Use-Related Vehicle Depreciation

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ABSTRACT

An objective procedure to determine the depreciation component of vehicle operating costs requires the identification of the time- and use-related parts of depreciation. This division can be obtained from an analysis of vehicle survivor curves. Truck survey data on vehicle use by age are used to create vehicle survivor curves. These curves are based on an analysis of 86,615 vehicles and used to produce a procedure to differentiate between time and use. Vehicle depreciation due to use is shown to be based on predicting a vehicle's maximum potential life mileage, which provides the basis for determining the depreciation component of vehicle operating costs. This use-related depreciation is a function of road surface conditions based on relationships developed in the Brazil highway costs study.

Constructing and maintaining highways require money. Increasingly economic analyses have evolved to assess the costs and benefits of proposed investments in construction and maintenance. An important part of these analyses is the determination of the vehicle operating costs to be associated with alternative investments. These costs are related to fuel and oil consumption, tire wear, vehicle maintenance and repair, and depreciation. A procedure for determining the depreciation component of these vehicle operating costs is presented.

DEPRECIATION

There is general consensus that the costs of owning a vehicle can be divided into two categories. These vehicle cost categories are termed running costs and standing or fixed costs. Running costs involve using a vehicle (i.e., consuming fuel and oil, wearing out the tires) and deteriorating the vehicle. Some of the vehicle's deterioration is corrected by investing in maintenance and repair. Such repair only retards the deterioration process because the vehicle eventually wears out, or, at an extreme, the maintenance and repair burden becomes excessive and is equivalent to recapitalizing the vehicle.

Running costs for tire wear or fuel and oil consumption are directly related to vehicle use. Maintenance and repair are not as direct because vehicle repairs can be caused by such nonuse factors as the weather and vandalism. However, most repairs necessitated by nonuse factors can be isolated, and the maintenance and repair expenditures due to operating the vehicle can be identified.

A problem exists in attempting to identify the reduction in a vehicle's capital value that is related to its use on the road. At one extreme, a vehicle may be allowed to stand idle; deterioration is due to obsolescence and environmental factors. In this case, none of the vehicle's lost capital value should be treated as a running expense.

Winfrey (1) contends that only those costs altered by operating a vehicle on the road should affect decisions related to roadway design, construction, and maintenance. It seems clear that one could purchase a vehicle and never use it on the road. It might or might not deteriorate and become scrap. The point is that it has not been used on the road, and therefore its capital value cannot be depreciated against the road as a running cost. Conversely, one can picture a situation where a vehicle is purchased and operated on the road continuously, so that the maximum possible road use is obtained before the vehicle is scrapped.

Most vehicle use falls somewhere between these two extremes. Therefore, the reduction in a vehicle's capital value is due both to using the vehicle on the road and to time-related influences. If one accepts the premise that the loss in a vehicle's capital value should be divided into a use category and a time category, the problem is to determine how to proportion this division. The next problem is to determine how roadway characteristics affect the running cost portion.

TIME AND USE COMPONENTS OF DEPRECIATION

A method is needed for dividing depreciation into a time component and a use component. The method proposed assumes that vehicles decay or become obsolete over time and that they wear out when operated on a road. In the absence of information to the contrary, the rate at which a vehicle decays due to time has been assumed constant. This is shown as the intercept t in Figure 1. The rate at which a vehicle wears out due to use depends on the severity of use, and this determines slope b of the curve in Figure 1. If the percentage of total service life that is used up in 1 year is defined as W and the annual use as m, then

$$W = t + bm$$

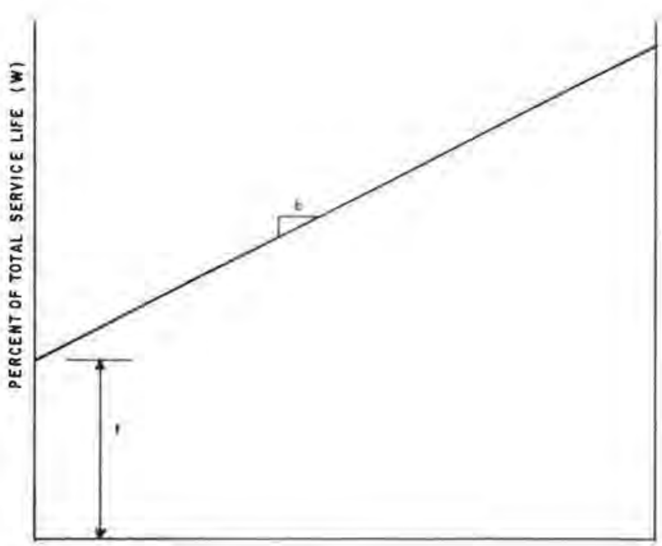

FIGURE 1 Percent of total service life related to annual use.

W is the portion of the vehicle's capital value that should be depreciated each year assuming constant annual mileage. The total capital value is unity, so the service life (SL) and the life mileage (LM) of a vehicle can be expressed as

$$SL = 1/W = 1/(t + bm)$$
$$LM = SL(m)$$
$$LM = m/(t + bm) \quad (1)$$

An examination of U.S. Truck Survey survivor data suggests that a vehicle decays or becomes obsolete due to time in 40 years. This can be defined as the vehicle's maximum service life, and t would be

$$t = 1/\text{Maximum service life}$$
$$t = 1/40 = 0.025$$

The survey data also suggest that a vehicle has the potential to be driven approximately 800,000 miles. This defines a vehicle's maximum life mileage, and the rate of wear out due to use (b) would be

$$b = 1/\text{Maximum life mileage}$$
$$b = 1/800{,}000 = 0.125 \times 10^{-5}$$

If these values for t and b are substituted into Equation 1, one obtains the curve shown in Figure 2.

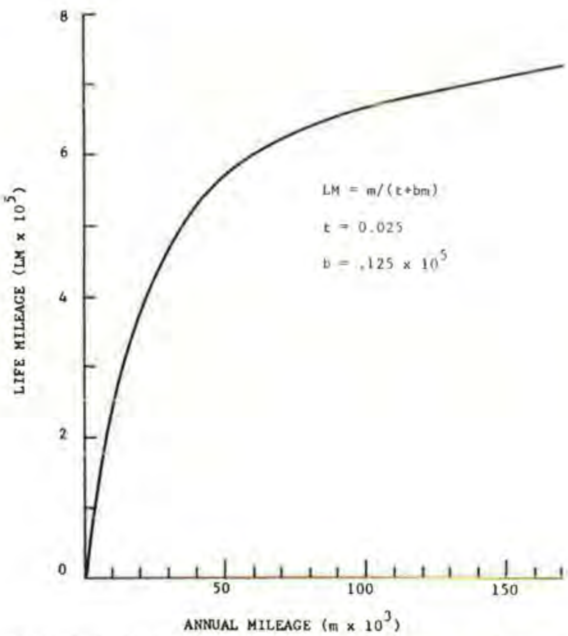

FIGURE 2 Life mileage as a function of annual mileage.

Daniels (2) has shown that the key to allocating depreciation to time and use is to determine the tangent to the curve as shown in Figure 3 and the tangent's intercept with the Y axis. Figure 3 shows how the slope and annual use define the portion of life mileage associated with time, and the intersection of the slope through the life mileage axis indicates the use-related portion of depreciation as shown in Figure 3. The derivative of Equation 1 with respect to annual mileage (m) gives the slope of the curve:

$$dLM/dm = (t + bm - bm)/(t + bm)^2 = t/(t + bm)^2$$

The slope is now multiplied by annual mileage (m) to produce T, which is divided by LM on the ordinate

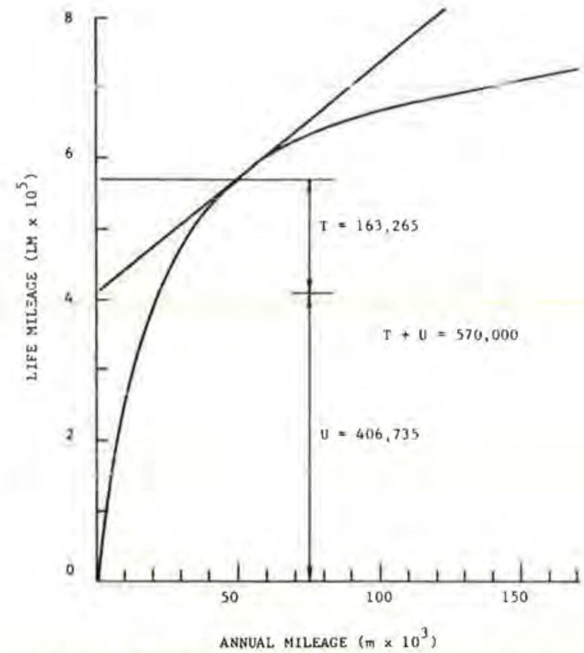

FIGURE 3 Variation of life mileage with annual mileage.

and shown to be equal to the portion of depreciation to be attributed to time:

$$T = tm/(t + bm)^2$$
$$T\ LM = [tm/(t + bm)^2]/[m/(t + bm)]$$
$$= t/(t + bm) = P_{time}$$

Because unity must be depreciated, the portion attributed to use must be P_{time} or

$$P_{use} = 1 - t/(t + bm)$$

The total capital value of a vehicle that is depreciated is normally considered to be the new vehicle's cost less scrap value and less the value of the original set of tires. This capital cost (C) needs to be divided into a use and a time component. The use portion of depreciation has been defined as P_{use}; therefore the depreciation cost per mile (D) of vehicle operation on the road is determined by dividing the portion of C assignable to road use (P_{use}) by the vehicle's life mileage (LM) or

$$D = C \times P_{use}/LM$$
$$D = C[1 - t(t + bm)]/[m/(t + bm)]$$

$$D = C[(t + bm - t)/(t + bm)][(t + bm)/m]$$
$$D = C(b)$$

This shows that only the coefficient b is needed to compute the part of a vehicle's capital value to be depreciated per mile of travel (i.e., the use component of depreciation).

DATA REQUIREMENTS

The key to determining an average b value for a class of vehicles on the road is to develop a life mileage-annual mileage curve for each class of vehicle. These curves can be constructed if vehicle fleet data are available on the distribution of vehicle age and mileage. The average service life of a fleet of given class and model year vehicles will be the average of the lives of the individual vehicles making up the fleet. However, the average service life for the fleet cannot be determined until all vehicles in the fleet have been retired from service. This occurs 30 or 40 years after the first registration of the vehicles in the fleet. Further, if a 1945 pickup truck is the model year and class being analyzed and the last 1945 pickup is retired in 1980, the average service life of a 1945 vehicle may not be a very accurate guide for predicting the service life of 1980 model pickup trucks.

Another approach is to examine the survivors in each age group of vehicles in use on a given date. By comparing the number of vehicles for each model year with the total number of vehicles of that vehicle model year that was put into service, the survival portion for the given date can be determined. This will produce a survival curve for the fleet being examined. It reflects the best available estimate of the future service life of the fleet in use at the date selected. If the pattern of vehicle service life is changing with time, there may be some inaccuracy in the prediction. A correction can be made if there are data available on the composition of the fleet for a number of recent years. The rate at which vehicles are being retired at each age can be determined, and, if this rate is not constant, a rate of change adjustment can be determined and used to improve the forecast of retirements for each age. This procedure would produce an improved and more up-to-date estimate of the expected service life for the current vehicle fleet.

TRUCK CENSUS DATA

Vehicle age and use information was obtained from the Census of Transportation, 1977 Truck Inventory and Use Survey Tape (3). The census tape was screened and vehicle records showing unacceptable life mileage or annual mileages were deleted. The unacceptable vehicles had either life mileages exceeding 4 million miles or annual mileages exceeding 300,000 miles. Only vehicles of designated model years later than 1945 and not classed as off-the-road vehicles were used.

The census tape provides a sample of the trucks on the road at a given time. The number of vehicles that enters the population each year is estimated and the number of trucks in each age category is used to establish the survival curves for the trucks on the road. From these survival curves and truck annual mileage, the average service life and average life mileage of trucks can be determined. Further, by grouping the census tape sample into different truck classifications, the average service life and average mileage for each truck class can be determined.

The vehicles were divided into five classes:

1. Light trucks [gross vehicle weight (GVW) less than 6,000 lb],
2. Light trucks (GVW 6,001 to 10,000 lb),
3. Medium trucks (GVW 10,001 to 19,500 lb),
4. Light-heavy trucks (GVW 19,501 to 26,000 lb),
5. Heavy-heavy trucks (GVW 26,000 lb or more).

Each class of truck was divided into 25 annual mileage categories. Two different summaries were created, one of annual vehicle mileage and a second of accumulated life mileage. The annual mileage was divided into 8,000-mile categories, and life miles were placed in 20,000-mile categories. Each vehicle class was summarized by age (based on model year). There were 86,615 vehicles in the sample and the number of vehicles in each class varied from 11,260 to 26,354.

LIFE MILEAGE-ANNUAL MILEAGE CURVES

Life mileage curves were created for each of the five vehicle classes identified. Average service life and life mileage can be established by constructing survivor curves based on the age distribution of vehicles currently in use, adjusted to reflect constant new registration in the relevant years. This was done in the following manner:

1. New vehicle registrations by year from 1946 through 1977 were obtained for each class of vehicle (4,5).
2. The census tape data were organized so that 25 annual mileage categories were established for each class of vehicle by age.
3. Each annual mileage category was analyzed separately and required that the distribution of vehicles be adjusted to reflect a standard level of registration before computing a survival portion. An example of the computations involved is given in Table 1.

TABLE 1 Computation Procedure for Developing Service Life Curves for Each Vehicle Class and Average Service Life and Average Life Mileage

Age (years)	Sample	Registered (in millions)	Survival Ratio/100	Survival Portion[a]	Annual Mileage	Weighted Annual Mileage[b]
1	800	3.1	2.6	1.00	15	15.0
2	700	3.0	2.3	0.88	14	12.3
3	600	2.9	2.1	0.81	13	10.5
4	500	2.8	1.8	0.69	12	8.3
5	400	2.7	1.5	0.58	11	6.4
6	300	2.6	1.2	0.46	10	4.6
7	200	2.5	0.8	0.31	11	3.4
8	100	2.4	0.4	0.15	9	1.3
9	50	2.3	0.2	0.08	8	0.6
10	20	2.2	0.1	0.04	7	0.3

[a] Average service life = 5.0.
[b] Average life mileage = 47.85.

4. The average annual mileage by age generated from the census tape was multiplied by the survival portion to get each year's contribution to the life mileage (see Table 1).
5. The sum of the survival portions for all vehicles gives the average vehicle service life for each annual mileage category.
6. The sum of the column reflecting annual mileage times the survival portion gives the average life mileage for each annual mileage category.

SERVICE LIFE-USE CURVES

The life mileage information developed from census tape data for the heavy-heavy (25,000 lb) class vehicles is shown in Figure 4. The points do not follow the curve form that was expected based on Figure 2. Actually, if the tangent is taken at the average annual mileage point for the entire population, the tangent passes through the origin, which would mean all depreciation should be attributed to time. An examination of other portions of the curve makes it clear that there are major use components of depreciation. Therefore, the tangent at the average annual mileage point for the population does not provide the desired time-use split as suggested by Daniels (2).

Service-life annual mileage data, developed from census tape data for heavy-heavy trucks, are plotted in Figure 5. This plot suggests that there may be two different curves, one for low annual use vehicles and a second for high annual use vehicles. A

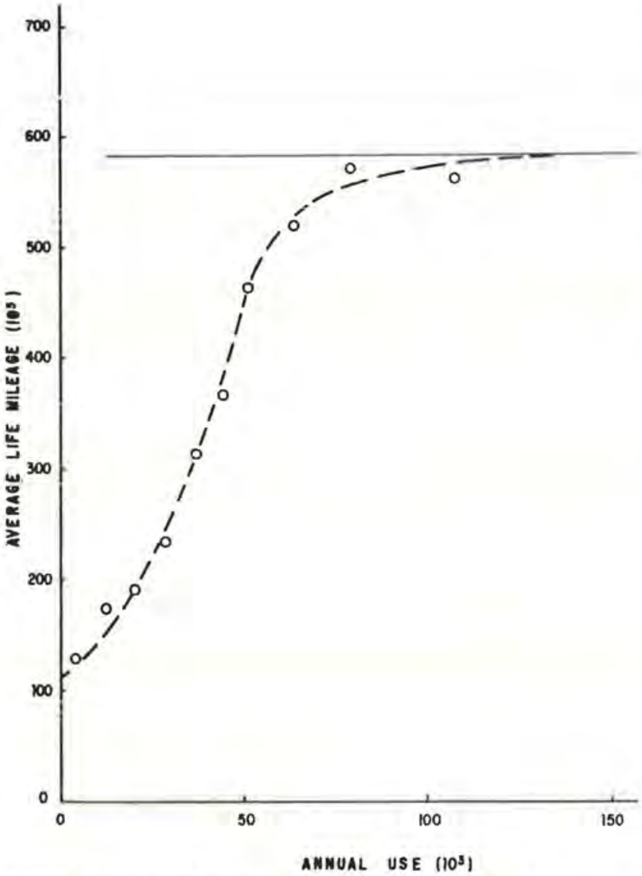

FIGURE 4 Life mileage-annual mileage data for heavy-heavy vehicles.

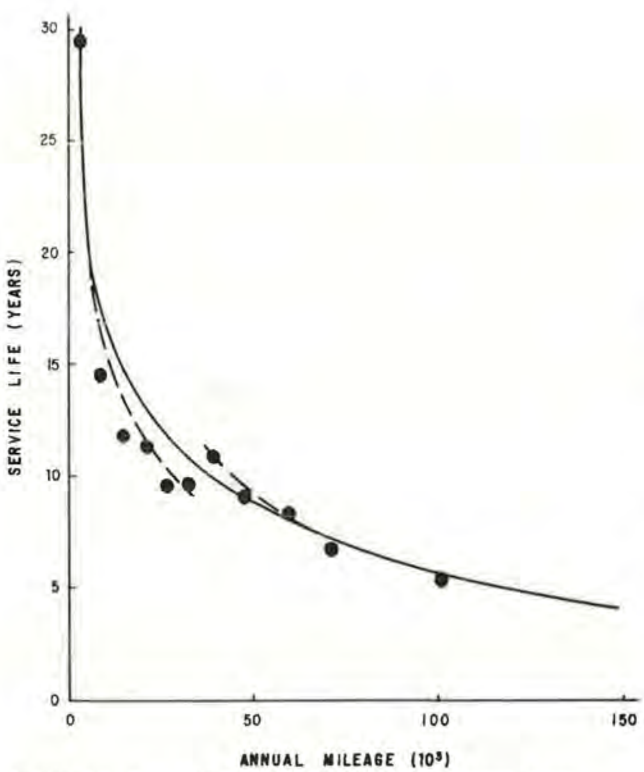

FIGURE 5 Service life-annual mileage data for heavy-heavy vehicles.

summary of the census tape data showed that the heavy-heavy vehicles could be divided into separate travel categories. Those vehicles in the local travel category had half the annual mileage of the others. Therefore, two sets of data were developed, one for local and a second for nonlocal heavy-heavy trucks. The service life data for the two travel categories are plotted in Figure 6. Although there are slight differences, the distinct separation of the local from the nonlocal, which was expected, did not materialize. Most probably, low annual use is more indicative of the factors affecting use and service life than is the designation of a travel category.

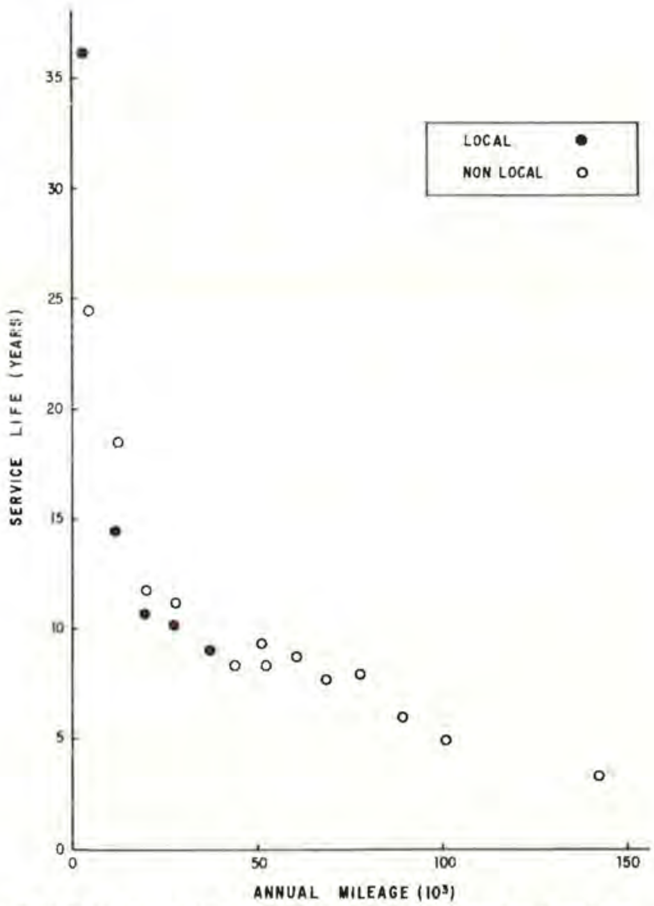

FIGURE 6 Service life-annual mileage data for local and nonlocal heavy-heavy truck operations.

A study of the plots suggested that there were different service life-annual mileage curves for low use and high use vehicles. Based on the plots, two theoretical curves were assumed. The equations presented earlier were

$SL = 1/(t + bm)$
$LM = m/(t + bm)$

where

SL = service life (years)
LM = life mileage
m = annual mileage
t = 1/maximum service life
b = 1/maximum life mileage

Based on the data plots, it was estimated that the maximum service life will be about 40 years (i.e., the service life possible with almost no use). This is vehicle deterioration due to obsolescence and environmental factors. A 40-year service life makes t equal to 1/40 or 0.025. It was also estimated that two different maximum life mileage classes would bracket the data. These were estimated to be 600,000 (curve A) and 300,000 (curve B) miles. These are the maximum life mileages possible for a vehicle not subjected to time deterioration factors. Therefore, b in the life mileage equation would be expressed as

$LM = m/bm$
$LM = 1/b$
$b = 1/600,000 = 0.167 \times 10^{-5}$
$b = 1/300,000 = 0.333 \times 10^{-5}$

Figure 7 shows service life-annual mileage plots for heavy-heavy vehicles (>25,000 lb) (3) compared with theoretical curves for 40-year maximum service life and 600,000 and 300,000 maximum life mileages (curves A and B).

Plotted in Figure 8 are curves C and D, based on the same 600,000 and 300,000 maximum life mileage values but with no time-related deterioration factor. It seems clear that including a time deterioration factor improves that data fit.

The service life information for local travel heavy-heavy trucks (3) is plotted with curves A and B in Figure 9. The first three points follow curve B closely. Starting at 20,000 miles annually, the points transition over to curve A. This suggests that trucks do not wear out as quickly through use when they average a higher annual mileage. We believe that low use reflects short trips on local streets at slow speeds under congested conditions and that longer trips are involved in higher annual mileage. Long trips are at higher, constant speeds and are made under less severe operating conditions.

The service life data for nonlocal trucks (3) are plotted in Figure 10. In this case, the points start on curve B but start transitioning toward curve A almost immediately. Therefore, the low mileage use made of nonlocal vehicles is less severe than that made of local vehicles because the former have a greater service life for the same annual mileage.

It is proposed that vehicles wear out due to both time and use. The time factor, if a constant as assumed, can be determined by identifying the intercept on the service life axis of the service life-annual mileage curve. The data plots indicate that this occurs between 35 and 45 years. The rate at which vehicles wear out because of use varies with the severity of use. On an average, low annual mileage is hard use and associated with a rapid wear-out rate. High annual mileage is associated with easy use and a much lower wear-out rate.

In conclusion, the split between the use and time component of vehicle depreciation can be determined directly from a vehicle's service life mileage-annual mileage curve. This curve reflects the type of use made of vehicles at each annual use level. A maximum service life value (t) can be estimated from the service life plot and a value for the wear-out rate can be computed directly for each annual use level.

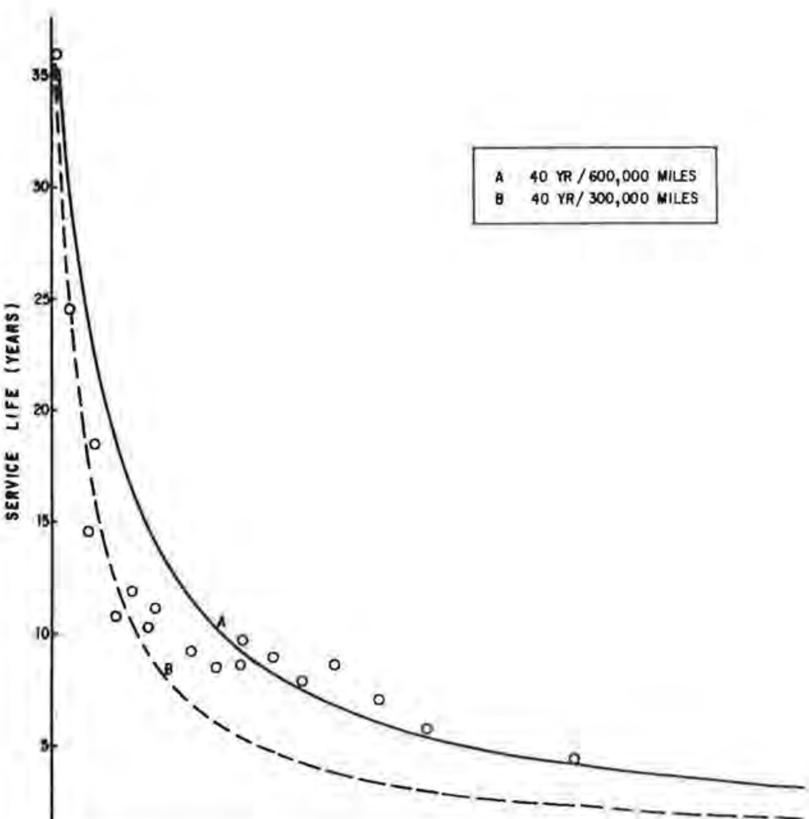

FIGURE 7 Heavy-heavy truck service life-annual mileage plots compared with theoretical curves.

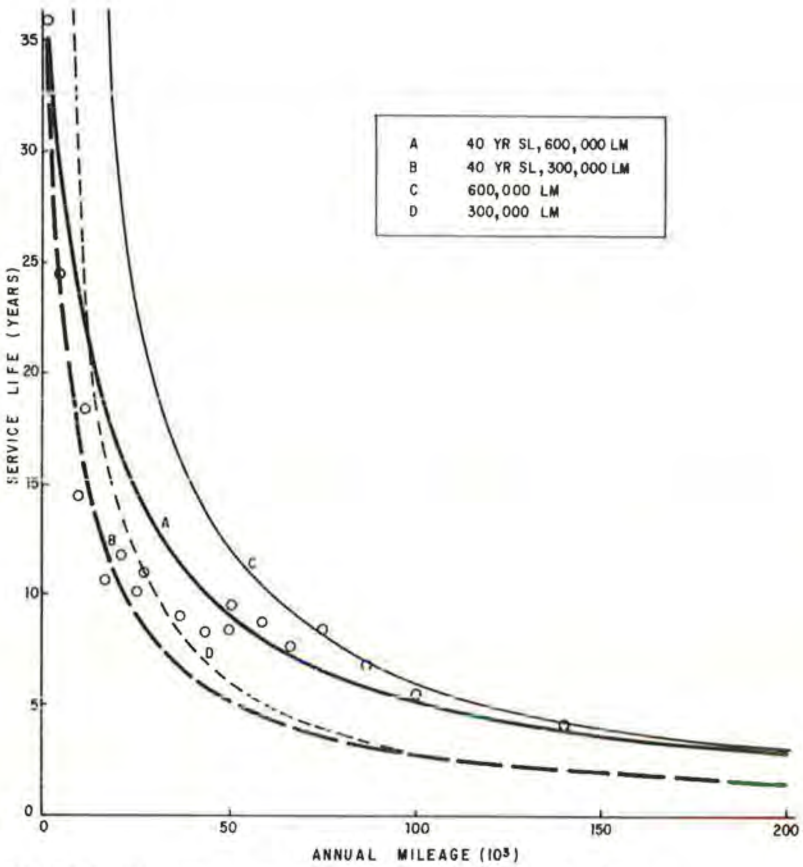

FIGURE 8 Theoretical curves relating service life to annual mileage.

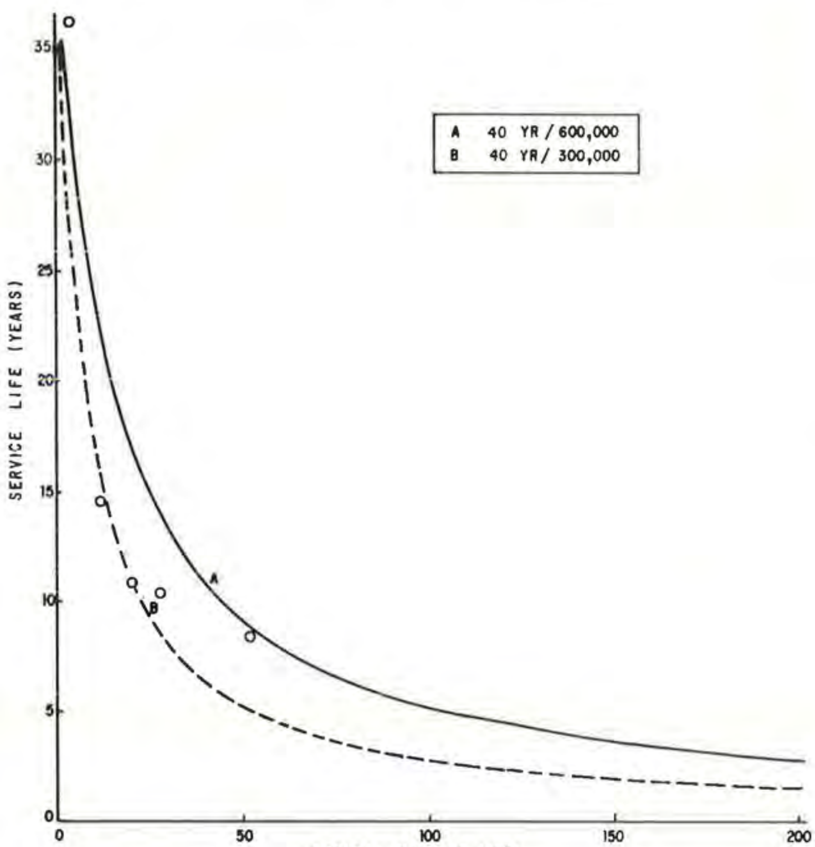

FIGURE 9 Heavy-heavy local truck service life-annual mileage plots compared with theoretical curves.

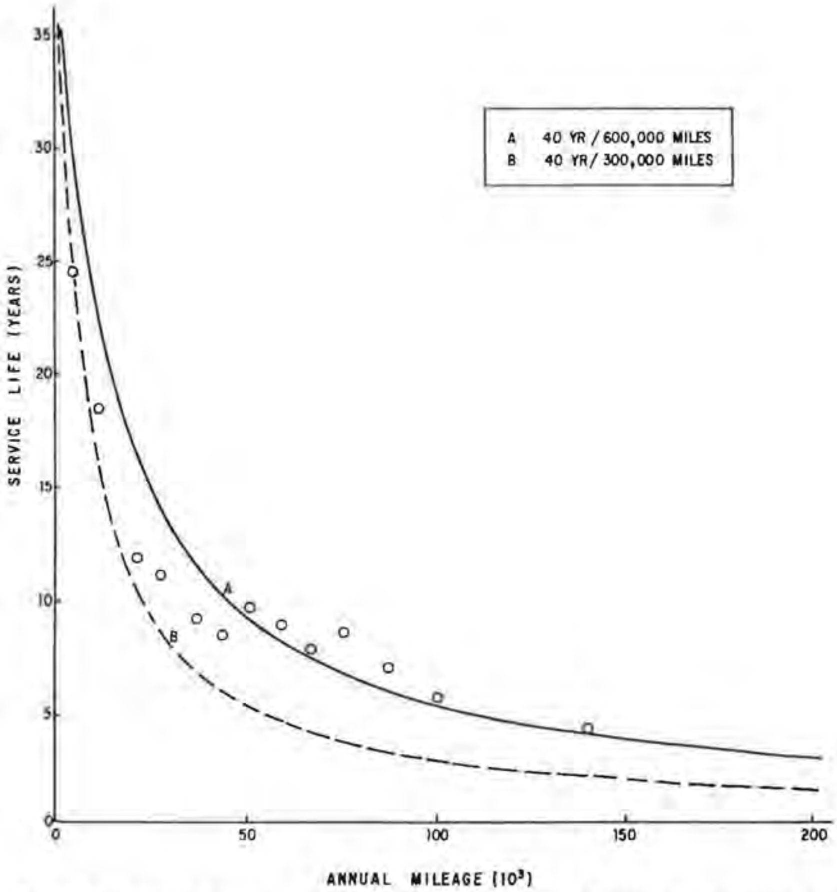

FIGURE 10 Heavy-heavy nonlocal truck service life-annual mileage plots compared with theoretical curves.

PREDICTING VEHICLE SERVICE LIFE CURVES

The service life curve for a vehicle depends on the conditions under which the vehicle is operating. Figure 11 illustrates five theoretical curves, each representing a maximum service life of 40 years and potential maximum life mileages ranging from 300 x 10^3 to 700 x 10^3. The maximum life mileage establishes the value for coefficient b in the general SL equation

$$SL = 1/(t + bm)$$

because b is the reciprocal of maximum life mileage.

The maximum service life for heavy-heavy vehicles estimated from the data falls between 35 and 45 years and was assumed to be 40 years. The reciprocal of maximum service life is t, which becomes 0.025. Therefore, the coefficient b associated with each heavy-heavy vehicle data point plotted in Figure 11 can be computed directly.

$$t/(t + bm)$$
$$SL = 1/(t + bm)$$
$$b = (1 - SLt)/SLm$$

The values of coefficient b computed for heavy-heavy trucks are shown plotted in Figure 12.

The curve drawn through the points falling between 0 and 60 x 10^3 annual mileage intercepts the ordinate at about 0.0037 x 10^{-3}. This is equivalent to a maximum life mileage of 270 x 10^3. Vehicles operating on this service life curve would be completely worn out after 270 x 10^3 miles if there were no time-related depreciation factors. This wear-out rate is the maximum indicated by the data. It is associated with heavy-heavy vehicles that operate very low average annual mileages. Such operation is thought to be under stop-go, congested conditions, which tend to wear a vehicle out more rapidly. The slope of the curve in Figure 10 is 0.37 x 10^{-4} and the average minimum b value seems to level off at about 0.0015. This value is associated with heavy-heavy trucks that achieve a high annual mileage, probably on long hauls and on good roads. No road is perfectly smooth, straight, flat, or uncongested. Therefore the data plots must reflect something less than ideal conditions. After a review of the available data, a b coefficient equal to 0.0012 was selected as the base value. This means that the maximum average life mileage for a heavy-heavy vehicle will be 833,000 miles.

The Brazil study (6) showed that annual vehicle use was a function of road roughness, geometry, and vehicle age. Increasing these factors reduced annual vehicle mileage. As annual mileage falls, so does life mileage, and reduced life mileage can mean that the vehicle is wearing out faster. Therefore, it seems reasonable to assume that vehicles operating on grades and rough roads wear out faster than those operating on smooth tangent sections of roads.

From Figure 12 it can be seen that local vehicles, which one might expect to be associated with factors that will wear them out faster than nonlocal vehicles, lie on the curve with slope -0.37 x 10^{-4}. This slope defines coefficient b as a function of annual mileage. Coefficient b for some of the nonlocal vehicles also lies on this constraining curve.

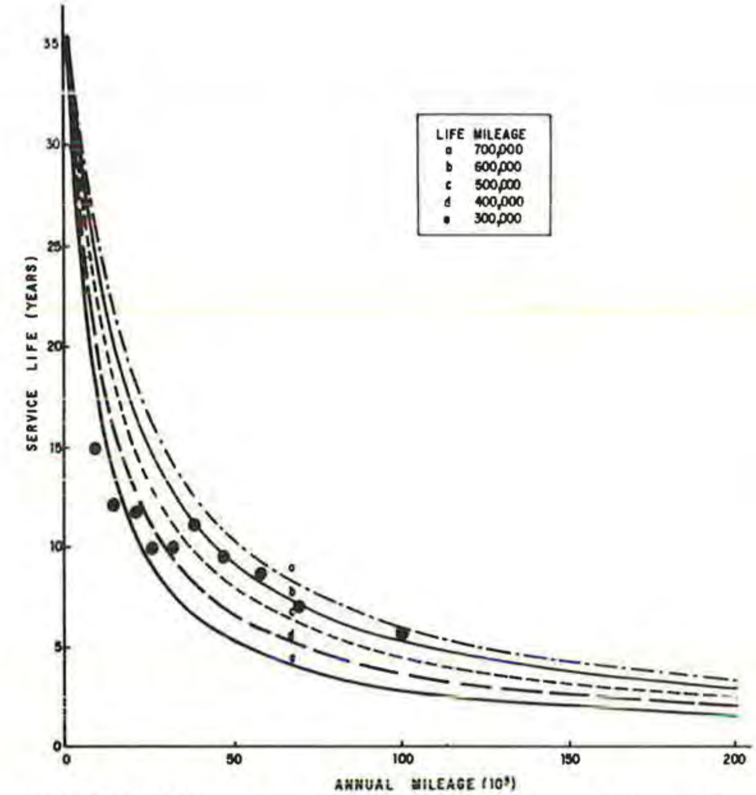

FIGURE 11 All heavy-heavy trucks compared with a series of theoretical curves relating service life to annual mileage.

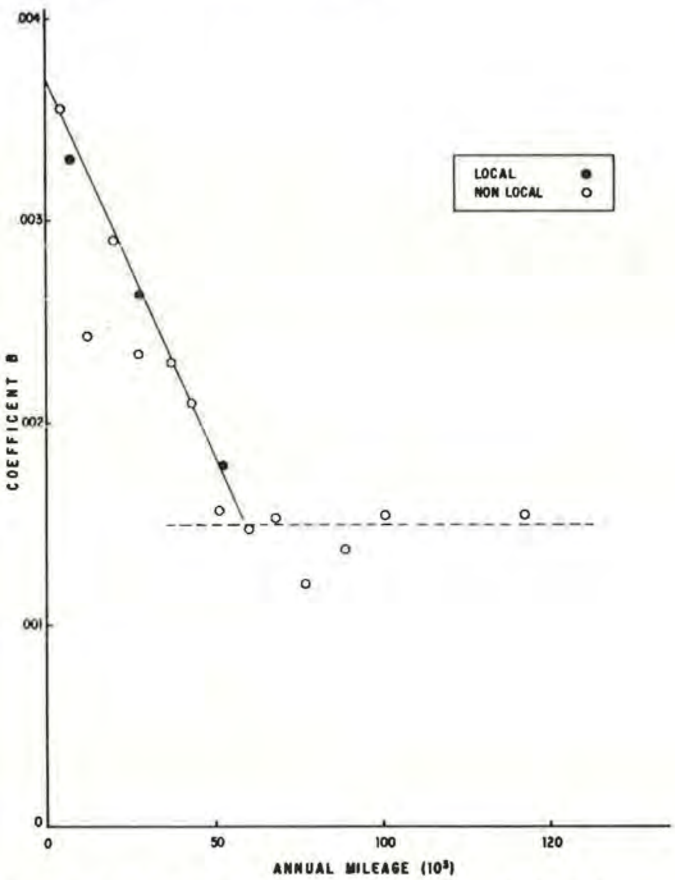

FIGURE 12 Coefficient b related to annual mileage for heavy-heavy trucks.

Other nonlocal annual mileage vehicles fall below the curve. These points may well reflect low annual mileage with no major change in life mileage, the type of mileage expected from a vehicle that is underused but not wearing out because of road factors such as roughness and geometry. Beyond an annual mileage of about 75,000 miles, coefficient b seems to level off. This suggests that there is a maximum (or optimum) average life mileage that can be pictured as slightly reduced because of overuse.

The usage equation developed during the Brazil study (6) for trucks is

$$U = e^{9.478 - 00267\,QI - 0.00193\,(R+F) - 0.0594\,AGE}$$

where

- U = monthly utilization in miles,
- QI = measure of road roughness based on Quarter car simulation over a defined profile,
- R+F = rise plus fall of vertical geometry in meters per kilometer, and
- AGE = average vehicle age in years.

If the Brazil equation is expanded for a road that is very smooth and flat for the average-age truck in Brazil, the annual mileage would be

$$U = e^{9.478 - 0.00267\,(15) - 0.00193\,(0) - 0.0594\,(4.30)}$$

$$U = e^{9.478 - 0.04 - 0.255} = e^{9.183} = 9730.30 \text{ km/month}$$

$$= 116\,764 \text{ km/yr}$$

$$= 72{,}569 \text{ miles/yr}$$

This annual mileage, if plotted on Figure 12, falls very close to the optimum coefficient b, (i.e., 0.0012×10^{-3}). Because it is believed that both roughness and geometry influence vehicle deterioration and therefore life mileage, the influence of both roughness and geometry on life mileage can be estimated by assuming that the reduction in annual mileage is due to an increase in coefficient b arrived at by projecting the reduction in annual mileage determined from the Brazil usage equation to a curve with slope -0.37×10^{4}. Therefore, we estimate coefficient b as

Assume QI = 100, R + F = 30, and AGE = 5

Then,

$$b = 0.37 \times 10^{-5} - 0.37 \times 10^{6}\,(e^{9.478 - 0.267 - 0.058 - 0.297})\,(12/1.609)$$

$$b = 0.37 \times 10^{-5} - 0.37 \times 10^{-7}\,(e^{8.856})\,(12/1609)$$

$$b = 0.37 \times 10^{-5} - 0.37 \times 10^{-7}\,(7016.36)\,(0.007458)$$

$$b = 0.0000037 - 0.000001936$$

$$b = 0.000001764$$

For these conditions the example shows that the maximum life mileage will be 566,893 miles (1/b).

SUMMARY

Vehicle depreciation was hypothesized to consist of time and use components. A service life model was proposed that contained a time component (t) and a use component (b). Data from the 1977 Truck Use Survey were used to develop service life curves that were compared with the proposed service life model. The data did not conform but indicated that the assumption of a time and a use component was correct. Further, a study of service life-annual mileage plots suggested that vehicle wear-out rates due to road use could be computed directly. This required that an estimate be made of maximum vehicle life mileage based on extrapolating the life mileage-annual mileage curve. Vehicle survival data could then be used directly in calculating vehicle wear-out rates (b) attributable to use.

Vehicle use related wear-out rates (b) were shown to be related to annual use under some conditions. By assuming that the major influence on the value of b was caused by adverse driving conditions, a procedure was proposed to predict b as a function of road geometry and road roughness.

Some of the assumptions made were tenuous but the procedure offers an approach to determining vehicle use related depreciation. Validation requires that vehicle survival and mileage information be developed for vehicle populations operating constantly on roads in various quality categories (i.e., good or poor surface conditions and low or high design characteristics).

ACKNOWLEDGMENT

This paper is based on a project that was sponsored by the Federal Highway Administration, Office of Highway Planning, Contract No. DOT-FH-11-9678 entitled "Vehicle Operating Costs, Fuel Consumption and Pavement Type and Condition Factors." The author wishes to acknowledge the assistance of John Zaniewski and Mickey Paggi who offered constructive comments and critique during the development of the methodology, Grover Cunningham who organized the data base, Robley Winfrey who explored approaches for developing use-related depreciation with the author, and Rob Harrison who critiqued the paper.

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