REPORT OF COMMITTEE ON HIGHWAY TRANSPORTATION ECONOMICS

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MOTOR VEHICLE OPERATING COSTS AS AFFECTED BY ROADWAY SURFACES

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SYNOPSIS

Changes of the last five years in the design of vehicles, in the construction of low-cost treated roadway surfaces, and in the character of vehicle traffic have made it desirable to revalue the factors previously used to estimate the relative costs of operating vehicles on various surfaces The operating cost items considered are fuel, oil, tires, maintenance, depreciation, insurance, and time

Since but few fuel consumption data are available for the present types of cars and trucks, particularly in connection with the newer types of surfaces, it is desirable to determine fuel consumption curves for typical vehicles on all common surface types In no previous research have weather and maintenance conditions been taken into consideration sufficiently to make possible accurate estimates of year around values of the cost factors

The speed of traffic on various types of roadway surfaces and the character of the traffic should be taken into consideration in determining relative vehicle operating costs The time factor, for which no data exist, should be applied to compensate for the difference in speeds Speed particularly affects fuel, oil, and tire costs

Tire costs per mile have been reduced greatly in recent years through the improvement of tires and surfaces and hence there are no test results available which can be applied to existing conditions Vehicle maintenance and depreciation have heretofore been assumed Some indication of the trend of these costs should be secured by the observation of vehicles operating on more or less regular schedules on selected types of surfaces Oil costs are known to vary with speed, but are probably independent of the surface

A few vehicle cost records are presented which indicate that the typical car is operated in the mid-west for 5 cents a mile, but no conclusion is reached for particular classes of roadway surfaces, since existing data do not permit of reliable estimates

Any differences in the cost of operating a motor vehicle over different level roadway surfaces should be manifest in the following cost items.

1 Fuel
2 Engine oil
3 Tires and tubes
4 Maintenance
5 Depreciation
6 Accident insurance
7 Time

It is the purpose of this paper to indicate the extent that these cost items may be evaluated on the basis of existing information for different classes of roadway surfaces and to suggest future studies which will permit of estimates of motor vehicle operating costs on definite classes of surfaces more reliable than those possible with existing information New studies are necessary because of the recent material changes in vehicle design, types of roadway surfacing, and character of traffic, and because many thousand miles of roads are yet to be improved

DISCUSSION OF COST FACTORS AND LITERATURE

Fuel Consumption and Power Requirements

Because of the variability of gasoline consumption, previous investigators have found it more suitable to measure tractive resistance, rolling resistance, or driveshaft horsepower than fuel consumption in tests to determine the relative fuel consumption or power requirements of road surfaces Roughness of the surface and bearing friction affect the rolling resistance as speed increases, but otherwise rolling resistance seems to be independent of speed, and dependent upon tire characteristics, temperatures, and surface conditions Except for the roughness factor, relative tractive resistances, determined under the same test conditions, remain the same for a group of surfaces regardless of the speed If power requirements are used to determine the relative fuel consumption of road surfaces, corrections must be made for the change in engine efficiency with load changes

Power requirements have been measured by the deceleration method using a space-time recorder, by coasting down grade, and electrically, results being given for specific temperatures, tire equipment, and vehicle weight and design A summary of the results of the main American investigations is given in Table I, the relative index of power requirement in each case being expressed as a ratio to the value obtained on average portland cement concrete It is realized that the value for average concrete may not have been chosen for equal surface characteristics in all of the investigations, and that the relative values may be in error. Since the investigations were carried on with different types of vehicles and tire equipment, and since some results are in tractive resistance and others in driveshaft horsepower or rolling resistance, comparisons are more easily made if the results are reduced to a common base The rather satisfactory agreement of the ratios in Table I, however, indicates that in general the relative power requirements for the classes of surfaces listed are as shown It should be noted that the ratios

TABLE I

Summary of Power Requirements of Road Surfaces

Surface and Class	Agg*			Agg†		Paustian‡			Shaw§		Moyer**
	Relative index of power requirement expressed as a ratio to the value obtained on average portland cement concrete										
	15 m p h	25 m p h	35 m p h	10 m p h	25 m p h	25 m p h	35 m p h	45 m p h	15 m p h	25 m p h	
Class I Rigid Pavements											
Concrete, average	1 00	1 00	1 00	1 00	1 00	1 00	1 00	1 00	1 00	1 00	1 00
Concrete, very good	0 82	0 84	0 90								
Concrete, rough	1 11	1 09	1 08	1 31	1 27	1 03	1 02	1 03			
Concrete, good, wet						1 15	1 11	1 08			
Asphaltic concrete, best	0 93	0 94	0 95								
Asphaltic concrete, average	1 00	1 00	1 00								
Bituminous concrete									1 00	1 00	
Bitulithic, fair to good	1 04	1 16	1 15	0 92	0 95						
Sheet asphalt, best	0 85	0 88	0 90								
Sheet asphalt, average	1 11	1 09	1 08						1 04	1 03	
Sheet asphalt, rough				1 31	1 43						
Rock asphalt, good, smooth						1 09	1 03	0 98			
Penet macadam, soft seal coat						1 18	1 14	1 11			
Brick, bit filled, average	0 96	0 97	0 97								1 05
Brick, grout filled, average	1 11	1 19	1 15	0 97	0 97						
Brick, grout filled, rough				1 26	1 10						
Class II Treated Surfaces											
Bituminous oil mat, good						1 18	1 09	1 05			
Bituminous mulch, good						1 26	1 22	1 14			
Bituminous retread, good						1 23	1 19	1 12			
Bituminous gravel, good						1 17	1 13	1 12			1 13
Bituminous gravel, fair						1 25	1 17	1 14			1 26
Bit gravel, poor, rough						1 88	1 66	1 48			
Tar gravel, good						1 28	1 27	1 22			
Sand-asphalt									1 15	1 11	
Class IV Untreated Gravel											
Gravel, good, claybound	1 30	1 25	1 20	1 05	1 05	1 31	1 27	1 18			1 42
Gravel, poor to fair	1 85	1 72	1 59	1 20	1 30						
Gravel, rough, loose spots	2 07	1 87	1 67								
Gravel, yearly average	1 67	1 56	1 46								
Gravel, frozen, fair						1 25	1 23				

* Agg (2) Space-time recorder, high pressure cord tires

† Agg (3) Space-time recorder, Dodge touring car, weighing 2720 pounds, balloon tires, 31 x 5 25

‡ Paustian (35) Gas-electric drive test car weighing 6300 pounds, 33 x 6 75 inch balloon tires

§ Shaw (38) Electric drive truck

** Moyer (31) Standard Studebaker 1932 coupe Space-time recorder

TABLE I—*Concluded*

Surface and Class	Agg*			Agg†		Paustian†			Shaw§		Moyer**
	Relative index of power requirement expressed as a ratio to the value obtained on average portland cement concrete										
	15 m p h	25 m p h	35 m p h	10 m p h	25 m p h	25 m p h	35 m p h	45 m p h	15 m p h	25 m p h	
Class IV Untreated Gravel *Continued*											
Gravel, soft, cutup						1 49	1 46				
Gravel, wet, packed						2 16	1 86	1 72			
Gravel, wet, well-packed						1 34	1 36	1 39			
Class V Natural Earth Surfaces											
Iowa earth, good	1 30	1 25	1 20	1 15	1 17						
Iowa earth, yearly average	1 85	1 66	1 67								
Iowa earth, rough				1 54	1 38						
Dirt racetrack, smooth									1 37	1 44	

generally decrease with speed, indicating that air resistance overshadows rolling resistance at the higher speeds General average ratios may be assigned as follows, using the classification of surfaces as recommended by Paustian [35]

	Relative Index of Power Requirement Ratio to Portland Cement Concrete
Class I Rigid pavements	
Excellent condition, clean, smooth, no waves	0 90
Average condition, smooth	1 00
Fair to poor condition, wavy, rough	1 15
Class II Treated surfaces	
Best condition	1 10
Average good condition	1 15
Fair to poor condition	1 25
Class III Nonskid, treated surfaces	
No data available	—
Class IV Untreated surfaces	
Best gravel surfaces	1 20
Average gravel, loose and soft at times	1 30
Poor gravel, rough, loose, soft	1 50
Class V Natural earth surfaces	
Best condition, dry, hard	1 20
Average, good to fair condition	1 45
Poor, soft, rough	1 70

There are not sufficient test results available to warrant closer approximations than these, particularly for year around averages To make possible the determination of the power requirements of surfaces within each of these five classes and to arrive at closer values, test data are needed on more surfaces of each type and over a greater range of weather and maintenance conditions and for new model vehicles of about 3,000 lb, gross road weight

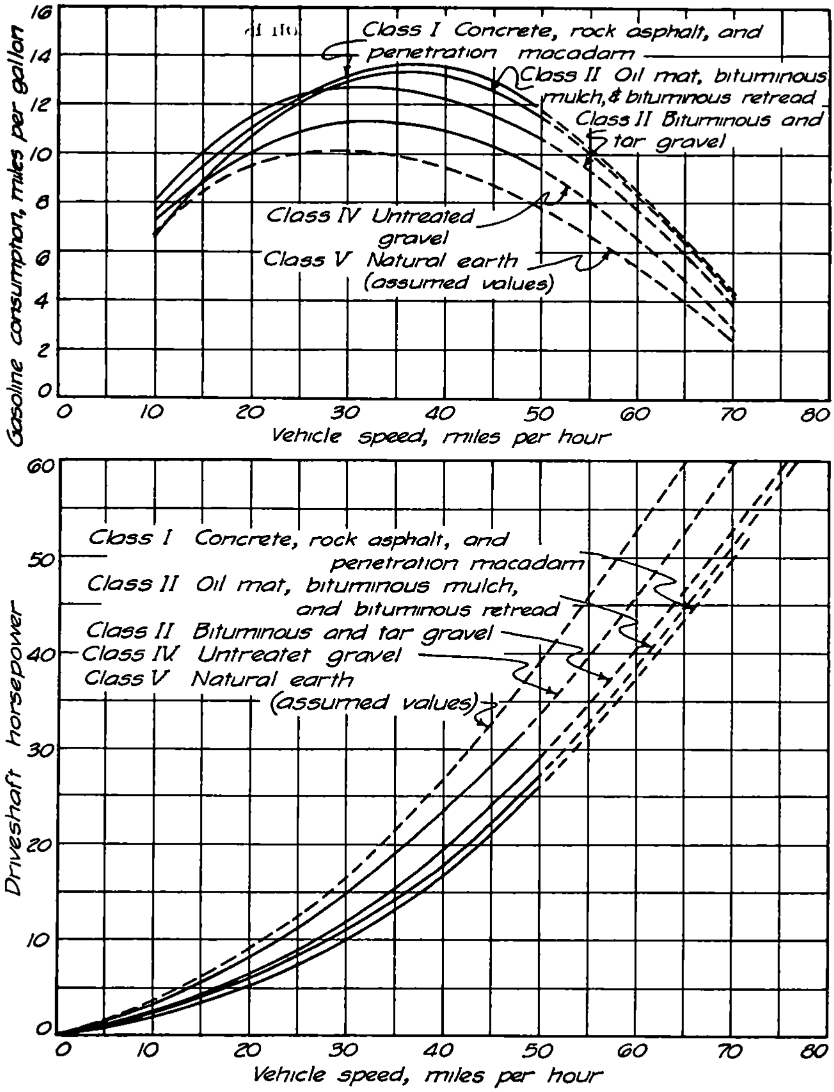

Figure 1. Gasoline Consumption and Driveshaft Horsepower Curves on Different Classes of Road Surfaces for the Gas-Electric Test Car Used by Paustian.[35]

To illustrate the use of the power requirement and fuel consumption data in calculating vehicle operating costs, the works of Paustian[35] and Moyer[31] will be discussed Figure 1 gives average driveshaft horsepower and gasoline consumption curves for Paustian's test car on Class

I, II, IV, and V surfaces Figures 2 and 3 give similar curves for the Studebaker car used by Moyer

Examination of Table II, columns (1) to (9), shows that the ratios of the rate of fuel consumption on Classes II, III, and V to those on Class I are much greater for the 6,300-lb gas-electric drive Cadillac than for the standard Studebaker A similar relation is found for the power requirement ratios, but these ratios for both cars are materially greater than the fuel consumption ratios, except for the Cadillac car at 45 miles

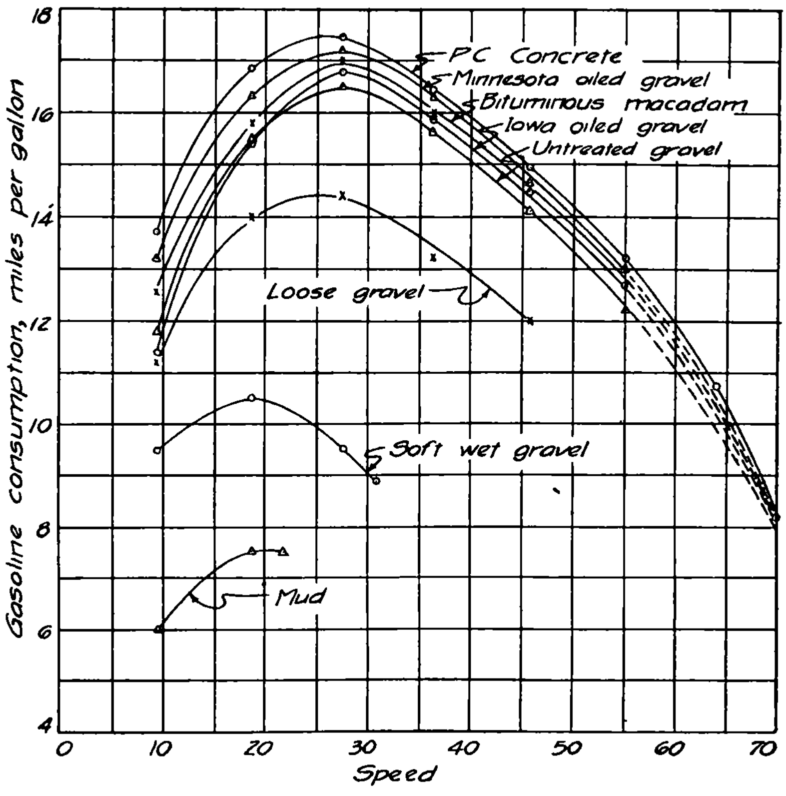

Figure 2. Gasoline Consumption Curves for the Studebaker Test Car[31] on Various Surfaces.

an hour, at which speed the fuel and power ratios are almost the same The gas consumption curves for the Cadillac gas-electric test car are rather flat, with the minimum consumption near 35 miles an hour, as contrasted with steeper curves for the average vehicle with the economical speed between 10 and 25 miles an hour

This portion of Table II shows that the relative fuel consumption of vehicles is dependent upon speed, and that if driveshaft horsepower or tractive resistance is used as a measure of fuel consumption, engine efficiency must be taken into consideration The table further shows that the fuel consumption index and the power requirement index are dependent upon the characteristics of the vehicle

Since speed definitely affects the fuel consumption index for the several classes of surfaces, it should be enlightening to determine the indexes at average road speeds for each class of surface

There is not sufficient material available from which to determine average speeds on these classes of surfaces, but the following averages

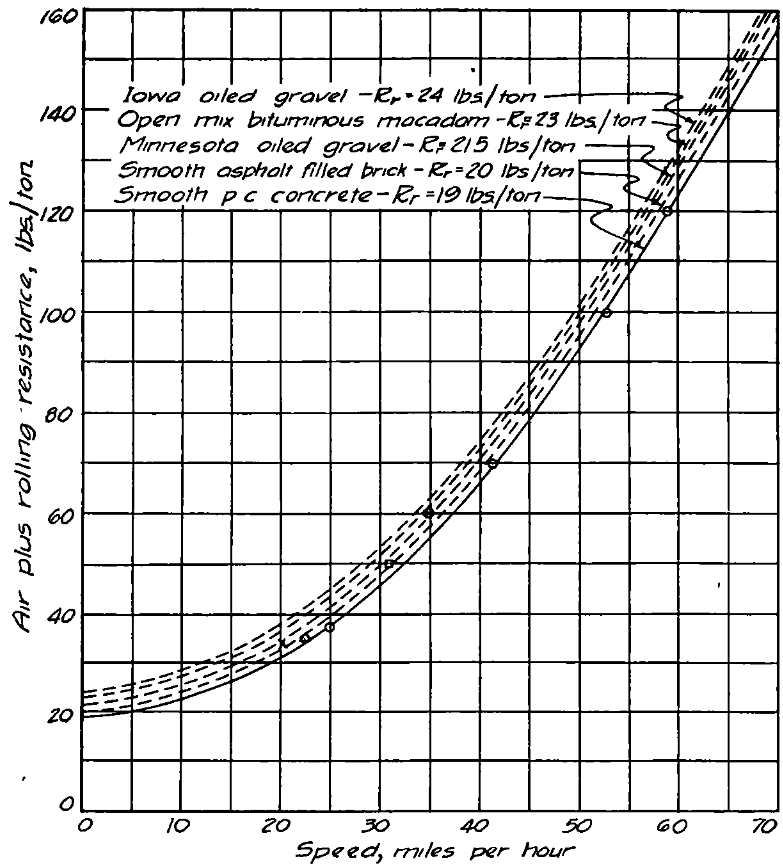

Figure 3. Tractive Resistance of the Studebaker Test Car[31] on Various Surfaces Obtained by Coasting at Constant Speed on Various Uniform Grades.

for passenger cars give an indication of relative values Obviously the condition of the surface, weather, and character of traffic (through or local) affect speeds

Traffic speed counts indicate that the average speed in miles per hour (day time and good weather but not necessarily the best surface conditions) of automobiles is as follows

	Moyer[32]	Lyon[22]	Greenshields[21]	Winfrey	Assumed average
Class I	44 0	43 3	47 8	51 9	45
Class II	—	—	41 3	41 8	40
Class IV	35 5	39 8	32 6	43 7	35
Class V	—	—	—	—	30

If the values for driveshaft horsepower and fuel consumption are taken from Figures 1 to 3 for these average speeds, the relative ratios for the two cars are as shown in columns (10) to (14), Table II

For the speeds selected as average, the fuel ratios for the Cadillac are in the same order and about the same as those computed for 35 miles

TABLE II

FUEL CONSUMPTION AND POWER REQUIREMENTS FOR FOUR SURFACE CLASSES AND TWO TEST CARS

Type of Road Surface	Basis of equal road speed								Basis of average road speeds				
	35 m p h				45 m p h								
	Gasoline Consumption		Driveshaft Horse power*		Gasoline Consumption		Driveshaft* Horsepower		Speed m p h	Gasoline Consumption		Driveshaft Horsepower*	
	m p g	Index	h p	Index	m p g	Index	h p	In dex		m p g	Index	h p	Index
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Cadillac gas-electric test car, Paustian[35]													
Class I	13 75	1 00	13 0	1 00	13 05	1 00	21 5	1 00	45	13 05	1 00	21 5	1 00
Class II	12 70	1 08	15 4	1 18	11 65	1 12	24 2	1 12	40	12 30	1 06	19 5	0 91
Class IV	11 30	1 22	19 1	1 47	10 35	1 26	28 5	1 32	35	11 30	1 16	19 1	0 89
Class V	10 05	1 31	21 5	1 65	8 85	1 48	31 2	1 45	30	10 15	1 29	16 5	0 77
1932 Studebaker Standard Coupe, Moyer[31]													
Class I	16 65	1 00	54 4	1 00	15 10	1 00	77 7	1 00	45	15 10	1 00	77 7	1 00
Class II	16 25	1 02	58 2	1 07	14 75	1 02	81 4	1 05	40	15 55	0 97	69 2	0 89
Class IV	15 85	1 05	61 0	1 12	14 25	1 06	84 0	1 08	35	15 85	0 95	61 0	0 78
Class V									30				

* Tractive Resistance, pounds per ton, for the studebaker car

an hour on all surfaces The ratios, however, for driveshaft horsepower are all less than 1 00 The fuel ratios for the Studebaker, under conditions of these average speeds, are less than 1 00, but not nearly as much less as are the ratios for tractive resistance

The study of vehicle operating costs as related to type and condition of road surface should be made on a basis of actual traffic conditions and it is evident that average vehicle speed varies with the road surface, even when the character of traffic is identical If average road speeds are used, a time evaluation is necessary to compensate for the less time on the road at the higher speeds

Insufficient data exist to permit of a more accurate comparison of fuel costs on different classes of road surfaces, and since the final savings must be in terms of fuel it is thought that fuel consumption measurements, both quantitative and rate of consumption, should be determined for the common classes of surfaces

Another method of comparing the relative fuel consumption of vehicles on road surfaces is to weight the percentage of traffic traveling at given speeds according to the rate of fuel consumption at the chosen speeds Table III gives such a calculation for the Cadillac and Studebaker test

TABLE III

RELATIVE GASOLINE CONSUMPTION CALCULATED FROM TRAFFIC SPEED DISTRIBUTION

Speed m p h	Percentage of Traffic				Rate of Gasoline Consumption, Miles per Gallon						
					Cadillac				Studebaker		
	Class I	Class II	Class IV	Class V	Class I	Class II	Class IV	Class V	Class I	Class II	Class IV
10	0 00	0 00	0 00	1 30	7 70	8 10	7 25	6 85	13 70	12 80	12 00
15	0 10	0 30	0 55	4 25	9 45	10 10	8 85	8 50	15 95	14 80	14 40
20	0 50	1 25	2 80	9 15	11 10	11 60	10 10	9 55	17 00	16 00	15 70
25	1 55	3 20	7 20	15 25	12 35	12 45	10 95	10 05	17 45	16 75	16 35
30	4 30	7 40	14 50	18 35	13 30	12 75	11 30	10 15	17 25	16 85	16 40
35	10 30	18 05	18 15	18 10	13 75	12 70	11 30	10 05	16 65	16 25	15 85
40	18 75	20 45	18 50	15 45	13 65	12 30	11 00	9 55	15 95	15 55	15 10
45	21 20	19 25	16 25	10 40	13 05	11 65	10 35	8 85	15 10	14 75	14 25
50	18 20	14 40	11 25	5 60	11 90	10 65	9 40	7 95	14 25	13 85	13 40
55	12 00	8 70	6 35	2 15	10 35	9 40	8 15	6 90	13 25	12 90	12 35
60	7 10	4 65	3 25	0 00	8 65	7 85	6 65	5 60	12 00	11 60	11 15
65	3 65	1 85	1 20		6 70	6 05	4 90		10 45	10 10	9 65
70	1 60	0 50	0 00		4 50	3 90	2 90		8 65	8 35	8 05
75	0 60	0 00									
80	0 15										
85	00 00										
Weighted rate of fuel consumption					11 91	11 42	10 38	9 53	14 58	14 86	14 83
Fuel consumption index					1 00	1 04	1 15	1 25	1 00	0 98	0 98

cars and the traffic speed curves shown in Figure 4. The fuel consumption indexes for the Cadillac are almost identical with those in column (12) of Table II for the speeds of 45, 40, 35, and 30 miles an hour for the four classes of surfaces. For the Studebaker, however, the results are different than any of those in Table II

No quantitative value should be placed on the foregoing analyses because of the limited data available and the assumptions that were made, particularly regarding traffic speed and its distribution Also, the surfaces tested by Paustian and Moyer were not the same and the Cadillac car had a gas-electric drive These analyses are not offered to show the economy of operating motor vehicles over any particular surface, but to suggest types of analyses that should not be overlooked, since they take into consideration, engine efficiency and traffic conditions

The methods, nevertheless, are believed to be sound and if applied to sufficient test data should result in accurate determinations of the relative fuel consumption of vehicles when operating on different types of road surfaces

The gasoline consumption curves of several cars and trucks driven on level concrete given in Figure 5, indicate the range of such curves and show that the Cadillac and Studebaker curves discussed herein are not very commonly found

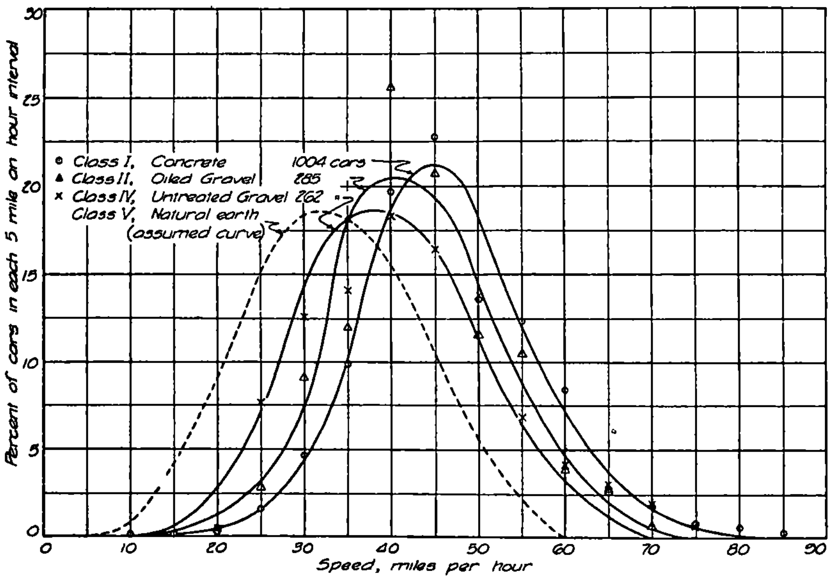

Figure 4. Distribution of Traffic on Iowa Highways according to Speed. Observations by Moyer and Winfrey 1933 and 1934.

Summary on Fuel Consumption and Power Requirements

Existing information on relative power requirements of road surfaces is adequate for speeds up to 45 miles per hour for a few particular surfaces under particular conditions

Data are insufficient for most of the newer types of low-cost surfaces, and for all surfaces under year-around conditions of weather and maintenance

Existing data do not show any definite relationship between speed and rolling resistance, nor the roughness factor

Fuel consumption curves need to be determined for all surfaces under year-around conditions of weather and maintenance and for all common types of vehicles for speeds up to 80 miles an hour

Traffic speed counts are lacking for most surfaces and classes of vehicle traffic.

No data of the foregoing character are available for truck traffic

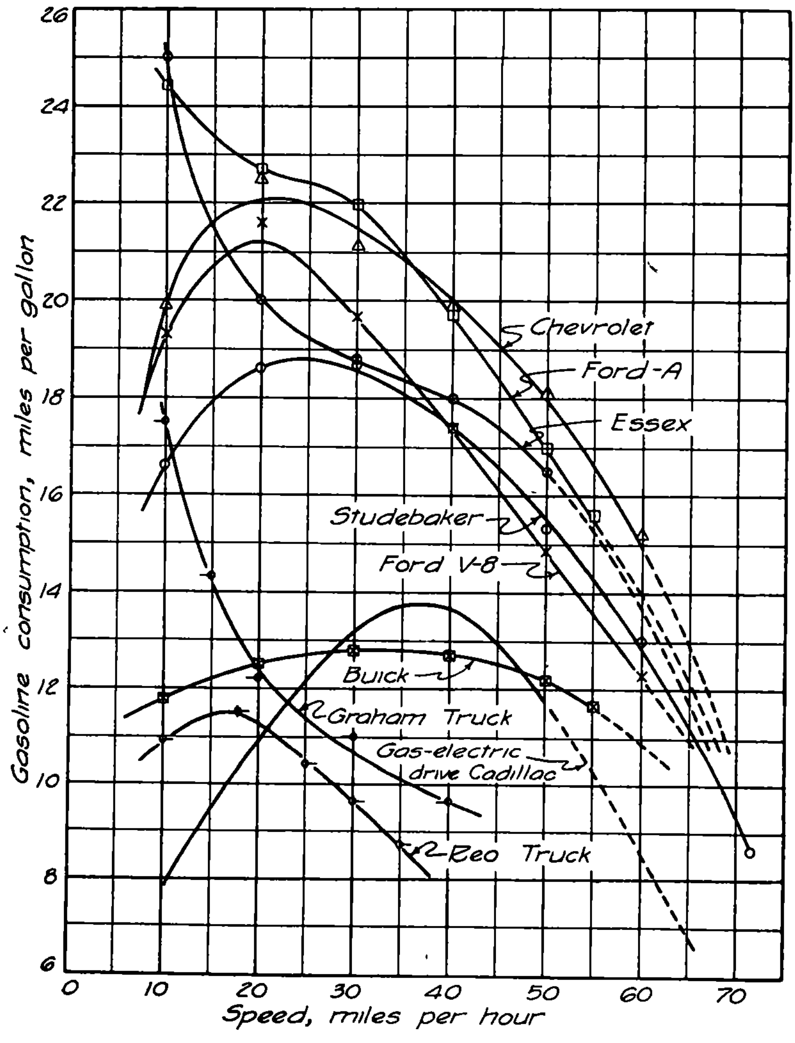

Figure 5. Gasoline Consumption of Typical Cars on Concrete

Oil Consumption

The power requirements of road surfaces probably have no effect upon the consumption of lubricating oil, but oil consumption does increase with engine speed and average speeds of traffic vary with the condition of road surfaces Since the increased speed is made possible by improving the surface, the resultant increase in oil costs should be charged to the improved surface

The rate of oil consumption is controlled largely by the engine speed, type and condition of the engine, and character of oil Figure 6 gives typical curves taken from several sources as presented by Graves [20]

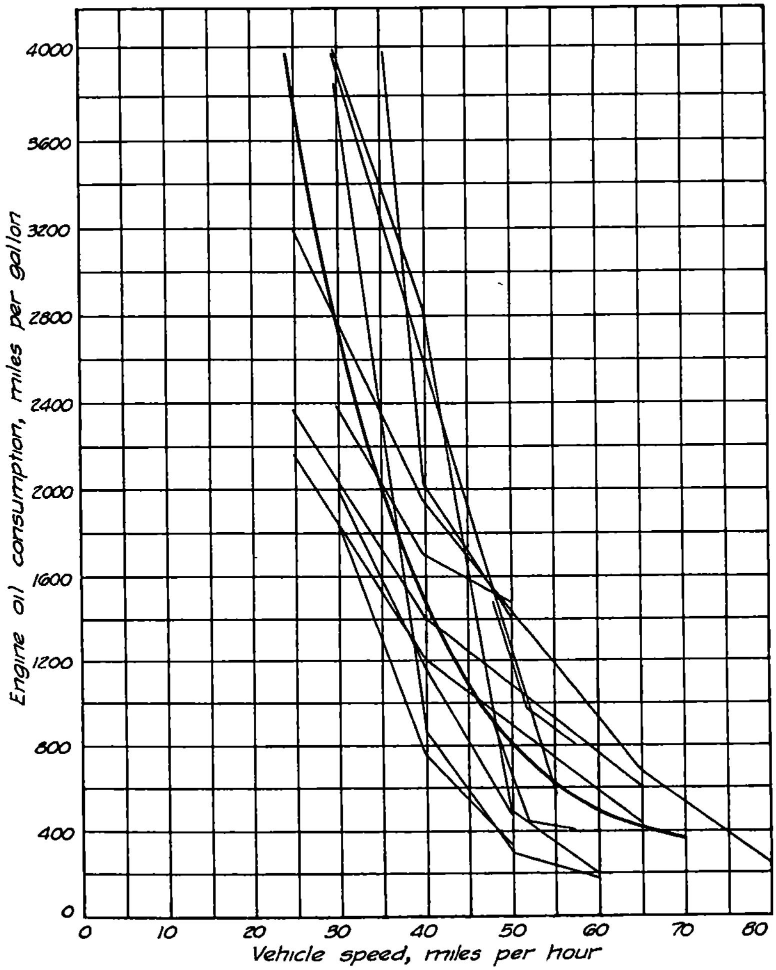

Figure 6. Engine Oil Consumption for Several Automobiles and Grades of Oil. (After Graves.)

These curves show a wide range in oil consumption but always a definite increase with speed At 45, 40, 35, and 30 miles per hour the relative oil consumption is 1 00, 0.73, 0 54, and 0 39, respectively. Thus, at 45 miles per hour the oil consumption is almost twice that at 35 miles per hour.

Summary

Assuming that oil consumption does not increase with driveshaft horsepower, but that it is more nearly proportional to speed, existing data are sufficient to determine the relative oil costs on various classes of surfaces.

Additional search should be made to show whether speed alone is a satisfactory index of oil consumption.

Tire and Tube Costs

Tests show that on certain road surfaces tire treads wear much faster than on others. Such tests, however, have not determined the total loss in value of tires with mileage, since the effects upon the carcasses and tubes were not determined. As indicated in the discussion of fuel consumption, speed has an effect upon the rate of tire wear, and the speed differential on various types of surfaces should be taken into consideration when determining the relative tire costs for different surfaces

Tire tread wear tests at the University of Kansas,[23, 24] at the State College of Washington[12, 14, 15, 41, 42] conducted in 1924, 1925, and 1926, and by the Portland Cement Association[7] in 1930 constitute the main literature on tire wear tests

The 1924 and 1925 studies are of little value in determining relative wear under today's conditions for they were run with high pressure tires at 35 miles per hour or less The Portland Cement Association tests[7] were valuable in developing methods of tests, but only two surfaces were studied.

Professor McNown[24] summarizes his 1926 tests as follows for 30 x 5.77 balloon tires on a 1925 model Dodge touring car, at 78°F. air temperature, and 35 miles per hour:

	Wear Index	Test Mileage
Concrete, excellent	1 00	401
Concrete, fair	1 56	805
Brick, excellent	0 87	441
Sand-clay, good	0 35	309
Gravel, good	0 55	600
Penetration macadam, fair	1 29	328
Asphaltic concrete, good	0 92	510

These tests are significant in so far as they show materially lower wear on untreated surfaces than obtained in his earlier work with high pressure tires Test mileages are insufficient to establish reliable coefficients as illustrated later by tests by the Iowa Engineering Experiment Station of 1930, and heretofore unpublished. Also, since a fair concrete is given a wear index of 1 56 as compared to excellent concrete of 1 00, there is considerable question as to the proper value to assign to average concrete Tire wear on concrete surfaces is greatly affected by the aggregate in the concrete and the surface texture

Professor Dana's 1926 tests[15] with balloon tires at 30 miles per hour resulted in the following:

	Wear Index	Test Mileage
Concrete pavement, 2 to 5 years old	1 00	3,431
Oil-treated crushed basalt, smooth and hard	0 28	1,200
Crushed basalt macadam, very little loose material	3 83	6,683

Since these tests on concrete were run on a course only 9 miles in length, they may not apply very generally to average concrete The test mileages are sufficient to establish reliable coefficients except in the case of the oil-treated crushed basalt It is doubtful if the low coefficient of 0 28 for this surface represents an average value

The Portland Cement Association tests at 40 miles per hour resulted in a coefficient of 1 00 for good concrete, and 1 81 for a "nonskid" type asphaltic concrete. Test mileages were 3,088 6 and 3,523 3, respectively Tread wear in these tests was by measurement of the tread depth and is recommended by the authors as more reliable than the weighing method The two coefficients given are accurate for the two particular surfaces, but they should not be taken as general values for these two types of surfaces

In 1930 the Iowa Engineering Experiment Station ran a series of wear tests of balloon tires at 35 pounds pressure on concrete and gravel surfaces on routes in all directions from Ames and as much as 120 miles distant The general road speed was 35 to 40 miles per hour and driving was under traffic conditions throughout the day Table IV gives the results.

Since these tests were run at intervals between April and September, over surfaces in many Iowa counties under all degrees of maintenance, the results should be a good index for the relative tire wear of concrete and gravel. The wear on gravel was 1 36 times the wear on concrete

Attention is called to the variation in wear as measured on individual test runs of about 500 miles These differences may be due to errors in weighing and climatic conditions, as well as to differences in road surface and driving conditions, but they serve to indicate the desirability of conducting tire wear tests over many miles of surfaces in all stages of maintenance and under year around weather conditions

Tire wear tests have been conducted with several types of vehicles and tires under a wide range of weather and surface conditions and a comparison of the relative wear of surfaces is difficult The 1925 and 1926 results indicate that tire wear with high pressure tires is not the same as with balloon tires, particularly on surfaces having loose material The condition of the surface at the time of test affects the wear greatly, and, as a result, many tests on a large number of surfaces are necessary to determine the normal averages

TABLE IV

TIRE WEAR TESTS AT AMES, IOWA

20 x 5 25-inch balloon tires at 35 lb pressure, car weight, 3000 lb Nominal road speed, 35 to 40 m p h Average speed 30 m p h (approx)

Date 1930	Run No	Aver Air Temp Deg C	Miles Driven	Tread wear, four tires		Surface Condition
				Total Grams	Grams per 100 miles	
			Gravel Surfaces			
April 18, 19, 21	1-G 1	11 8	552	26 1	0 047	Fair
April 30, May 1-2	1-G 2	22 8	502	39 8	0 079	Good
	2-G 3		478	72 3	0 151	Good
May 6–8	2-G 4	18 1	571	56 7	0 099	Wet and damp
June 13–14	2-G 5	23 1	449	25 3	0 056	Wet and rough
June 16–18	1-G 6	23 6	497	66 9	0 135	Rough
June 30, July 1-2	1-G 7	25 5	522	91 1	0 175	Rough
Sept 12–13	2-G 8	32 6	500	77 2	0 154	Rough
Sept 15–16	1-G 9	20 8	500	59 9	0 120	Rough and loose
Sept 17–18	2-G 10	28 5	500	75 7	0 151	Rough and loose
Sept 19–20	1-G 11	23 8	500	61 1	0 122	Rough and loose
Total			5571	652 1	0 1171	
Dec 29–31, 1930	2-G 12	−3 8	508	33 9	0 067	Rough, frozen
Jan 1–3, 1931	1-G 13	2 0	508	34 4	0 068	Rough, frozen
Jan 3–6, 1931	2-G 14	0 1	495	31 3	0 063	Rough, frozen
Jan 7–12, 1931	1-G 15	2 2	501	16 8	0 039	Rough, frozen
Total			2012	116 4	0 058	
			Concrete Surfaces			
May 20–21	1-C 1	19 0	516	37 6	0 073	Average concrete
May 14–16	2-C 2	13 1	518	40 0	0 077	Average concrete
May 17–19	1-C 3	11 1	342	32 7	0 096	Average concrete
May 20–21	2-C 4	28 0	362	28 7	0 079	Average concrete
	1-C 5		448	37 0	0 083	Average concrete
June 2–4	2-C 6	25 8	443	55 1	0 124	Average concrete
June 10–12	1-C 7	24 2	517	64 0	0 124	Average concrete
June 19–20, 27–28	2-C 8	28 8	436	29 8	0 068	Average concrete
Sept 21–22	2-C 9	26 0	525	39 7	0 076	Average concrete
Sept 23–24	1-C 10	29 5	501	31 7	0 063	Average concrete
Total			4608	396 3	0 086	

Ratio of wear on gravel to wear on concrete $= \frac{0\ 1171}{0\ 086} = 1\ 36.$

The recent work by Moyer on coefficient of friction[30] and that by Paustian on tractive resistance[35] indicate the variability of surfaces of a given class. Tire wear varies similarly, and should be measured under the same test conditions.

Deficiencies in previous tire wear tests may be summarized as follows:

The number of test miles has been insufficient to determine reliable coefficients.

In general, only a limited number of surfaces have been tested and these under only one condition. All-year tests would be better, since the coefficient of friction tests by Moyer indicate that the surface resistance to braking is affected by both moisture and temperature

There are no data available showing relative wear at speeds greater than 35 miles per hour, except on one concrete surface compared to one "nonskid" asphaltic concrete surface The newer types of low cost and stabilized surfaces have not been tested

Previous tire wear tests do not apply to the quality of tire manufactured today, nor to the low pressure balloons. The best available tire wear data are for high pressure cord tires

With the exception of the 1930 Iowa tests, all previous tests were conducted on comparatively short test courses at constant speeds, thus the effects of accelerating and braking have been eliminated, as have the variables due to construction methods and maintenance

No test data are available for truck tires

Future tire wear tests should determine the relative wear at speeds from 20 to 80 miles an hour

Vehicle Maintenance Costs

There are no available data to indicate the effect of road condition on the general maintenance cost of a vehicle Engine maintenance is probably more nearly proportional to total revolutions and speed than to the power developed or rate of gasoline consumption Chassis and body maintenance are perhaps somewhat proportional to gasoline consumption because of vibrations, but they are more directly proportional to the character of the road surface It is established (but not quantitatively measured) that oily, gravelly, rough, and muddy surfaces are much harder on vehicle maintenance than smooth, rigid surfaces This is almost wholly because of the dirt and excessive vibrations which are absent on the smooth, rigid surfaces

It is thought that rigid bodies and frames, rubber cushioning, springing, painting, and general improvements have so reduced the costs of maintenance that the increase on lower types is less than the rate of fuel consumption increase Certainly, batteries, lighting, anti-freeze, brakes, and washing would not so increase

Vehicle Depreciation

It is well known that the automobile retail trade values motor vehicles according to age and not according to mileage. Under the NRA code, not even the physical condition of the car was given consideration on a trade-in. This same retail market depreciates a car to junk value in less than the average life (7 to 8 years) of cars However, few cars, in satisfactory operating condition, are junked regardless of their age. Mileage and physical condition, therefore, as well as obsolescence, determines their total life

At equal speeds on all classes of roads, it seems reasonable that the smooth, more rigid and weather-proof surfaces would permit of driving vehicles on them a greater life mileage than the rough, flexible, and weather-affected surfaces For this reason, Class I surfaces should result in less vehicle physical wear than other surfaces

At the actual average road speeds, the depreciation on the lower type surfaces should be less, since the slower speeds should be less severe on the car. On the other hand, if life mileage is considered rather than life years, it is possible that the depreciation cost in cents per mile, would not be less at the lower speeds, since less total mileage would be driven before the car was discarded because of obsolescence However, these differences are largely because of the nature of car owners rather than because of the road surface conditions The real difference would be measured by the mileage obtained by identical vehicles under identical operation throughout the same period over the different types of surfaces

On a time basis the depreciation would be the same regardless of the surface, but on a mileage basis, the depreciation cost per mile would be less on the high type surfaces, because of the probable greater total mileage driven before the car would be junked

Summary

A study of mileages of cars in typical sections of the country would possibly cast some light upon the subject

No literature is known which gives the facts of experience so far as the depreciation rate is concerned

Accident Insurance Costs

Improved roads have a tendency to concentrate the traffic and increase the average road speed, both of which have led to a higher accident rate on good roads and a consequent higher insurance cost to the car owners. Insurance rates for public liability, property damage, and collision have increased in accordance with the increase in accident rate, but the insurance cost per vehicle mile over the road may not have been increased because of the increase in volume of traffic In any case, the car owners in the insurance territory in which main-traveled highways exist pay an insurance rate greater than that paid by the owners in less congested areas

Summary

Perhaps the insurance companies could assemble pertinent data on which to base a conclusion as to whether there is justification in a higher vehicle insurance charge for the higher type surfaces as compared to the lower types

In any case, insurance companies are certain that fast driving and congestion are directly responsible for accidents

Time Evaluation

At the eighth annual meeting of the Highway Research Board, Agg stated, "It is becoming more and more apparent, that before it is possible to make an adequate statement of, or formulate an adequate principle upon which to base an estimate of, the value of road improvement, it will be necessary to take into account the value of time to traffic This is something intangible and upon which there is likely to be considerable difference of opinion and apparently little basis for a dogmatic statement "[5]

As yet no one has attempted a complete evaluation of this time factor, though with the traffic speed counts and traffic surveys available, progress along this line should be possible Certainly, time must be evaluated if comparative costs are to be determined on the basis of actual road speeds as is suggested herein In the cases where the roads are not passable throughout the year, for either passenger car or truck traffic, time evaluation is an important factor It is especially important if relative speeds are considered

It is suggested that studies be instituted on this subject Existing data on average speed, traffic analysis, tractive resistance, and weather should afford a starting basis

Vehicle Operating Costs

Vehicle operating costs are not known as accurately as desirable, because of the material change in traffic during the past four years Bulletins 106 and 114 of the Iowa Engineering Experiment Station[43, 44] are the best sources at this time, but Bulletin 106 does not cover the newer types of cars, and Bulletin 114 does not deal with trailer equipment nor trucks heavier than 5-ton capacity

Table V gives a few cost records recently collected by the author These reports indicate that the per mile cost for cars is less than four years ago, particularly for tires and maintenance Table VI shows estimates of the cost of operating the composite Iowa car under 1934 conditions, as compared with results previously given by the author[43] and Agg and Carter [6] Five cents a mile is a fair estimate of the present total cost of operating average cars in the mid-west

For the purpose of comparing the relative economy of various road-

TABLE V

CAR OPERATING COST RECORDS, CENTS PER MILE

Item	Ford Model A 1929 Sport Coupe	Ford Model A 1930 2-Door Sedan	Pontiac 6 1928 Coupe	Ford V-8 (Fleet)	Essex 6 1929 Coach	Oakland 1929 Sedan	Hudson 6 1929 Sedan
1 Gasoline	1 055	0 953	1 288	1 17	1 284	1 438	1 154
2 Engine Oil	0 223	0 203	0 183	0 18	0 230	0 280	0 264
3 Tires and tubes	0 125	0 123	0 204	0 16	0 230	0 149	0 179
4 Maintenance	0 586	0 493	0 943	0 37	0 815	1 694	0 488
5 Depreciation, 15% per year	1 585	0 780	1 517	0 79	1 300	2 512	2 040
6 License	0 269	0 117	0 226	0 05	0 159	0 254	0 220
7 Garage	0 561	0 312	0 559	0 18	0 528	0 478	0 363
8 Interest, 6%	0 328	0 218	0 379	0 14	0 364	0 581	0 596
9 Insurance	0 354	0 146	0 476	0 13	0 313	0 410	0 324
10 Total Cost	5 086	3 345	5 775	3 17	5 223	7 796	5 628
11. Gasoline, gallons	1,669	3,164	3,220		3,176	4,320	4,477
12 Gasoline, miles per gallon	18 71	18 24	13 64		15 68	12 19	13 29
13 Engine oil, quarts		493	332		411		559
14 Oil, miles per quart		117 1	132 2		121		106 4
15 Operation period	1929–33	1930–34	1930–34	1932–33	1929–34	1928–34	1930–34
16 Years operated	3 64	4 67	6 0		5 00	5 27	4 54
17 Miles operated	31,223	57,717	43,910	7,363,183	49,810	52,674	59,500
18 Average annual mileage	8,578	12,360	7,318	23,000	9,962	9,995	13,110
19 Cost new, dollars	653	600	740	550	864	1470	1782
20 List weight, pounds	2,285	2,375	2,435	2,500	2,639	3,305	3,825

way surfaces, however, it is desirable to know the operation costs on surfaces of definite characteristics These can be obtained by observation of the operation of large numbers of vehicles which operate almost wholly over surfaces of a given class Fleet operation, delivery vehicles, and family cars in certain territories offer possibilities for these studies

Not only are these studies necessary to bring out the relative differences in operating costs of driving on various surfaces, but they are necessary to determine what the operating costs are for rural driving as compared to city driving and general all around driving Cost records heretofore have been for total driving and these have been assumed to apply to "intermediate surfaces," because the facts on which to base an assumption to the contrary were missing Traffic studies have indi-

TABLE VI

ESTIMATED OPERATING COSTS FOR THE IOWA COMPOSITE CAR, CENTS PER MILE

Item	7,000 Miles per Year		11,000 Miles per Year		
	Bul 106 1931	Est, 1934	Bul 91 1928	Bul 106 1931	Est, 1934
1 Gasoline	1 27	1 18	1 31	1 27	1 18
2 Engine Oil	0 25	0 22	0 22	0 25	0 22
3 Tires and tubes	0 43	0 20	0 64	0 43	0 20
4 Maintenance	1 22	0 80	1 72	1 22	0 80
5 Depreciation	1 63	1 35	1 39	1 63	1 35
6 License	0 22	0 20	0 14	0 16	0 14
7 Garage	0 69	0 69	0 44	0 44	0 44
8 Interest, 6%	0 47	0 44	0 36	0 32	0 30
9 Insurance	0 33	0 36	0 21	0 22	0 23
10 Total Cost	6 51	5 44	6 43	5 94	4 86
11 Gasoline, miles per gallon	15 75	15 75		15 75	15 75
12 Oil, miles per quart	102	115		102	115
13 Cost new, dollars	905	840		905	840
14 List weight, pounds	2350	2500		2350	2500

cated that the rate of travel through cities is 15 to 20 miles per hour, which is much less than on rural highways The conditions of braking, accelerating, and driving are also different, and, therefore, the costs of operating a vehicle 60,000 miles on rural class I pavements would not be the same as 60,000 miles of operation within city limits on similar surfaces

In the study of the operating cost of vehicles, the hours of actual travel, if known, would shed some light upon the division of costs between urban and rural mileage, and, therefore, upon the assignment of relative cost indexes for maintenance and depreciation costs to assign to the different classes of roads

Since August 5, 1934, Prof. R G Paustian of Ames, has had a battery clock in operation on his automobile, so connected that the clock records the engine hours He later proposes to make the connection such that road hours will be measured independently of engine hours His results for 2,025 miles of driving during 71 hours of engine running time indicate an average speed of 28 5 miles an hour and a gasoline consumption of 15 35 miles per gallon. On one trip of 183 miles the average speed was 45 8 miles an hour, and most trips of 30 miles or so were driven at an average rate above 40 miles an hour with a gasoline mileage as high as 18 5 miles per gallon

His driving in and around Ames, Iowa, averaged about 15 miles an hour Under these conditions he secured as low as 12 miles to the gallon of gasoline Additional records of this type are needed as a basis for interpreting cost records

Summary on Operating Costs

In the field of motor vehicle cost studies it is desirable to collect complete cost records and mileages on cars used for the following three general purposes (1) Salesmen's fleets, (2) regular route delivery service, (3) family driving, separated into rural and urban ownership Likewise, similar cost records need to be assembled for truck and bus traffic

Analysis of registration records and traffic surveys should be made to determine the characteristics of the average vehicle in each class, as well as the general characteristics of the vehicles using each class of surface

Calculation of Costs for Vehicles Operating on Different Roadway Surfaces

Since 1928 most investigators endeavoring to estimate vehicle operating costs on various classes of road surfaces have used the work of Agg and Carter,[6] both as to method and cost ratios, though more recently their ratios have been modified to some extent Agg and Carter use the following cost ratios and surface classifications.

	High type (all pavements)	Intermediate type (gravel, macadam, and treated surfaces)	Low type (natural soil and light gravel)
Gasoline	1 00	1 20	1 47
Tires and tubes	1 00	2 22	2 90
Maintenance	1 00	1 20	1 47
Depreciation	1 00	1 10	1 24
All other items	1 00	1 00	1 00

These authors concluded that the tractive resistance for year around operation at about 35 miles an hour on these three classes of surfaces was 70, 110, 160 pounds per ton, respectively. The ratios of these three values were reduced in accordance with engine tests and road measurements of gasoline consumption to those tabulated above The reduction takes into consideration the greater engine efficiency at the higher loads Unfortunately the actual engine efficiencies are not given so the method cannot cannot be compared wi th present engines, but in any case a redetermination is necessary to take into account the changes in engine performance since 1928 These authors concluded that the maintenance costs of vehicle operation vary directly as the fuel consumption, and that depreciation costs increase at one-half the rate that fuel consumption increases Data have not been assembled to prove or disprove the correctness of these two assumptions, but it appears that the ratios are not as high for present vehicles and traffic

A few tire wear tests reported since do not support the high ratios of 2 22 and 2 90 used by Agg and Carter, though data are not available on which to base refined estimates Waller and Phelps later[42] suggested a ratio of 2 00 instead of 2 22 for the intermediate surface

TABLE VII

1933 Cost of Operating a Composite Automobile in Washington—by Phelps[37]

Cost Item	Concrete		Oiled Roads		Intermediate (Gravel)		Crushed Rock	
	Index	Cost, cents per Mile	Index	Cost, cents per Mile	Index	Cost, cents per Mile	Index	Cost, cents per Mile
Gasoline, 25¢ per gallon	1 00	1 36	1 05	1 43	1 20	1 64	1 20	1 64
Oil, 25¢ per quart	1 00	0 22	1 00	0 22	1 00	0 22	1 00	0 22
Tires	1 00	0 16	1 50	0 24	2 00	0 32	4 00	0 62
Maintenance	1 00	1 02	1 05	1 07	1 20	1 22	1 20	1 22
Depreciation	1 00	0 64	1 025	0 66	1 10	0 70	1 10	0 70
Total		3 40		3 62		4 10		4 40

For the state of Washington, Phelps[37] arrived at the costs and ratios shown in Table VII from a review of the work by Agg and Carter[6] and Winfrey[43, 44], making such adjustments as, in his opinion, were necessary to meet Washington conditions and his judgment

Summary

Since the surfaces in the intermediate class vary widely in power requirements and tire wear characteristics it is suggested that the classification proposed by Paustian[35] be used and that estimates of vehicle operating costs be made more specific as to type of surface

The method advanced by Agg and Carter is sound in principle Their results and those of later investigators are weakened only in so far as their assumptions may depart from facts As additional information relative to these assumed relationships becomes available, more accurate estimates should take into consideration the elements of road speed and time evaluation.

Since the comparisons are usually made, not for city streets, but for rural highways, the various cost ratios should be applied to cost records of vehicle operation on rural highways

SUMMARY AND RECOMMENDATIONS FOR FUTURE WORK

In the past ten years many highway engineers have made estimates of the savings to vehicle traffic which result from improving roadway surfaces, but in each case, certain assumptions of very basic importance were necessary, which to the scientific minded, throw considerable doubt on the results These investigators, however, have realized the necessity of gathering sufficient facts to reduce the assumptions, or at least the probability of error in them, and have emphasized the importance of the researches necessary to achieve accuracy. One quotation from Morrison is cited as typical of many statements made about the lack of facts on this subject:

"In this discussion, assumptions have been made as to such items as the amount of differences in operating costs over different types of surfaces, the value of a car-minute, and the amount of time saved by certain improvements, and then the assumed values have been used as if they were correct, which may be far from the case There are dozens of investigators, all over the country, working on such things as minor improvements in construction items, but only a very few appear to be studying the far more important factors involved in highway economics. Much research is needed to determine properly the factors which materially affect, or should affect, the outlay of millions The immediate spending of comparatively large sums to shed more light on this subject would seem to be an excellent investment The use of improperly evaluated factors where large expenditures are involved is an economic tragedy "[28]

This quotation sums up the situation adequately, for the only two items for which the relative costs have been measured are gasoline and tires which together comprise only 4 4 mills of the 7 mills which Phelps (Table 7) estimated is saved by changing from gravel to concrete (Paustian[34] estimated 8 mills) Tire savings comprise 1 6 mills of the 4 4, and this is computed on a basis of twice the cost of tires on concrete, which ratio is not supported by investigations with balloon tires

Consequently, and in view of the present character of traffic and vehicles, the author believes that any estimate of the saving in motor vehicle operating costs effected by road surface improvements and calculated on the basis of past researches and necessary assumptions is wholly unreliable A well-planned research program, should, in one year, remove this phase of highway economics from the clouds that must clothe any "scientific" conclusion predicated on mere assumptions.

While past estimates of saving in vehicle operating costs due to road improvement have served adequately, estimates of greater accuracy for a wider range of surfaces is now needed Many thousands of miles of roads in the country are yet to be improved, and, as low-cost methods of surfacing are coming into use, it becomes increasingly important to know accurately the effect of these road improvements upon the cost of vehicle operation and upon highway safety.

Researches which will add materially to the existing knowledge in the field of the economics of highway improvement are suggested in the following:

1 A sub-classification of Paustian's five classes of surfaces and a standard nomenclature for all road surfaces

2 Gasoline consumption rate curves for typical vehicles up to 80 miles an hour over several typical courses of each surface class under sufficient variable weather conditions that curves for year around conditions can be drawn

3 Power requirements (tractive resistance or driveshaft horsepower) for the same surfaces tested in 2, and under the same surface and weather conditions

4 Tire wear tests at speeds up to 80 miles an hour under traffic conditions for both standard balloon and low pressure balloon tires on the same classes of surfaces for which gasoline consumption and tractive resistance tests are run as in 2 and 3 These tests should cover 3,000 to 5,000 miles of driving for each test condition over many sections of surfaces and in such types of weather that year around averages will be reliable

5 A study of tire costs and tire mileages as well as the causes of tire failure, from the records of tire companies

6 Coefficient of friction tests for the same surfaces tested for tire wear

7 The collection of operating cost records for vehicles operated regularly on known types of surfaces, for family cars of both urban and rural ownership, and for "salesmen's" cars and fleets

8 A determination of operating costs for trucks, trailers, and busses

9 The determination of average road speed and the percentage of vehicles of each class at each speed for the several classes of surfaces under varying weather conditions

10 Additional traffic surveys for the purpose of determining the number and classification of vehicles which use each class of surface

11. The determination of annual and life mileages for each class of vehicle for typical geographical localities

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