel-consumption standards for passenger vehicles and light trucks that will result in increasingly fuel-efficient vehicles in the future. Projections of characteristics of the mix of vehicles on the road that can be expected to change as a result of industry compliance with the standards are presented through 1995, based on a variety of government and industry publications. The average mass (weight), power, and engine size of passenger vehicles—including light trucks with a maximum gross vehicle weight of 3860 kg (8500 lb)—will obviously decrease during this period. Fuel economy will continue to improve steadily, and average acceleration performance will not decline appreciably after the 1983-1985 period. The characteristics of recreational vehicles will change, mostly in the next few years. All of these changes in on-the-highway averages will be brought about through "replacement" of heavy and high-performance vehicles by others of more modest weights and powers rather than through the introduction of very small or low-performance vehicles, which will lead to a more homogeneous vehicle population.

The fuel embargo of 1973 and 1974 and the spot fuel shortages of the summer of 1979 have aroused wide public reaction and contributed to a change in consumer buying habits. Vehicle purchasers are, on the average, seeking more fuel-conserving cars. In response to this demand and to U.S. Department of Transportation (DOT) mandates, the automobile industry is gradually changing its fleet mix to produce vehicles that generally have better fuel-consumption characteristics. This is being accomplished primarily through size and weight reductions as well as a shift to smaller engines (with accompanying performance impacts). To improve overall efficiency, other changes in vehicle technology are also being introduced.

It is of interest to project the long-range impact of these changes on vehicle operations, traffic safety, and overall fuel consumption. To do this, it is first necessary to predict the distributions of the characteristics of vehicles that will be on the road in future years. This prediction process and the results obtained are the subject of this paper. The process assumes an orderly progression of changes based on present rule making and associated projections. It does not consider possible catastrophic events, such as curtailment of automobile production, cessation of fuel imports, or imposition of fuel rationing. The projected characteristics can then be used in analyses or models to estimate impacts of interest.

This paper deals with two basic vehicle categories: passenger and recreational vehicles. The first category includes American and imported automobiles as well as all light trucks (e.g., pickups and vans) with a gross vehicle weight (GVW) of as much as 3860 kg (8500 lb). Recreational vehicles include motor homes, pickup campers, and passenger-vehicle/trailer combinations.

POPULATIONS OF PASSENGER VEHICLES

The aim of this study was to estimate the average characteristics of vehicles that will be on the road in future years as well as the distributions around the averages. The estimation process required, first, breaking down each year's sales into identifiable vehicle categories, each described in terms of such factors as weight, engine size and power, and production. Then all of the sales over the 15-year period prior to the year of interest were accumulated. This accumulation process accounted for the scrappage rates of the vehicles as well as the decreasing annual mileage with age. Finally, averages and other quantities were determined on a travel-weighted basis (that is, vehicles driven more kilometers in the year of interest counted more heavily in the averaging process). Thus, the averages and distributions should be representative of what one would find by measuring all vehicles passing a given location. The assembly process, which involved summing over 3000-4000 identifiable vehicle categories, was made feasible by using specially written computer programs.

For convenience, passenger vehicles were generally divided into three groups: American cars, foreign cars, and light trucks. Then detailed vehicle characteristics were assembled only for selected model years (because of the rather painstaking process required). The characteristics for intervening years were estimated by the computer program, by use of interpolation. The following subsections provide more detail about the assembly process.

Data on Vehicle Characteristics

The most important determinant of acceleration performance is the ratio of a vehicle's net engine power to its mass [commonly, but imprecisely (from a technical viewpoint), called its weight]. Other characteristics, such as transmission and axle ratios, frontal areas, and aerodynamic drag coefficient, also have an effect. Unfortunately, these latter characteristics are not generally available other than on a special-case basis. Therefore, performance capability was estimated solely on the basis of power-to-mass ratio. More specifically, for each vehicle model identified, the maximum net power of the engine and an appropriate vehicle mass (weight) were recorded. For automobiles, this was taken as the curb weight (empty vehicle weight plus fuel and coolant) plus a driver and a passenger--e.g., curb weight plus 140 kg (300 lb). It was assumed that light trucks are usually more heavily loaded than automobiles; a load of approximately 230 kg (500 lb) was therefore assigned for these vehicles. Projections for future American automobiles are available from the National Highway Traffic Safety Administration (NHTSA) (1). For these vehicles, the "inertial weights", which are roughly equivalent to curb weights plus 140 kg, were given, and the vehicles were placed in inertial weight-class intervals of 114 kg (250 lb). Thus, less precision is available regarding these vehicles.

Estimates of fuel consumption are more complex than estimates of vehicle performance. Some studies (2) use the concept of an engine map (a representation of specific fuel consumption as a function of engine speed and engine power output) to estimate total fuel consumption. Unfortunately, engine maps are available for only relatively few current engines. In this study, only those vehicle characteristics that have the strongest effect on fuel consumption and are readily available for nearly all vehicles were considered. These characteristics are loaded weight and engine displacement. Other vehicle parameters that have an effect on fuel consumption and are being improved from year to year (such as reduced frictional losses and other means of increasing efficiencies) could be incorporated in an approximate fashion based on model year.

Assembly of Vehicle Data by Model Year

Detailed data on vehicle characteristics were assembled for the model years 1967, 1971, 1974, 1977, and 1981-1985. Vehicle data for the 1967 model year were taken from a previous research report by St. John and Glauz (3), which analyzed available data for that year and presented the resulting vehicle distributions. That work provided 19 vehicle categories, each with a different power-to-mass ratio and corresponding sales volume. A typical vehicle weight for each class was taken from Table E-1 of that study. All powers quoted at that time were gross powers. A regression analysis performed in another study (4) indicated that the net engine power is approximately 0.746 times the gross power. This correction was made to all 1967 values.

Data for the 1971 model year had already been analyzed in a previous project (4). The results of that analysis yielded a distribution of performance characteristics represented by 31 vehicle categories. This distribution also required that gross powers be converted to net powers by using the multiplicative factor 0.746.

Data for the 1974 and 1977 model years were assembled by using a similar process. Data for American automobiles, foreign automobiles, and light trucks were compiled separately. The 1977 American automobile population, for example, was determined largely from the April 1977 Automotive Industries annual report, which gives, for each model of each manufacturer (e.g., American Motors Pacer, Chrysler LaBaron, and Ford LTD-II), the number of each of the optional engine sizes installed. The report also gives engine displacement, net power, and other details for each engine. Vehicle masses were obtained from NHTSA documentation (5). Some judgment and approximation were required in some instances. For example, the same basic engine size [e.g., 5752 cm^3 (351 in^3)] was often available at more than one power rating as a result of such factors as different carburetors. Production data for subdivisions within models (e.g., station wagons) are not quoted.

American automobile data for 1974 were assembled in essentially the same way as the 1977 data except that engine sales were not given at as fine a level of detail. Where this detail was lacking, the 1977 figures were used as a guide to apportion the optionally available engines to each vehicle model. The April 1975 Automotive Industries report (and, thus, the 1975 engine data) was used to determine the net powers because the figures quoted in 1974 were gross powers.

The foreign-automobile distributions were also determined by incorporating data from the 1974, 1975, and 1977 Automotive Industries reports. Automotive Industries, however, provides sales information for only the 10 leading foreign manufacturers, which in 1977 accounted for only 83 percent of U.S. sales of foreign vehicles. Therefore, NHTSA documentation (6) was used to supplement this information. Vehicles for which sales were extremely small, such as Rolls Royce, Lotus, and Ferrari, were not included in the final tabulation.

NHTSA documentation includes data on the sales of 1976-1977 light trucks by manufacturer and by type of light truck (7). Light trucks include pickups, vans and panel trucks, general utility trucks (such as jeeps), station wagons built on a truck chassis (such as the American Motors Cherokee), and other types (such as light platform or stake trucks). The April 1977 Automotive Industries report provides some engine-sales distributions for each manufacturer's light trucks by model. Additional data were obtained from U.S. Department of Energy (DOE) documentation of data obtained from NHTSA (8). Where sales data were not explicitly provided, it was necessary to augment these data by judgment or assumption to split sales figures among options. Loaded-vehicle weights were obtained from a recent issue of the Official Used-Car Guide of the National Automobile Dealers Association (9). Light-truck data for 1974 were assembled by following a similar process.

Rather complete sales projections and characteristics of 1981-1985 American automobiles have been assembled by NHTSA (1). NHTSA had analyzed four alternative projections. In agreement with their final decision regarding rule making for vehicle fuel-consumption requirements, the projection for "alternative 2" was used. This alternative includes predicted weight reductions resulting from body redesign and substitution of materials, a selection of engines with efficient spark ignition, technological improvements to spark-ignition engines, the addition of a torque lockup clutch and fourth gear to automatic transmissions, and improvements in other areas such as lubricants and accessories. Alternative 2, however, does not include any significant market penetration of diesel engines or additional penalties attributable to emission controls. The figures given were all based on the 1971-1975 average sales and were adjusted to agree with the total annual sales projected by NHTSA for each of the years from 1981 through 1985 (6).

Only limited information is available on 1981-1985 projections for sales of foreign cars (6) and light trucks (7,10). Procedures were devised to quantify expected trends in the weights, powers, and engine sizes of these vehicles (11).

In agreement with the NHTSA rule-making assumptions, we projected that there would be no further changes in model-year vehicle characteristics or sales mixes after 1985. Thus, the detailed 1985 data were simply adjusted to obtain future total vehicle sales as estimated by NHTSA (sales were assumed to increase at a basic rate of 2 percent/year).

Combining the Assembled Data

After assembling the detailed data for certain model years, a computer program interpolated for the intervening model years and extrapolated for model years prior to 1967 and after 1985. Then the annual vehicle travel distance for each vehicle category (i.e., make, model, year, engine size, etc.) was calculated based on the number of vehicles sold, the fraction not yet scrapped by the year of interest, and the annual distance traveled by all vehicles of a given vintage. The program then computed the weighted characteristics previously described, ordered them in terms of increasing power-to-mass ratio, and printed the calculated values together with cumulative sums. From these data, averages and distributions could readily be determined.

Resulting Passenger-Vehicle Distributions

Figure 1 shows the expected average trends in passenger-vehicle characteristics through 1995. The average vehicle mass is projected to decline by more than 230 kg (500 lb), or 14 percent, during this time interval. Most of this decline will occur between 1981 and 1985, and very little change is projected after 1990. The average engine size is expected to decrease rather steadily between now and 1985--by more than 23 percent--and little thereafter. Likewise, average engine power should decrease almost 24 percent. Performance, as reflected in power-to-mass ratio, will only decrease about 15-16 percent, and most of this change will have occurred by 1983. Thus, although average weights and engine sizes will continue to decrease appreciably for about 10 or 12 years (leading to continuously improving fuel economy), the decrease in average performance will occur much quicker, and the most noticeable effects should be felt within the next 5 or 6 years.

Traffic operations are expected to be affected not just by average vehicle characteristics but also, and more importantly, by differing characteristics among road users. Thus, the distribution of characteristics is of extreme interest. The distributions of performance capabilities, as indicated by power-to-mass ratio, are shown in Figure 2 for the years 1978, 1981, 1985, and 1995. Clearly, the major change during this period will be a decrease in the fraction of moderate and high-performance vehicles; relatively little increase will be observed in the percentage of vehicles that have very poor acceleration capabilities. In other words, the spread in vehicle performance should lessen in future years, and this should lead to a more homogeneous mix of passenger vehicles.

For purposes of comparison, Figure 2 also shows the distribution of power-to-mass ratio for the 1967 model year. This distribution is much broader than current or projected distributions. It includes a substantial fraction of vehicles that perform very poorly (e.g., the 1967 Volkswagen Beetle and Microbus, which had relatively small engines) as well as a large fraction of high-performance vehicles [those with 6600-cm^3 (400-in^3) and larger displacement engines]. This comparison suggests that the most pronounced changes in the distribution of the performance characteristics of passenger vehicles may, in fact, have occurred prior to 1978.

It is often convenient, in making projections or performing analyses, to deal with several discrete vehicle "types"--each of which has a prescribed set of characteristics--rather than with the total distribution. As an example, assume that the total distribution is represented by five vehicles, of which the first type represents the 10 percent of vehicles on the road that have the poorest acceleration capabilities and the others simulate the next 15, 20, 25, and 30 percent, respectively, according to performance. The power-to-mass ratios and other characteristics for these vehicle types are given in Table 1 for selected years between 1978 and 1995. Although performance capabilities of each type decrease with time, the most pronounced changes are for the higher-performance types of vehicles (31 and 4 percent decreases for the highest- and lowest-performance types, respectively).

The average mass (weight) for the lowest-performance category remains rather stable, but the mass of the next category increases. This category contains a substantial fraction of pickup and panel trucks, the sales of which are projected to increase (and have increased) more rapidly than those of other passenger vehicles. The masses (weights) of the remaining vehicle types will all decrease, especially between 1978 and 1985. These types are predominantly American automobiles.

The data given in Table 1 also show the decrease in engine displacements. Again, the effect of light trucks on the second performance category is obvious. A relative stability after 1985 is also evident.

The previous projections are, in a sense, somewhat conservative regarding vehicle acceleration performance. They assume, in agreement with NHTSA presumptions, no significant market impact for any but gasoline-powered engines. Yet some scientists anticipate a marked change in power plants, including diesels, electric vehicles, and hybrid vehicles (which have electric and internal-combustion engines). Indeed, diesel-powered automobiles are already being extensively promoted by one domestic manufacturer (General Motors), as well as by at least three foreign firms (Mercedes-Benz, Volkswagen, and Peugeot). An alternative (more extreme) estimate of vehicle performance characteristics might be made by projecting extensive market-share impacts by these other types of vehicles.

A recent report (12) contains results of rather extensive modeling of the markets for postulated future vehicles. In addition to gasoline-powered vehicles, several other alternatives are considered. The "most likely" results, adapted from that report, are given in Table 2.

Two important conclusions can be drawn from these projections:

1. Diesel engines will become a substantial fraction (28 percent) of total passenger vehicles, which definitely contradicts the NHTSA assumption of no significant market impact by diesels.
2. The dominant electric vehicles that are projected will have much greater performance capabilities than current electric vehicles.

The projections imply that there will be substantial fractions of vehicles with new power plants, whose average power-to-mass ratios will approximate the calculated 1995 average for (predominantly) gasoline-powered vehicles. Thus, these new projections (12) would not greatly change the performance characteristics given earlier.

It is informative to examine traffic characteristics under hypothesized "worst-case" performance distributions. The report by Train (12) was critically examined for this purpose. Train's projected power-to-mass average of 49-W/kg (0.03-hp/lb) powered vehicles seems rather high compared with that for current vehicles. The three foreign imports range from 30 to 35 W/kg (0.018-0.021 hp/lb); the ratio for the Oldsmobile diesel is about 43 W/kg

Figure 1. On-highway average passenger-vehicle characteristics.

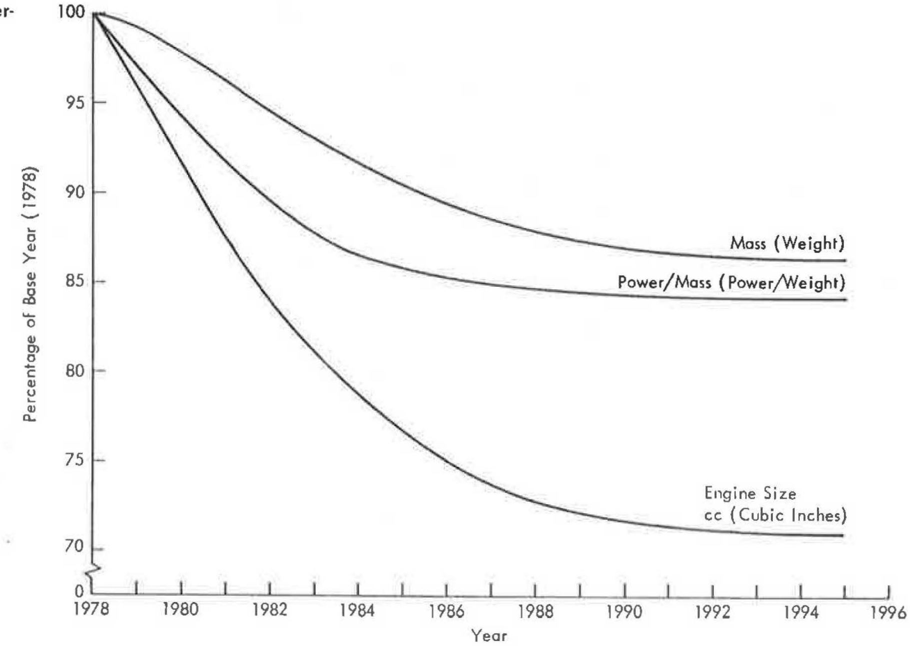


Figure 2. Distribution of power-to-mass ratios of passenger-vehicle populations, accumulated by vehicle kilometers of travel.

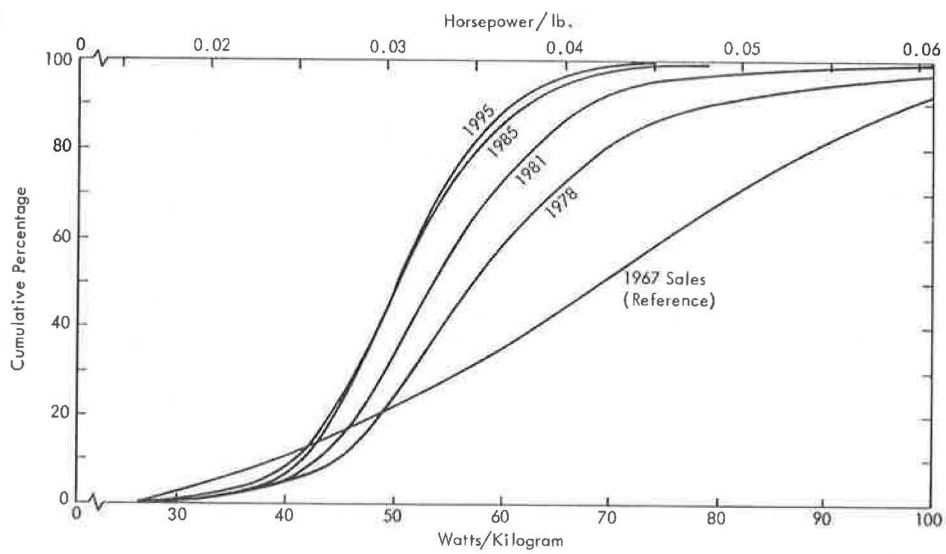


Table 1. Characteristics of representative vehicles.

Year	Performance Category[a] (%)	Power-to-Mass (W/kg)	Mass (kg)	Engine Displacement (cm^3)
1978	0-10	39.0	1511	2606
	10-25	47.8	1638	3557
	25-45	52.9	1754	4278
	45-70	59.5	1785	4851
	70-100	77.8	1888	6704
1985	0-10	37.8	1499	2606
	10-25	43.9	1761	4032
	25-45	47.8	1547	3458
	45-70	52.0	1494	3328
	70-100	61.2	1651	4474
1995	0-10	37.3	1500	2622
	10-25	43.9	1741	3852
	25-45	47.5	1445	3032
	45-70	51.6	1439	3229
	70-100	59.2	1536	4016

Note: 1 W/kg = 0.0006 hp/lb; 1 kg = 2.205 lb; 1 cm^3 = 0.061 in^3.

[a]Ranked according to increasing power-to-mass ratio.

Table 2. Alternative vehicle characteristics for 1995.

Power Plant	Mass (kg)	Power-to-Mass (W/kg)	Range (km)	Percentage Owned
Gasoline				
1	1360	50	—[a]	29.0
2	900	60	—[a]	41.0
Diesel	1500	50	—[a]	28.0
NiZn battery	420	16	80	0.01
Hi-temp battery				
1	1300	33	160	0.03
2	1900	50	240	2.0

Note: 1 km = 0.62 mile; 1 kg = 2.205 lb; 1 W/kg = 0.0006 hp/lb.

[a]Unlimited in the sense that the vehicles can be rapidly refueled as needed.

(0.026 hp/lb). Thus, it is not clear why such an increase is hypothesized. Furthermore, in addition to the many flaws that Train pointed out, his model did not impose any new constraints, economic or otherwise, on gasoline-powered vehicles; that is, it did not assume any increase in gasoline prices or any type of rationing (which many believe to be possible). The model therefore reflected little of an incentive to own electric vehicles that would balance the negative factors of limited range and hypothesized higher initial and operating costs.

In this study, to examine a more nearly worst-case situation, it was assumed that either 5 or 20 percent of the 1995 vehicles were new, low-powered automobiles with a pessimistic power-to-mass ratio of 33 W/kg (0.02 hp/lb). If these vehicles replace a uniform, random selection of the other vehicles, and not just a low-performance or high-performance segment of them, the performance capabilities of the representative 1995 vehicles would be as follows (1 W/kg = 0.0006 hp/lb):

	Power/Mass (W/kg)		
Performance Category (%)	Baseline	5 Percent Low Powered	20 Percent Low Powered
0-10	37.3	33.9	32.1
10-25	43.9	42.6	36.5
25-45	47.5	46.2	43.7
45-70	51.6	51.1	49.8
70-100	59.2	59.0	57.9

Based on these assumptions, the average power-to-mass ratio would decline modestly, from 50.5 W/kg (0.03 hp/lb) to 49.6 or 47.0 W/kg (0.029 or 0.028 hp/lb), but the performance range would increase.

Method of Modeling Vehicle Performance

The assembly process aggregated passenger vehicles into populations on the road by performance class. Conceptually, this process is complicated by the difficulty of defining the term "performance".

Performance is defined here as the acceleration capability (a) of a vehicle as a function of speed (v) on level pavement. One may model this function as a straight line:

$$a = a_0(1 - v/v_m) \quad (1)$$

where a_o is the extrapolated acceleration at zero speed and v_m is the extrapolated speed at zero acceleration (conceptually, a "maximum" speed). However, this model is known to be inaccurate at low speeds; initial acceleration is substantially less than a_o at v = 0 and then increases rapidly at low speeds to exceed the modeled values. In addition, at high speeds this model tends to slightly underestimate acceleration capability and maximum speed. After several alternative approaches were examined, this model was used, but it was fitted to best represent midrange speeds--say, 50-100 km/h (30-60 miles/h), the speed at which most maneuvers of interest occur.

A major problem is the lack of uniformly good source data. A number of organizations routinely test and report on vehicle performance. Unfortunately, their data vary greatly in quantity as well as in comparability. Even for vehicles that are nominally identical, widely disparate results are reported by different organizations, and these differences are usually consistent; some organizations' results will generally be higher than others. Data from various issues of Consumer Reports and Consumer's Research were emphasized. These data tend to be more conservative than some, but they are probably relatively typical of data on average vehicles driven (hard) by persons other than professional race drivers.

Not all current and past model-engine combinations have been tested, and obviously no performance data exist for future vehicles. Therefore, one must determine the a-versus-v curve for each combination by using available or projected vehicle characteristics, such as weight and power.

Research to date (3-5) suggests that the slope a_o/v_m is about the same for most vehicles--between 0.08 and 0.10/s. Moreover, little explanation can be found for variations between vehicles; the differences appear to be more dependent on test or analysis procedures than on readily identifiable vehicle parameters. A constant value (for all vehicles) of a_o/v_m = 0.085/s is suggested, since this value is about at the midpoint for current vehicles, after one accounts for possible exaggeration in the test procedures used by some organizations.

The next step involves estimating a_o as a function of vehicle characteristics. Preliminary evidence suggests that the best single parameter is the mass-to-power ratio, although better predictions could clearly be made by using additional quantities such as gear-train characteristics and aerodynamic drag. Unfortunately, since these data are not usually available, they cannot routinely be used. The most obvious model would be of the following form:

$$a_0 = \alpha + \beta(W/kg) \quad (2)$$

In fact, this is what was used in the NHTSA study (3).

A more general approach was used here. Since the quantity usually measured directly is time, not acceleration, a relation of the following form was postulated:

$$t = K(W/kg)^\beta \quad (3)$$

where t is the time required to accelerate from one speed to another [48.3-96.6 km/h (30-60 miles/h)]. This relation was made linear by using a logarithmic transformation:

$$\ln t = \ln K + \beta \ln(W/kg) \quad (4)$$

Linear regression techniques were used to evaluate K and β. The data base included 186 vehicles (1977 and 1978) reported on in various issues of Consumer Reports, Consumer's Research, Motor Trend, and Car and Driver. These data covered accelerations over different (but similar) speeds in the midspeed ranges of the vehicles. The results showed that the exponent β did not vary appreciably by publication or by speed (in this midspeed range). Moreover, β was not significantly different from the simple value -1. Thus, the following simplified expression is sufficiently accurate:

$$t = K(kg/W) \quad (5)$$

The linear regression analysis yielded K = 500.6 and a standard deviation of 6.1, which indicates a very good fit (simple Pearson correlation coefficient r = 0.83).

If the basic equation (Equation 1) is integrated over the speed range of 48.3-96.6 km/h (30-60 miles/h) and the above values of a_o/v_m and K are inserted, one obtains

$$a_0 = 1.14[(2 - e^{-42.55R})/(1 - e^{-42.55R})] \quad (6)$$

in meters per second squared and

$$v_m = a_0/0.085 \quad (7)$$

in meters per second, where R is the mass-to-power ratio. The resulting acceleration performance curves are shown in Figure 3.

POPULATIONS OF RECREATIONAL VEHICLES

The populations of recreational vehicles (RVs) were assembled by using a procedure similar to that used for passenger vehicles. The computer program described earlier was modified to match the characteristics of RVs to the characteristics of potential towing vehicles--the future passenger-car and light-truck populations.

The characteristics of RVs that are representative of the current population--including weight, engine power, frontal area, and aerodynamic drag coefficient--are given in Table 3. These data were based on surveys of RV weights recently conducted for NHTSA (13) and on published and unpublished information assembled by the Midwest Research Institute (3,4). The basic types of RVs considered were motor homes, slide-in camper boxes, camping trailers, and travel trailers. Two types each of motor homes and travel trailers were considered because the range of weights for these vehicles is much greater than that for camper boxes and camping trailers.

There are currently two opposing trends that will affect the size and weight of future RVs:

1. Owners are demanding more fully equipped vehicles, and the added features tend to increase the vehicle size and, especially, the total vehicle weight.
2. Faced with rising material costs and the public's interest in greater fuel economy, manufacturers are attempting to use lighter materials and improved designs to reduce vehicle weights.

Because the available data are insufficient to forecast either trend accurately, we have assumed that the trends will offset one another. Thus, Table 3 represents the characteristics of future as well as current RVs and RV components.

The performance of RVs, unlike that of passenger cars, must be based on two independent parameters: zero-speed acceleration (a_o) and "maximum" speed (v_m). These parameters can be determined from the combined characteristics of the RV (and its towing vehicle, if any). The zero-speed acceleration for RVs was determined from the power-to-mass ratio by using the relation previously developed for passenger cars. Greater dispersion about this relation was found for RVs than for passenger cars, but no justification for modifying the relation was found.

Maximum speed (in meters per second) was determined (4) as

$$v_m = 3.133 + 0.0977[1/(\alpha R)]^{1/3} \quad (8)$$

where

- α = $(\rho C_D A/2W) + C_{RV}$ ($s^2 m^2$),
- ρ = atmospheric mass density = 1.226 kg/m^3,
- C_D = aerodynamic drag coefficient (Table 3),
- A = projected frontal area of vehicle (m^2) (Table 3),
- W = combined weight of RV and towing vehicle (N),
- C_{RV} = coefficient for rolling resistance = 6.7×10^{-6} for speed (m/s), and
- R = mass-to-power ratio (the reciprocal of power-to-mass was used for purposes of simplification).

Certain simplifying assumptions were made in assembling the population of RVs on the road for any given year:

1. For camping trailers and travel trailers, only towing-vehicle models that represent more than 0.1 percent of total vehicle miles of travel in the year of interest were considered.
2. For slide-in camper boxes, only pickup-truck models that represent more than 0.01 percent of total vehicle miles of travel in the year of interest were considered.
3. A minimum power-to-mass ratio of 19.7 W/kg (0.012 hp/lb) was required for the combination of RV and towing vehicle, as a conservative estimate of the lower bound of the current RV population. Thus, it was assumed that future RV owners will not select a grossly underpowered towing vehicle.
4. A minimum "maximum" speed (v_m) of 72 km/h (45 miles/h) was required of the combination of RV and towing vehicle. This cutoff value was selected on the assumption that owners would not choose a

Figure 3. Acceleration performance curves for passenger vehicles.

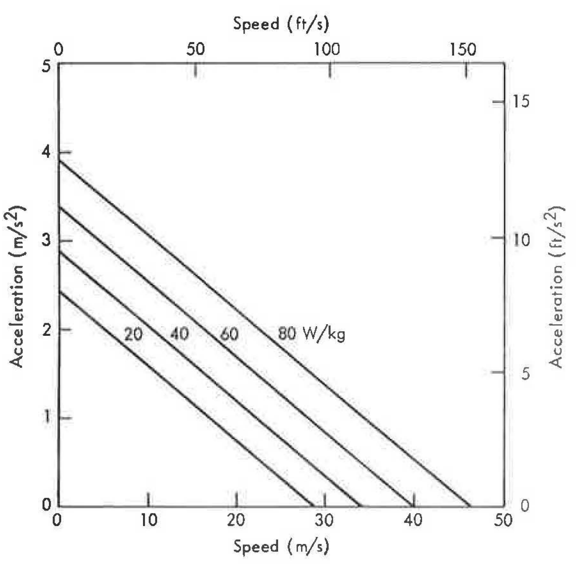


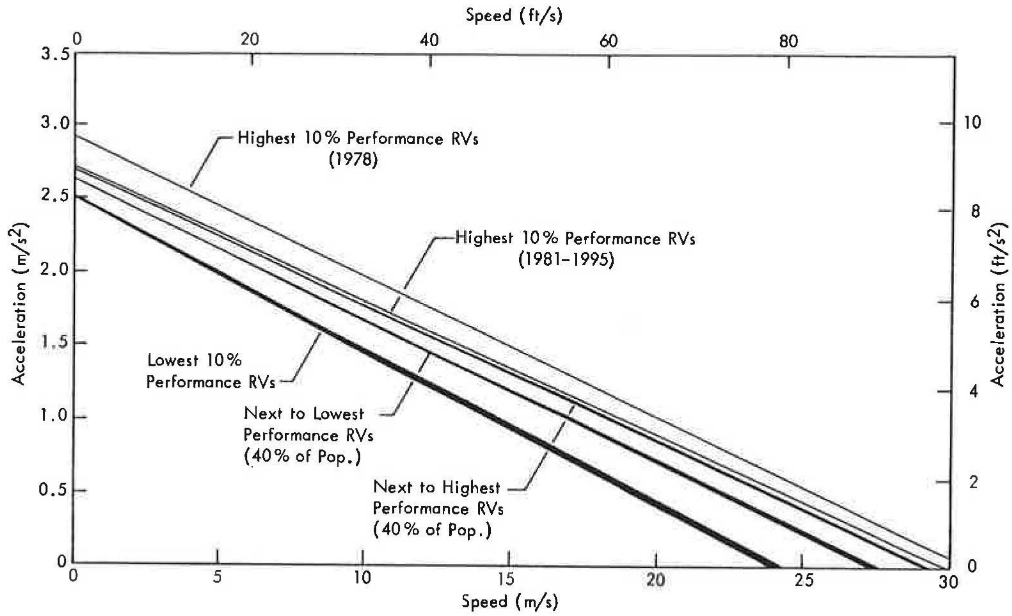
Table 3. Characteristics of representative RVs.

Type of Vehicle	Mass[a] (kg)	Power (kW)	Frontal Area (m^2)	Aerodynamic Drag Coefficient (C_D)[b]
Motor home				
1	4100	139	5.76	0.6
2	5700	167	5.76	0.6
Slide-in camper box	1400	–[c]	5.39	0.59
Camping trailer	1100	–[d]	2.60	1.1[e]-1.24[f]
Travel trailer				
1	1700	–[d]	5.95	0.59[e]
2	3000	–[d]	5.95	0.63[f]

Note: 1 kg = 2.205 lb; 1 kW = 1.34 hp; 1 m^2 = 10.76 ft^2.

[a]Including normal owner's payload.
[b]Based on the frontal area of the vehicle.
[c]Determined by the power of the light-truck population in the year of interest.
[d]Determined by the power of the passenger-car and light-truck population in the year of interest.
[e]When towed by a passenger car.
[f]When towed by a pickup.

Figure 4. Acceleration performance curves for RVs.



towing vehicle that, on level terrain, could not maintain 72 km/h--currently a typical minimum speed limit on freeways. This limitation and limitation 3 above simply imply that owners will tend to make rational decisions (as they do now) from among available options.

Vehicle miles of travel for each RV combination in the population were estimated based on past sales history, future sales estimates, and survivability for the appropriate RV type and towing-vehicle model, together with average annual vehicle miles per vehicle for each RV type and towing-vehicle model. The distribution of vehicle performances for RVs as a function of the parameters a_o and v_m was then cross tabulated (11).

It was found that the characteristics of most RVs placed them roughly along a diagonal of the tabulation, from low a_o and v_m to high a_o and v_m. This feature of the performance distribution was used to select typical RVs that represent four performance ranges: the lowest-performance 10 percent of the population, the next-to-lowest 40 percent, the next-to-highest 40 percent, and the highest-performance 10 percent of the population. Weighted averages for a_o and v_m were then computed within each RV performance range to represent typical vehicle performance in that range. This was done for five years of interest: 1978, 1981, 1985, 1990, and 1995. The resulting performance capabilities of typical RVs in those years are summarized in Figure 4.

It is apparent in Figure 4 that there is no substantial impact on RV performance characteristics over time except for the highest-performance 10 percent of the RV population, the performance of which drops markedly between 1978 and 1981 and then does not change significantly. The performances of the vehicles that represent the other percentile ranges are hardly distinguishable from year to year. This finding results in part from our assumptions about vehicles selected by RV owners; it is also consistent with the findings about future passenger-car and pickup-truck characteristics, which indicate that the performance of the highest-performance cars will diminish but that very little change will occur in the low-performance end of the mix. Essentially, cars and trucks that offer moderate performance will remain available and will be selected by RV drivers, as they are now, to avoid the limitations of vehicles that offer extremely poor performance.

CONCLUSIONS

The central finding of this study of future vehicle populations is that, based on current NHTSA presumptions, expected changes in vehicle characteristics will not be as drastic as popularly supposed.

The major changes in the distribution of the characteristics of passenger vehicles on the road, including trucks with a maximum GVW of 3860 kg (8500 lb), have already occurred or are projected to occur by 1985. The average weight of such vehicles on the highway will be 10 percent less in 1985 than in 1978 and 14 percent less in 1995. Similarly, average engine size and power will decline 25 percent by 1985 and slightly more by 1995. The power-to-mass ratio, however, will not change appreciably after 1985. This implies that, although fuel-consumption characteristics will continue to improve through 1995, little change in vehicle performance after 1985 is expected.

The reduction in average vehicle weight and power will come about through the replacement of heavy, high-powered vehicles by vehicles of more modest size and performance capabilities and not through the introduction of very small, low-powered vehicles. Thus, the future vehicle mix will be more homogeneous than it is now or has been in the past.

The findings presented in this paper are, for the most part, predicated on projected extensions of today's technology. It appears likely, however, that by 1995 substantial numbers of electric, hybrid, or deisel-powered passenger vehicles may be on the roads. This would probably further reduce average performance and fuel consumption. Again, higher-performance vehicles would be replaced by ones that provide poorer performance (but probably not poorer than that of many vehicles now in use).

Since RVs are towed primarily by passenger cars and pickup trucks, RV projections are based in large measure on passenger-car projections. The projections indicate that the highest-performance RVs will disappear by 1981 but that otherwise the performance distribution for RVs will change very little. In particular, we do not expect the appearance of RVs that provide extremely poor performance, since passenger vehicles capable of providing current minimum performance levels will remain available to RV owners.

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Headway-Distribution Models for Two-Lane Rural Highways

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The distribution of vehicle headways on two-lane, two-way roadways has been the subject of continuing research for a number of years. The growing interest in headway-generation models is related to the increased application of simulation techniques to describe traffic-flow patterns through the use of digital computers. A headway-distribution model developed for varying traffic-volume conditions (80-630 vehicles/h/lane) is described. The model was developed as part of a research project on the feasibility of using simulation techniques for depicting traffic flow on two-lane highways. A total of 18 sets of headway data (2 sets for each site) were collected from nine sites in North Carolina. The process of model development consisted of testing the field data by using a number of existing simple models and progressing with increasing degrees of complexity until an acceptable match between the field data and the model output was obtained. The study showed that none of the existing models (the Negative Exponential, Pearson Type III, and Schuhl models) provided satisfactory results for the wide range of traffic volumes tested. A modified form of the Schuhl model, incorporating parameters developed from the North Carolina data, provided the most reasonable approximation of the arrival patterns noted in the field. Parameters developed in the study are presented, along with a nomograph that can be used by traffic researchers to describe the time spacing between successive arrivals of vehicles on two-lane highways.

The distribution of vehicle headways, or the time spacing between successive arrivals of vehicles on two-lane roadways, has been a subject of continuing research for a number of years. Several past studies have attempted to describe mathematically the distribution of vehicle headways in two-lane traffic streams. The growing interest in headway-generation models is related to the increased application of simulation techniques to describe traffic-flow patterns through the use of digital computers. The development of a headway-prediction model as an appropriate descriptor of the input traffic stream is considered a mandatory requirement of any such simulation model. The importance of the headway generator, as a part of the simulation program, derives from the fact that the distribution of vehicle headways constitutes the single most important characteristic of traffic-flow patterns on two-lane roadways. The ability to accurately predict the arrival patterns of vehicle traffic by use of a headway-distribution model is thus the primary prerequisite for such a simulation model.

Drew (1), in his book on traffic-flow theory and control, discusses the theoretical concepts and practical implications of the mathematical models