REPORT OF DEPARTMENT OF HIGHWAY TRANSPORTATION ECONOMICS

R L MORRISON, *Chairman*

RURAL MAIL CARRIER MOTOR VEHICLE OPERATING COSTS ON VARIOUS TYPES OF ROAD SURFACES

By R A MOYER

Associate Professor of Highway Engineering, Iowa State College

SYNOPSIS

Operating cost records for 293 cars operated by rural mail carriers in Iowa and Indiana have been assembled, summarized, and analyzed for the purpose of determining the operating cost differentials for various types of road surfaces This report concludes a study of car cost records, supplementing the report for 159 cars presented at the 1937 meeting of the Highway Research Board Unit operating costs were determined for each type of road surface from the detailed daily record of these cars covering every phase of operation

The total travel for the 293 cars amounted to 3,094,546 miles which was very nearly equally divided between the four seasons of the year and three surface types,—pavement, untreated gravel, and earth

From the graphical analysis the average cost of operation for the year-round condition was found to be about 7 8 cents per mile for earth, 4 5 cents per mile for gravel, and 3 8 cents per mile for pavement The unit cost of transportation by replacement of cars with horses, etc , when the roads were impassable to cars, averaged about 11 cents per mile as compared to an average of less than 5 cents per mile with the cars The average rate of travel, including stops, was 14 0 m p h on gravel and pavement and about 7 0 m p h on earth

From the statistical analysis by the method of least squares, the average cost of gasoline, oil, tires and maintenance for the year was 3 14 cents per vehicle mile on earth, 2 54 on gravel, and 1 55 on pavement The unit cost of gasoline was 0 05 and 0 18 cent higher on gravel than on earth and pavement respectively Also, the tire cost was 0 04 and 0 12 cent higher on gravel than on earth and pavement respectively The total unit costs of operating an "average" car for 8,000 miles annually based on the results of this study amounted to 6 22 cents per mile on earth, 5 62 on gravel, and 4 63 on pavement The multiple correlation coefficients obtained by the least squares method was 0 89 for the total unit costs, 0 98 for gasoline costs, 0 95 for tire costs, 0 78 for oil costs, and 0 60 for maintenance costs

Applying these data to determine the traffic volume necessary to justify an investment of $1000 per mile and an extra maintenance cost of $40 per year in improving a county trunk earth road with a gravel surface, it was found that 35 vehicles a day are required if operating costs only are considered, and 7 vehicles a day if the factors of mileage, age, extra help, and travel time are evaluated Also, an annual expenditure of more than $500 per mile of road per 1,000 vehicles of traffic per day for snow and ice removal is justified based on the savings in operating costs, time, and reduction in accidents, resulting from complete snow and ice removal

With unit operating costs ranging from 2 cents per mile to 12 cents per mile for passenger cars, an average saving of 1 cent per vehicle mile, providing an annual saving of two-and-a half billions of dollars for the country, as a whole, is a goal worthy of the organized efforts of all engineers and car owners who control the vast expenditures for highway transportation

At the 1937 meeting of the Highway Research Board, a report was presented[1] covering a study of the cost records for 159 cars operated by rural mail carriers in Iowa and Indiana Unit operating costs were determined for each type of

[1] Proceedings, Highway Research Board, Vol 17, p 53

road surface from the detailed daily record of these cars covering every phase of operation, such as, miles of travel on each surface type, rate of travel, weather, number of stops, load, gasoline and oil consumption, tire expense, maintenance costs, garage rental, license fees, taxes, insurance, depreciation, interest, and extra help During the past year, the records for 134 additional cars have been assembled, summarized, and analyzed The close agreement in the results for the 159 cars originally studied and the 293 cars which comprised the final total, indicated the reliability of results when using what might seem to be a relatively small number of cars as a sample. The wide spread in unit operating costs on unimproved roads, especially when comparing the costs for the winter and summer seasons, again indicated clearly the marked advantage which can be gained by operating on improved stabilized or hard surfaced roads As was mentioned in last year's report, the average motor vehicle tax which is used to pay for the construction and maintenance of highways rarely exceeds one half cent per vehicle mile, whereas the "mud tax" when driving on unimproved roads may easily be 5 to 10 times as great

While few people advocate maintaining an unimproved road system, the majority of car owners do not fully realize the price they have to pay to operate on mud roads To combat the mud in many instances the expedient of placing loose gravel, sand, crushed rock or similar granular material on the road has been followed While this method can be carried out at low cost, it is not generally realized that certain items of operating cost are not greatly improved, in fact, the average year round unit costs for these items may be greater than for earth roads That is, the loose gravel or rock frequently increases average fuel, tire, and maintenance costs and creates a dust and accident hazard which may be greater and more serious than on the natural earth roads

With 30,000,000 motor vehicles using our streets and highways, the importance of economical operation cannot be overemphasized A reduction in the average cost of operation of one cent per vehicle mile would represent a saving of more than two-and-a-half billion dollars a year, an amount considerably greater than that spent for all construction and maintenance on this nation's streets and highways While the attainment of such a reduction in operating cost may appear to be highly improbable, a careful study of car cost records covering a wide variety of operating conditions, provides convincing evidence that if an *organized effort* were made to reduce car costs, an average reduction of one cent per vehicle mile would not only be possible, but could be accomplished in a relatively short time

The results of this and previous studies, indicate that the differences in unit operating costs for passenger cars which may be attributed to variations in road surface type or condition may easily be as much as two cents per mile, and if the value of time is considered, this difference may be doubled or tripled Furthermore, if the effect of variations in age and annual mileage are included, the total unit operating costs may vary from 2½ cents per mile to 12 cents per mile The public should be informed concerning the needs in highway construction to eliminate waste created by operating on uneconomical road surfaces and on congested and hazardous highways, and also concerning those phases in the operation of a car which contribute to the tremendous waste and extravagance which a poorly informed and poorly organized driving public alone will countenance

In this report data are presented which will indicate the significance of various items of operating costs and also will indicate how these costs may be reduced Special emphasis is given to the data which show how the highway engineer can contribute toward such a reduction by the improvement of road surfaces and by suitable road maintenance operations While the report covers an analysis of car costs in only one type of car operation, that of cars operated on rural mail routes, the records are complete and provide a detailed account of every important element in car operation known to effect car costs and thus provide a fairly definite measure of possible reductions in car costs for all types of operation

Among the more important cost factors which the highway engineer should consider are the savings due to the type of road surface, the type of road maintenance, and the extent of snow removal As was mentioned in last year's report, in the case of main highways where the traffic volume is large, it is easy to show that the savings in operating cost justify the expenditures for a first class pavement However, there are many streets and highways in need of improvement where the traffic is much lighter than on main state highways and for which a more careful analysis of all of the cost factors is necessary if a wise selection of the type of surface improvement, maintenance, and extent of snow removal is to be made While a gravel surface is usually selected under low traffic conditions to provide a passable all-weather surface, the data in this study indicate that an investment of $1000 per mile for gravel surfacing may be justified with as few as seven vehicles per day In like manner, many other economic decisions can be made if complete cost data are available similar to that to be presented in this report

In the 1937 report detailed information was given concerning the methods and forms used in obtaining the route and car descriptions, the daily record of operation for each car, and the methods used in analyzing and reducing the data on the monthly, quarterly, and annual summary sheet All of the later work was conducted using the same methods and will, therefore, not be covered again in this report

ANALYSIS OF COST RECORDS AND DISCUSSION OF RESULTS

Description of cars The car commonly used by mail carriers as reported by the owners is the light, low-priced type There were a number of heavy, medium-priced cars and also cars with special construction to operate through mud and snow, such as by the use of raised fenders, large radius wheels, and special attachments to the wheels The cars as a whole may be considered as representative of those which generally use the secondary or farm-to-market roads

Ages of the cars At the middle of each reported period these varied from one month to 10½ years; the average was 2 years 9 months Most of the cars were under 2 years old, but there were also several which were 7 or 8 years old used almost exclusively on mud roads and which brought the average up to the above value Of the 293 cars investigated during the 12 months period from November 1, 1935 to October 31, 1936, 202 or 68 9 percent were later than 1933 models

Description of road surfaces The types of road surfaces were divided into four separate groups—(1) rigid pavements, (2) semi-rigid treated types, (3) surfaced but untreated, and (4) natural earth With very little mileage of the semi-rigid treated type in Iowa, it was hoped that records could be obtained from rural mail carriers in Indiana where this surface is more common. However, not enough of these reports were obtained to justify an analysis of this surface type separately, and, therefore, these were combined with the rigid types which consisted largely of portland cement concrete The rigid and semi-rigid treated types are referred to hereinafter as pavement, surfaced but untreated types as gravel, and natural earth as earth A summary of the mileage traveled on the various surfaces for the four seasons of the year is given in Table 1

It is interesting to note that of the total mileage of 3,094,546 miles traveled by the 293 cars, 31 8 percent was on

TABLE 1

Summary of Mileage Traveled by 293 Cars on Each Surface Type for the Year 1935–36

Period	Total mileage	%	Mileage on each surface type		
			Pavement	Gravel	Earth
Winter	644,042	20 8	166,231	250,966	226,845
Spring	780,931	25 2	235,897	288,854	256,180
Summer	899,141	29 1	346,036	289,959	263,146
Fall	770,432	24 9	232,822	283,513	254,097
Year	3,094,546	100 0	980,986	1,113,292	1,000,268
Percent of total	100 0		31 8	35 6	32 6

TABLE 2

Summary of Mileage Traveled by Cars A, B, and C on Each Surface Type for the Year 1935-36, Using Car Models Later than 1933 Models

Type of car	Total mileage for each car type			No of Cars	Mileage per car			
	Paving	Gravel	Earth		Paving	Gravel	Earth	Total
A	269,005	281,157	304,634	72	3,736	3,905	4,231	11,872
B	302,479	320,504	226,397	65	4,654	4,931	3,483	13,068
C	154,184	182,178	109,698	35	4,405	5,205	3,134	12,744
All cars	725,668	783,839	640,729	172	4,219	4,557	3,725	12,501

pavement, 35 6 percent on gravel, and 32 6 percent on earth Also, of the total mileage 20 8 percent was traveled during the winter 25 2 percent during the spring, 29 1 percent during summer, and 24.9 percent during the fall season It can be seen that the mileage was fairly evenly divided between both the three surface types and the four seasons of the year 1935–36

In Table 2 the average mileage on each surface type is given for the three popular makes of car most commonly used by the mail carriers in this study These data again indicate that the mileage is fairly evenly divided on each surface for these selected groups of cars

Analysis of records The same graphical and statistical methods were used in analyzing the data for the 293 cars as were used for the first 159 cars covered in last year's report In the graphical method, the data were plotted in terms of percentages of miles traveled on a given surface as compared with total mileage traveled on any two surfaces or on all surfaces Since it was desirable to compare the cost of operation on three different surface types, this method was not entirely satisfactory because only two, or at the best three, variables could be used The statistical method of least squares was used to obtain average values of operating costs on the three different surface types and proved to be highly satisfactory The graphical method makes it possible to visualize the data while the statistical method permits more exact solution of specific cost items

Comparison of unit costs In Figure 1 the average unit cost of operation for the 293 cars is shown for varying percentages of total mileage traveled on earth roads as compared to the mileage on pavement and gravel Since the distribution of the individual cars is practically the same as in the 1937 report it is not repeated here The average total unit operating cost (excluding extra help) varied from 3 8 cents per vehicle mile for cars operating exclusively on gravel and paving to 7 8 cents per vehicle mile on earth The minimum cost on gravel and pavement was about 2½ cents per mile as compared to 5 cents per mile on earth and the maximum is about 6 cents per mile on gravel and paving as compared to about 12 cents per mile on earth One reason for this wide spread in costs between minimum and maximum values is due to the wide variation in annual mileage and in the annual depreciation charges against the car To determine the extent of this effect, the unit costs of more than 200 cars with annual mileages above 5,000 and for year models later than 1933 were examined. The average unit costs for this group of cars (Fig 1) were about the same as for all 293 cars but the spread in costs particularly for the cars operating largely on earth was reduce by about 2 cents per mile

The average unit cost including extra help is also shown in Figure 1 The unit cost of extra help averaged about 0 2 cent per mile on paving and 1.0 cent per mile on earth This does not mean that the unit price of extra help was higher on earth roads than on pavement, but rather that considerably more extra help was necessary on earth roads than on paving

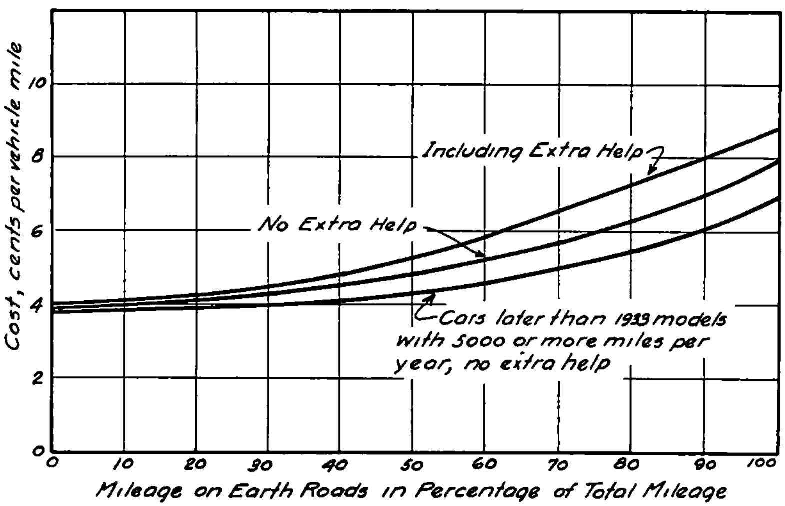

Figure 1. Unit Cost of Operation for Varying Percentages of Total Mileage Traveled on Earth Roads as Compared to Mileage on Other Surface Types for 293 Cars Operated during 1935–36.

The unit transportation replacement cost corresponds to extra help "without car" and averages approximately double the average cost with the car (See Figure 8, 1937 report) These costs vary widely and for obvious reasons bear no definite relation to the type of surface replaced

The extreme seasonal effect on operating cost is shown in Figure 2 The unit costs shown include only the cost of gas, oil, and maintenance The average on paving is 0 7 cent per mile higher in winter than in summer and 1 2 cents per mile higher on earth in winter than in summer It should be noted that the effects of age and mileage are negligible, and the spread in unit costs (See Fig. 9, 1937 report) is due largely to the type of surface and the season of the year help amounts to about 0 6 cent per mile on paving and 2 4 cents per mile on earth This shows the effect of snow, ice, and rain to be much greater on earth roads than on other types

Comparison of unit costs on earth, gravel, and paved roads graphically Since it seemed desirable to determined the differences in operating costs for each of the three types of surfaces, the cars were divided into three groups thereby making it possible to compare costs on earth and

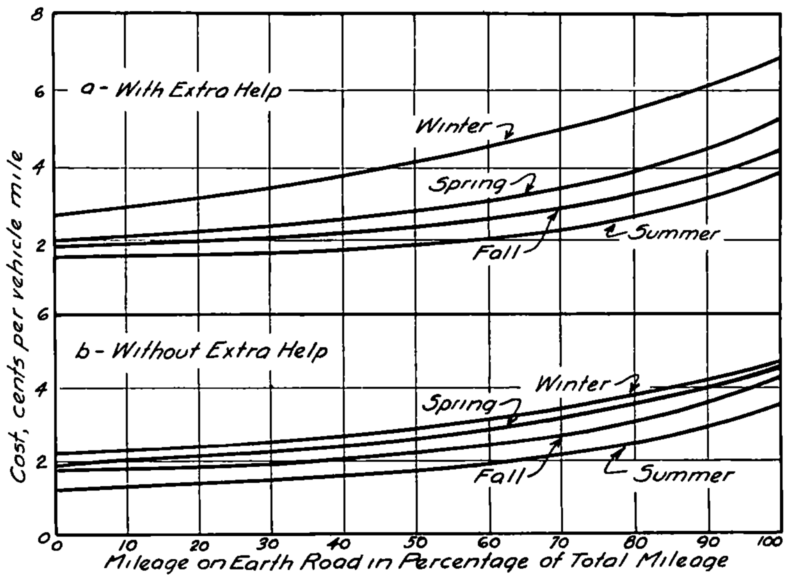

Figure 2. Unit Cost of Gas, Oil and Maintenance for Varying Percentages of Total Mileage Traveled on Earth Roads as Compared to Mileage on Other Surface Types for Seasons of 1935–36, (a) With Extra Help, and (b) Without Extra Help

The points are grouped quite closely to the average line for the summer season which is a good argument in favor of snow and ice removal and in so doing maintaining summer driving conditions on winter roads

In Figure 2 the average cost of extra help is also included with gas, oil, and maintenance These curves indicate that the cost of extra help in summer is very small, averaging only 0 1 cent per vehicle mile on paving and 0 4 cent per vehicle mile on earth During the winter extra gravel, on earth and pavement, and on gravel and pavement Each group was composed of cars which were operated for at least 90 percent of their total mileages on the two surfaces being compared The total cars in each group did not provide a large enough sample to assure conclusive results, but the trends are fairly well defined (Fig 3) The greatest difference was obtained when comparing the costs on gravel or paving with the costs on earth which amounted to about 3 to 4 cents per mile; the least difference being obtained when comparing costs on gravel and on concrete which amounted to less than 1 cent per mile

In Figure 4 the unit costs are shown for the four seasons, and this again shows that the seasonal effect is greatest on earth roads and least on gravel and paving

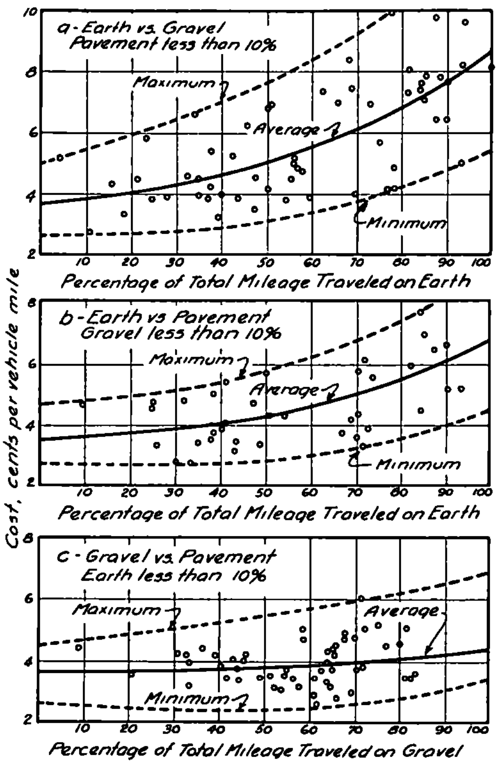

Figure 3. Unit Cost of Operation (Excluding Extra Help) on (a) Earth as Compared to Gravel, (b) Earth as Compared to Pavement, and (c) Gravel as Compared to Pavement.

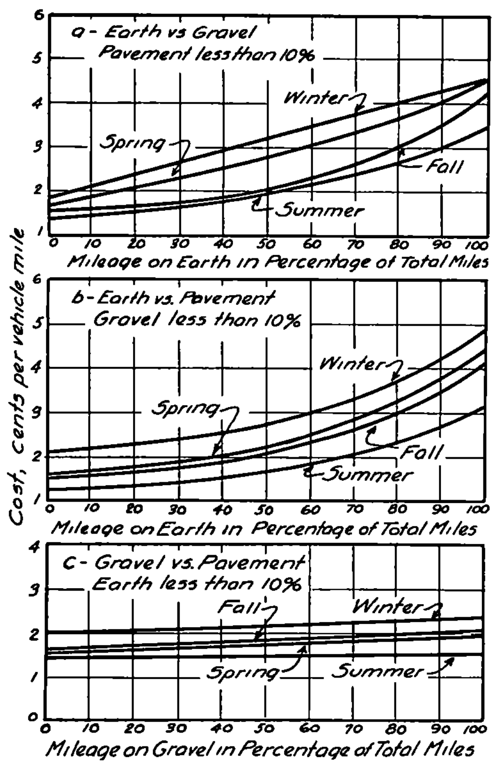

Figure 4. A Comparison of the Unit Cost of Gas, Oil and Maintenance for the Four Seasons on (a) Earth vs. Gravel, (b) Earth vs. Pavement, and (c) Gravel vs. Pavement

Annual mileage In the 1937 report it was shown that wide variations in annual mileage had a marked effect on unit operating costs According to the data in Figure 5, the cars operated largely on paving by rural mail carriers averaged about 20,000 miles per year whereas cars operated on earth averaged only about 4,000 miles per year In a number of cases the same carrier operated two cars, one when the roads were good, the other when the roads were muddy or otherwise in poor condition This is a partial explanation why the annual mileage of cars operated on earth roads was so low At the same time, it is significant that the total unit costs on earth were notably higher than on pavement and part of this difference is definitely due to the low annual mileages of cars operated on earth It is questionable whether the operation of a "mud" car for such low annual mileages is economically justifiable, because there is little to indicate that the unit gas, oil and tire costs would be lower for the two cars than if only one were used Only the savings in maintenance and in the need for less frequent car washings would justify the added cost in the fixed charges for the "mud" car

summer and winter are given and the curves show that the average rate on paving is 14 miles per hour or about double the average rate on earth where it is 7 miles per hour The rate during

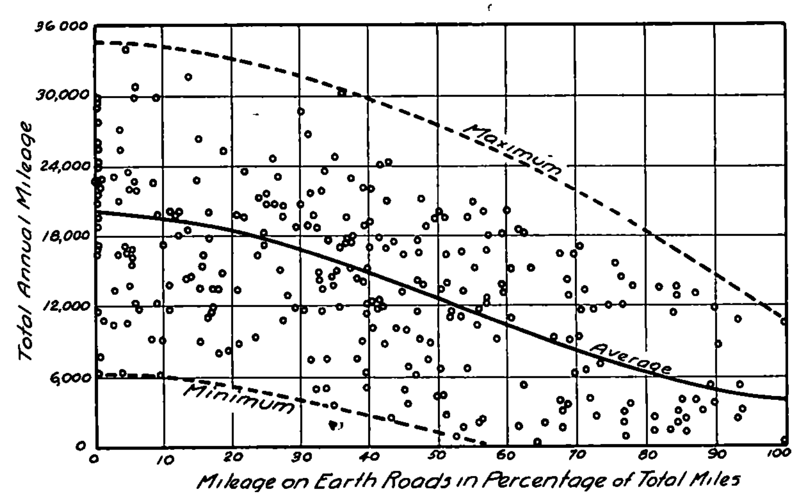

Figure 5 Annual Mileages of 293 Cars for Varying Percentages of Total Mileage Traveled on Earth Roads as Compared to Mileage on Other Surface Types

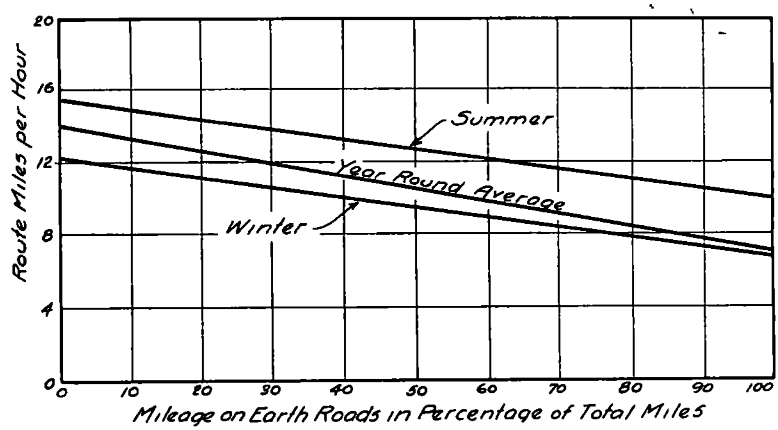

Figure 6. Average Miles of Route Covered per Hour, Including Stops for Varying Percentages of Total Mileage Traveled on Earth Roads as Compared to Mileage on Other Surface Types for Winter, Summer and the Whole Year.

Rates of travel The rate of travel is defined as the total miles traveled divided by the number of hours spent on the route In Figure 6 the average rates of travel for the entire year and for the summer is approximately 25 percent higher than during the winter During the fall it is slightly higher than in the spring

The most significant fact respecting the differences in rate of travel on earth and on paving is the large time saving effected by travel on pavement There can be little doubt that cutting the time on the route by 25 to 50 percent provides a real time saving factor which has money value and that this alone may justify the construction of hard all-weather roads

Relation of unit operating cost to total mileage of cars The unit cost of gas, oil, and maintenance as related to the total mileage traveled during the life of the car is shown in Figure 7 While the mileage in unit costs is the effect of the age of cars on unit costs Figure 8 indicates a fairly definite trend upward in cost until an age of five or six years is reached The unit cost remains fairly constant beyond this point The sharp upward trend during the first year is accounted for by the fact that maintenance is practically nil when the car is new, but that it increases with age until it becomes more or less constant A portion of the increase in unit cost with age is due to improvements in the more

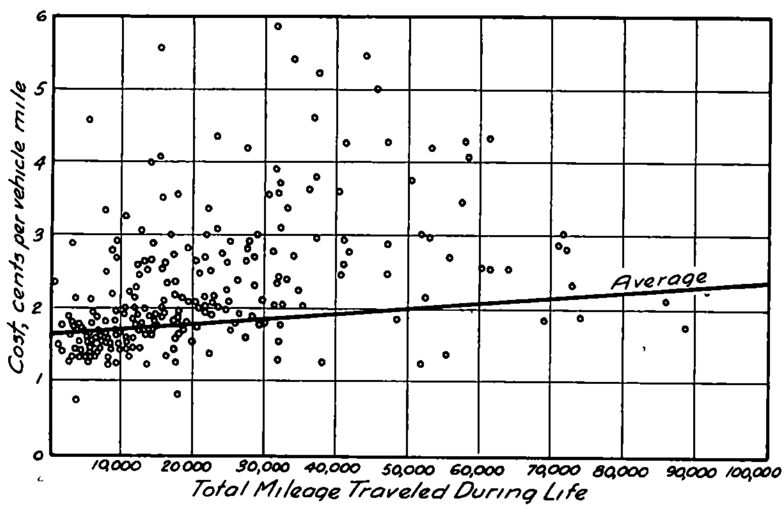

Figure 7. Unit Cost of Gas, Oil and Maintenance at Various Mileages Traveled during Life of Cars up to the Middle of Reported Period

sample is not as large as it should be, especially for cars operated over large total mileages, a definite trend upward in the unit costs as the mileage of the car increases is clearly evident This increase is largely due to an increase in maintenance costs because the unit cost of oil and gas should not change very much if the car is kept in good repair The curve was not intended to indicate the average cost at each mileage but merely to indicate the approximate trend

Relation of unit cost to age of car Closely related to the effect of total recent model cars which have raised efficiency and lengthened useful service lives Incidentally, the low cost trend shown during the early life of the car provides a basis for the practice followed by certain car owners and fleet operators of trading in at the end of the first or second year These costs are not the total unit costs but include only gas, oil, and maintenance, the items of which average owners are usually most conscious If the unit costs due to fixed charges such as insurance, license fee, interest and depreciation were included the trend would be quite different. With low annual mileages, it would be completely reversed, but with annual mileages of 20,000 or more, the two cents per mile difference in unit cost due to age might be no more or might even be less than the unit costs due to the fixed charges which are highest when the car is new. It should be evident that the effects of age, annual mileage, depreciation, and maintenance are highly significant to the individual owner who desires to operate at the lowest unit cost, but The costs were computed only for gas, oil, tires, and maintenance because these items are directly affected by the type of surface. The recorded costs were used and only in computing the total unit operating cost were the uniform adjusted costs for such items as depreciation, garage rental, insurance, interest, and taxes used.

Comparison of unit costs for first 159 cars, for the last 134 cars, and for all 293 cars. A summary of the unit costs

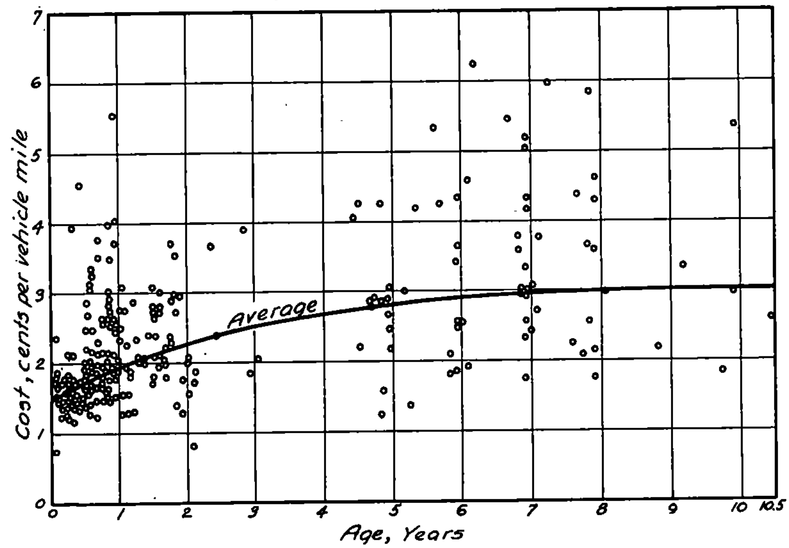

Figure 8. Unit Cost of Gas, Oil and Maintenance at Various Ages of Cars at Middle of Period Covered by Report

it is in these items that he is least informed and most likely to have the greatest spread in unit costs.

STATISTICAL ANALYSIS BY METHOD OF LEAST SQUARES

Since it was not possible to determine the exact average unit operating costs for the three types of surfaces by graphical solution because four variables had to be considered in the solution instead of the usual two or three, statistical analysis by the method of least squares was used to compute the average unit cost on each surface for the 293 cars.

for two groups of cars and for all 293 cars is given in Table 3. The relative unit costs shown in the table were determined by assigning a value of 100 for the total unit cost for the 293 cars on pavement as a base.

The comparative costs of gasoline, oil, tires, and maintenance for the 293 cars for the entire year were found to be 3.14 cents per mile on earth, 2.54 cents per mile on gravel, and 1.55 cents per mile on pavement. The cost of operation on earth for these items was, therefore, more than double the cost on pavement with a difference of 1.59 cents per mile.

The difference between the unit costs on gravel and on pavement for these same cost items amounted to 0 99 cents per mile A significant fact brought out in this summary is that the unit costs for gas and tires were higher on gravel than on earth A possible explanation for this difference is that in dry weather the untreated gravel roads are frequently loose and corrugated while the earth roads are hard and smooth In wet weather both the gravel and the earth roads may be soft, with the earth roads usually much softer than the gravel roads The data on rate of travel also indicate that the speeds on gravel are definitely higher than on earth which means that fuel and tire wear costs should be higher than at the slower speeds at which cars are operated on earth.

When the unit cost of gas is converted into miles per gallon, it is found that the average fuel consumption was 13 52 miles per gallon on earth, 13 04 on gravel, and 15 02 on pavement The average mileage per quart of oil was 113 on earth, 159 on gravel, and 264 on pavement

The greatest difference in cost items between surface types was for maintenance The maintenance cost on earth was 1 24 cents per mile, 0 61 cent per mile on gravel, and −0 02 cent per mile on pavement. This large difference was partially due to the greater ages of cars operated almost exclusively on earth, also, the cars operating largely on pavement were generally less than two years old and required little repair work Of course, the negative result indicated for maintenance on pavement is not a real value but is the result obtained using the straight line relationship in the least square method That is, in setting up the least squares equations it was assumed that the costs for gas, oil, tires, and maintenance varied uniformly with the mileage on each surface type That this was a reasonable assumption is shown in Table 4 where a multiple correlation coefficient of 0 98 is given as

TABLE 3

COMPARISON OF RESULTS OF THE LEAST SQUARES SOLUTION FOR OPERATING COSTS OF THE FIRST 159 CARS AS GIVEN IN LAST YEAR'S REPORT, OF THE LAST 134 CARS ANALYZED THIS YEAR, AND OF THE ENTIRE GROUP OF 293 CARS STUDIED IN THIS INVESTIGATION

Cost item	Pavement		Gravel		Earth	
	Cost, cents per mile	Relative cost*	Cost, cents per mile	Relative cost*	Cost, cents per mile	Relative cost*
Gas, oil, maintenance and tires for first 159 cars	1 73	112	2 46	159	3 17	205
Gas, oil, maintenance, and tires for last 134 cars	1 37	88	2 60	168	3 10	200
Gas, oil, maintenance, and tires for entire group of 293 cars	1 55	**100**	2 54	164	3 14	203
Gas, oil, and maintenance	1 29	83	2 16	139	2 80	181
Gas	1 22	79	1 40	90	1 35	87
Oil	0 09	6	0 15	10	0 21	14
Maintenance	−0 02	−1	0 61	39	1 24	80
Total tire cost	0 26	17	0 38	25	0 34	22
Tire replacement cost	0 24	15	0 36	23	0 32	21
Tire repair cost	0 02	1	0 02	1	0 02	1

* Relative cost assume the cost of gas, oil, maintenance, and tires for entire group of 293 cars when operating on pavement to be 100

having been computed for gas and 0 95 for tires The correlation coefficients for oil and maintenance are not as high, with values of 0 78 for oil and 0 50 for maintenance

In view of the negative value for the maintenance cost on pavement, a least squares solution was worked out using a curvilinear relationship instead of the straight line relationship for both oil and maintenance for 263 cars for which complete total life mileage data were available The results of these computations are shown in Table 2 and indicate that the curvilinear relationship is more accurate than the straight line method for both oil and maintenance It resulted in only a slight improvement in the correlation coefficient for oil, changing it from 0 78 to 0 79, but gave a marked improvement for the coefficient for maintenance, raising it from 0 50 to 0 60 The negative value for maintenance on pavement was changed to a positive value of 0 10 cent per mile which is not unreasonable in view of the large annual mileage and the relatively low ages of the cars operating largely on pavement Some objection may be raised to attributing unit cost differentials to the surface which are in part due to mileage or age Actually it is to be

TABLE 4

Comparison of Least Squares Solution Using Straight Line Relationship and Curvilinear Relationship for Variable Operating Cost Items When Operating on Various Surface Types, Also the Correlation Coefficient and Standard Deviation for Each Cost Item

Cost item	Type of solution	Cost on concrete, cents per mile	Cost on gravel, cents per mile	Cost on earth, cents per mile	Multiple correlation coefficient	Standard deviation, dollars per year
Gasoline	Straight line	1 19	1 35	1 28	0 98	22 96
Oil	Straight line	0 09	0 14	0 21	0 78	7 64
	Curvilinear	0 11	0 15	0 21	0 79	7 51
Maintenance	Straight line	−0 15	0 43	0 97	0 50	55 84
	Curvilinear	0 10	0 56	1 01	0 60	51 61
Tires	Straight line	0 27	0 39	0 34	0 95	7 42
Total	Straight line	1 40	2 31	2 80	0 89	72 91
Total	*Curvilinear	1 67	2 45	2 84		

* Includes straight line solution for gasoline and tires and curvilinear solution for maintenance and oil

TABLE 5

Results of the Least Squares Solution for Unit Operating Costs for Various Items for the Seasons of 1935-36

Cost item	Costs in cents per vehicle mile											
	Winter			Spring			Summer			Fall		
	Pavement	Gravel	Earth	Pavement	Gravel	Earth	Pavement	Gravel	Earth	Pavement	Gravel	Earth
Gas, oil, and maintenance	1 89	2 47	3 50	1 28	2 28	3 07	1 36	1 77	1 96	1 39	1 74	2 69
Gas	1 50	1 54	1 58	1 15	1 45	1 45	1 21	1 24	1 13	1 21	1 32	1 27
Oil	0 11	0 16	0 22	0 10	0 14	0 21	0 10	0 15	0 20	0 12	0 11	0 20
Maintenance	0 28	0 77	1 70	0 03	0 69	1 41	0 05	0 38	0 63	0 06	0 31	1 22

expected that the mileage on pavement should be greater than on earth because during certain seasons of the year travel on earth is so slow that it is impossible to maintain the high speeds and mileage obtained on pavement

Unit costs for the seasons The costs of gas, oil, and maintenance for the seasons in Table 5 show very little difference in unit cost on pavement during spring, summer, and fall, but in winter it was from 0 5 to 0 6 cent per mile higher than during the other seasons The unit cost on gravel was about the same during the summer and fall, but was 0 5 cent per mile higher during spring and 0 7 cent higher during winter than during summer or fall The greatest difference between unit costs for the seasons occurred on earth roads, the cost in cents per mile increasing from 1 96 during summer to 2 96 during fall, 3 07 during spring, and 3 50 during winter

Unit costs for different car makes Three makes of cars were selected for which the largest number of records were available All of the cars in the three groups were later than 1933 models and their average route speeds, average ages, and the relative amount of travel on each type of surface as indicated in Table 2 were about the same The results of this analysis are shown in Table 6

The unit costs for cars "A" and "B" agree quite well but the results for car "C" are not consistent when compared with "A" and "B" or with the unit costs for all the 293 cars It is possible that the sample for car "C" was too small to obtain accurate results with only 35 cars being used as compared to double that number for cars "A" and "B."

TABLE 6

COST OF OPERATION IN CENTS PER VEHICLE MILE FOR THREE LOW PRICED CAR MAKES ON VARIOUS TYPES OF SURFACES

Cost item	Car "A"			Car "B"			Car "C"			Cars "A," "B," and "C"		
	Pavement	Gravel	Earth	Pavement	Gravel	Earth	Pavement	Gravel	Earth	Pavement	Gravel	Earth
Gas, oil, tires and maintenance	1 47	2 64	2 86	1 42	2 46	2 82	2 54	2 14	2 08	1 68	2 47	2 70
Gas	1 14	1 44	1 42	1 15	1 39	1 23	1 43	1 27	1 12	1 20	1 38	1 30
Oil	0 06	0 11	0 23	0 10	0 15	0 15	0 14	0 12	0 23	0 10	0 13	0 19
Tires	0 28	0 41	0 26	0 27	0 38	0 36	0 27	0 37	0 36	0 28	0 40	0 31
Maintenance	−0 01	0 68	0 95	−0 10	0 54	1 08	0 70	0 38	0 37	0 10	0 56	0 90
Ave annual mileage per car on each surface	3736	3905	4231	4654	4931	3483	4405	5205	3134	4219	4557	3725

Average total unit operating cost data for the "composite" car and for the "average" car In determining the average total unit operating cost for the 293 cars on earth, gravel, and pavement, the results of the least squares solution were used for the cost of gas, oil, tires, and maintenance and the cost for the remaining items such as depreciation, garage rental, taxes, etc were computed for a "composite" car and for the "average" car For the "composite" car, the average age and the delivered price of one of the most commonly used low priced cars was used together with the depreciation, insurance, garage rent, interest, and license fee for this make of car For the "average" car the recorded costs were used to determine the average unit costs The greatest differences between the unit costs for the "composite" and the "average" car are due to the variable rate of depreciation at various ages of the car That is, the depreciation is not the same for each

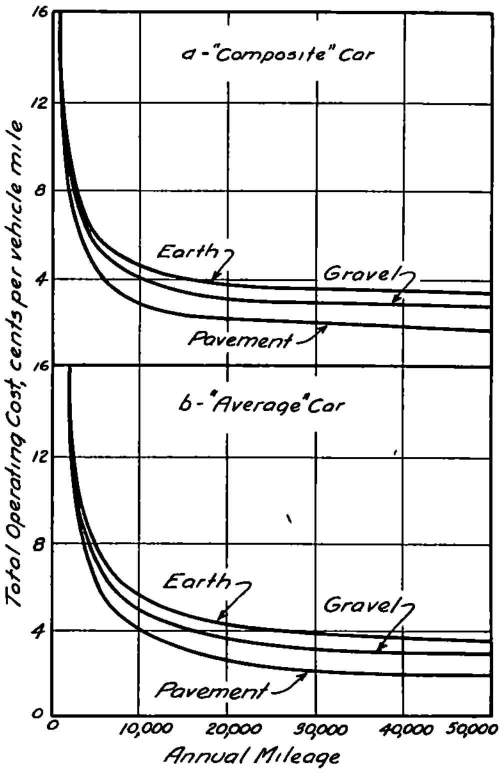

Figure 9. Total Unit Operating Cost for the "Composite" and "Average" Car on Various Surface Types as Related to the Annual Mileage.

year over the life of the car but is considerably higher during the first two years than at later periods The average age of the 293 cars at the beginning of the reported period was 2 years and 5 months and using a delivered cost of $700 the annual depreciation for this age would be $63 70 as compared with the actual average depreciation of $149 51 obtained from the depreciation values computed for each of the 293 cars

The total unit costs per mile were thus computed for the "composite" car and for the "average" car for annual mileages varying from 1,000 to 50,000 The curves in Figure 9 indicate clearly the marked effect annual mileage has on unit costs especially for annual mileages less than 15,000 At 14,560 miles, which was the average annual mileage of the 293 cars, the total unit costs of operation of the "composite" car was found to be 4 19 cents per mile on earth, 3 59 on gravel and 2 60 on pavement If the annual mileage is reduced to 8,000 which is a fairly typical average for cars in this country, the costs for the "composite" car will be 5.03 cents per mile on earth, 4 42 on gravel, and 3 41 on pavement

In Table 7 the various cost items and the total operating cost for the "average" car when operating on pavement, gravel, and earth are given. The operating cost of the "average" car at an average annual mileage of 14,560 is 4 83 cents per mile on earth, 4 23 on gravel, and 3 24 on pavement For an annual mileage of 8,000 the costs for the "average" car will be 6 22 cents per mile on earth, 5 62 on gravel and 4 63 on pavement

APPLICATION OF UNIT OPERATING COST DATA TO A STUDY OF ECONOMIC COMPARISONS OF EARTH AND GRAVEL ROAD SURFACES AND THE ECONOMIC JUSTIFICATION OF SNOW REMOVAL

In the 1937 report the unit operating cost data for the first 159 cars were used in making an economic comparison of earth and gravel for a local country road for traffic ranging from 0 to 50 vehicles per day. The conditions and limitations under which these data were used were explained and will not be repeated here However, the application of the unit cost data obtained from the 293 cars in an economic comparison of earth and gravel for a county trunk road with traffic ranging from 0 to 100 vehicles per day is given in Figure 10

The total annual transportation cost was computed by the formula·

Annual transportation cost = annual maintenance cost + annual depreciation + annual interest + annual vehicle operating cost

In making the economic comparisons shown in Figure 10, three different values of unit operating cost were used In (A) the unit operating costs on both crease being the 2 9 cents per mile time factor which is the value of time saved by traveling on gravel instead of earth assuming the driver's time to be worth 40 cents per hour

The curves in Figure 10 (A) indicate that a traffic volume of 35 cars per day will provide sufficient savings in gas, oil, tires, and maintenance to justify the $1,000 investment and the $40 per year extra maintenance required for the construction and maintenance of the gravel road For the unit cost values used in

TABLE 7

OPERATION COSTS OF THE "AVERAGE" AUTOMOBILE ON VARIOUS SURFACE TYPES*

Cost item	Pavement		Gravel		Earth	
	Annual cost, dollars per car	Cost, cents per mile	Annual cost, dollars per car	Cost, cents per mile	Annual cost, dollars per car	Cost, cents per mile
Gasoline	177 63	1 22	203 84	1 40	196 56	1 35
Oil	13 10	0 09	21 84	0 15	30 58	0 21
Maintenance	−2 91	−0 02	88 82	0 61	180 54	1 24
Tires	37 86	0 26	55 32	0 38	49 50	0 34
Garage	30 00	0 21	30 00	0 21	30 00	0 21
License fee and taxes	13 57	0 09	13 57	0 09	13 57	0 09
Depreciation	149 51	1 03	149 51	1 03	149 51	1 03
Interest at 6%	24 33	0 17	24 33	0 17	24 33	0 17
Insurance	27 85	0 19	27 85	0 19	27 85	0 19
Total (Annual Miles 14,560)	470 94	3 24	615 08	4 23	702 44	4 83
Total (Annual Miles 8,000)	369 26	4 63	448 46	5 62	496 46	6 22

* Costs for items in main body of table are computed for an average annual mileage of 14,560 miles

gravel and earth were computed using the same average annual mileage and age, resulting in a unit cost of 4 83 cents per mile on earth and 4 23 cents per mile on gravel, the difference being due to the increased gasoline, oil, tire, and maintenance costs on earth as compared to gravel. In (B) the unit cost on earth was raised to 8 83 cents per mile which represents an adjusted cost based on the lower annual mileage, the greater average age and the greater cost for extra help on earth than on gravel In (C) the cost on earth was further increased to 11 73 cents per mile, the additional in- (B) which include the cost of extra help, a traffic volume of 7 vehicles a day justify the change from earth to gravel And if the value of time saving is added, 4 vehicles per day will justify the change

In the computations for the annual transportation cost for Figure 10, no allowance was made for amortizing the $1,000 per mile construction cost of the gravel surface. While a properly maintained gravel road with adequate gravel replacement may be considered to have no definite service life but may be assumed to be perpetually maintained in a condition as good as new, it is evident that the surface must be paid for either out of current income or on borrowed money In Figure 11 an economic comparison between gravel and earth is

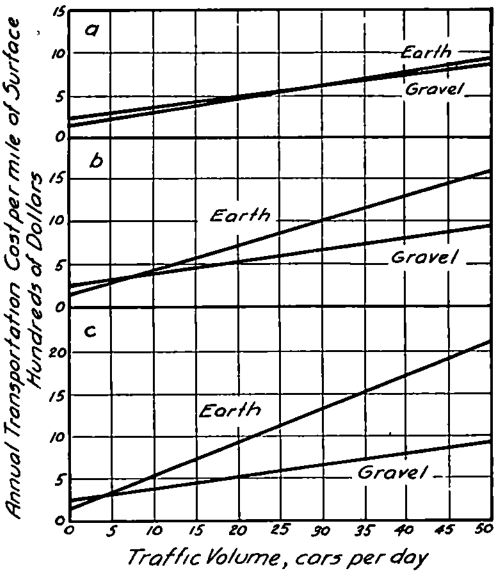

Figure 10. Economic Comparison of Cost of Transportation on Earth and Untreated Gravel for Various Traffic Volumes when Operating Cost Is Based on Various Factors for County Trunk Roads. (Construction cost of gravel = $1,000 per mile and maintenance cost $40 higher for gravel roads than for earth)

(a) Annual cost based on the unit costs on each surface type computed for the same annual mileage and age as the average mileage and age of the entire group of 293 cars

(b) Annual cost based on unit cost on each surface type computed for the average annual mileage and age of cars operating exclusively on each surface type.

(c) Annual cost based on unit cost on each surface type as computed for the cars operating exclusively on each surface type but including also a time factor for slower rates of travel on earth.

made for the same county trunk road as in Figure 10, except that an additional charge for amortizing the investment over a period of 10 years with interest at 4 percent is included. This will add an extra annual cost of $83 29 to the county trunk road and according to the data in Figure 11 (A) will require 72 vehicles per day to justify the change from earth to

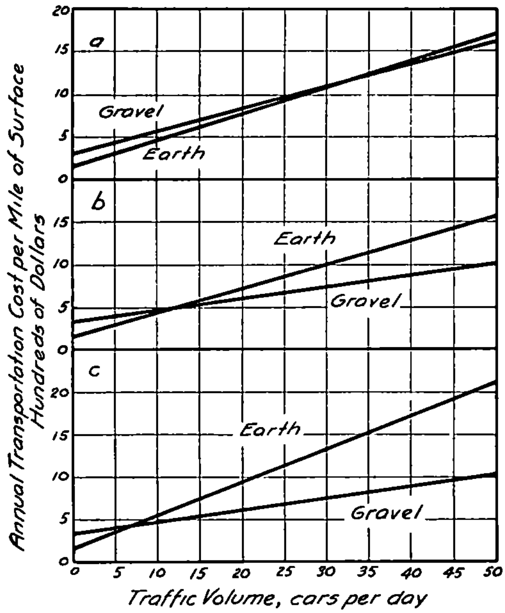

Figure 11 Economic Comparison of Cost of Transportation, including Amortization Cost, on Earth and Untreated Gravel for Various Traffic Volumes when Operating Cost Is Based on Various Factors for County Trunk Roads

(a) Annual cost based on the unit costs on each surface type computed for the same annual mileage and age as the average mileage and age of the entire group of 293 cars.

(b) Annual cost based on unit cost on each surface type computed for the average annual mileage and age of cars operating exclusively on each surface type

(c) Annual cost based on unit cost on each surface type as computed for the cars operating exclusively on each surface type but including also a time factor for slower rates of travel on earth.

gravel based on a 0 6 cent per mile saving in operating cost According to the data in (B) a traffic volume of 12 vehicles per day will be required and (C) indicates that a traffic volume of 7 vehicles per day will be required

In view of these data there seems to be little question but that surfacing of earth roads is justifiable with traffic of 20 or more vehicles per day based on savings in operating costs alone. Nor should the improvement of earth and loose dusty gravel roads be considered a minor problem because in Iowa alone there are still about 60,000 miles of earth roads and more than 30,000 miles of gravel roads in need of improvement At the same time it should be realized that the construction of an all-weather road brings with it many other advantages which cannot be definitely evaluated, such as better fire protection, health protection, and many social, educational, and marketing advantages which accompany the improvement of rural roads.

Economic justification of snow removal Not so many years ago, winter driving in certain sections of the country was attempted only by a few In those days highway departments were in no great hurry to clear the roads of snow and ice Now, with all the improvements in cars which make winter driving comfortable, traffic is almost as heavy in certain sections during the winter as during the summer Snow removal has become a major problem for highway maintenance departments While all departments are attempting to keep the roads open during heavy snows, there are no specific data available to indicate the extent to which expenditure of funds for complete snow removal are justified After giving the matter serious thought, maintenance engineers will readily realize that the costs of operation on snow bear a close relation to the costs of operation on earth roads It is frequently as easy to be stalled in soft snow as it is to be "stuck in the mud" Bucking snow drifts and driving in soft snow consumes extra gas and requires extra time The data in Table 5 of mail carrier car costs on pavement indicate that the cost of gas, oil, and maintenance was 0 5 cent higher during the winter than during the fall Now it is quite possible that a portion of this extra cost was due to the higher cost of operation at low temperatures, nevertheless, during the winter of 1936 for which these records were kept, there was ice and snow to contend with for at least two out of three months Furthermore, if the Iowa Highway Commission had not been fairly prompt in removing snow from its pavements, there would no doubt have been a further increase in operating costs

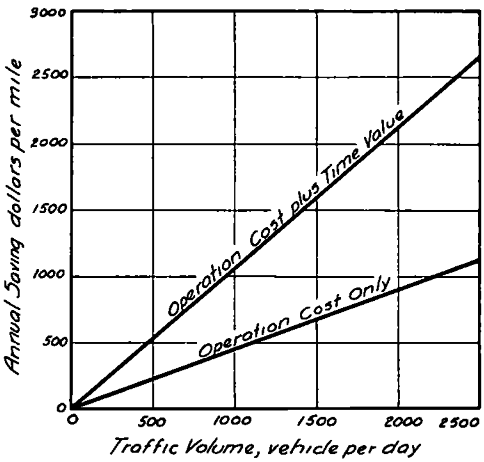

Figure 12 Expense Justified for Snow Removal per Mile of Road Due to Saving in Operating Cost and Time for Various Traffic Volumes during the Winter Season.

Therefore, it seems reasonable to assume that the extra cost of operating on snow and ice during the winter months is 0 5 cent per mile, and that this is the amount which can be saved if the snow and ice is completely removed and the road maintained in a summer driving condition

In Figure 12 the expense justified for snow removal per mile of road due to the above savings in operating cost over a given season is given for traffic volumes ranging from 0 to 2,500 vehicles per day If the saving in operating cost of 0 5 cent per mile is used, an amount equal to

$225 per year for traffic volume of 500 vehicles per day would be justified for snow removal If the saving in cost due to the saving in time, placed at 0 68 cent per mile in this study, is added to the saving in operating cost, an amount equal to about $500 per mile would be justified for the 500 vehicles per day

In arriving at the justifiable expense for complete snow and ice removal, the advantages in reduced accident hazards and savings due to a reduction in accidents have not been evaluated, but an analysis of accident records indicates that a very real saving is possible from this source

It seems appropriate to point out that this study of the economic problems related to operating costs has revealed many ways in which the highway engineer can reduce operating costs if funds are provided to make these savings possible There is no question but that unit operating costs have been reduced But at the same time, in view of the tremendous volume of traffic on our streets and highways and the many opportunities to cut costs, substantial additional reductions are possible

However, this implies that at least some transfer of funds from the car owner to the highway department is necessary That this need really exists is generally not apparent to the individual car owners. Hence, if the highway and traffic engineers are to accept the responsibility of furnishing highway transportation at the lowest cost, it will be part of their job to inform and educate the public along these lines In this way it will be possible not only to reduce unit operating costs but it will greatly enhance the utility of the car itself

SUMMARY

General Description

1. Daily records of 293 cars operated by rural mail carriers on various types of road surfaces in Iowa and Indiana during the year 1935–36 were assembled and analyzed.

2 The road surfaces were divided into three general groups referred to in this study as pavement, gravel, and earth

3 The cars used were largely of the light low priced type and were considered fairly representative of cars used on farm-to-market roads

4 The total travel for the 293 cars amounted to 3,094,546 miles which was very nearly equally divided between the three surface types and the four seasons of the year

The average annual mileage for all the cars was 14,560 miles of which approximately 12,550 miles were on roads on the carriers' routes and 2,010 miles on roads off the routes The average length of route per carrier was 43 miles

Graphical Analysis

1 From the graphical analysis, the average operating cost for cars traveling almost exclusively on gravel and pavement was 3 8 cents per vehicle mile and 7 8 cents per mile for cars traveling almost exclusively on earth

2 The average cost of extra help was 0 2 cent per vehicle mile on gravel and paving and 1 0 cent per mile on earth

3 The unit cost of transportation by replacement of cars with horses, etc , when the roads were impassable to cars, averaged approximately 11 cents per mile as compared to an average cost of less than 5 cents per mile with the cars

4. The trend of the curves in the graphical solution indicated an average annual mileage of 4,000 miles for cars operated 100 percent of their mileage on earth and 20,000 miles for cars operated 100 percent on gravel and pavement

5 The average rate of travel on the route during the year (including stops) was about 14 0 m p h on gravel and pavement and about 7 0 m p h on earth During the summer the average rate on gravel and pavement was 15 4 m.p h

and on earth 10 0 m p h as compared to 12 2 m p h and 6 8 m p h respectively for the winter

6 The unit cost of gas, oil and maintenance increased from an average of about $1\frac{1}{2}$ cents per mile for cars with life mileages under 10,000 miles to $2\frac{1}{2}$ cents per mile for cars with mileages above 40,000 miles. A similar trend was indicated for these costs when related to the age of the car with the curve leveling off for cars 5 years old or older.

Least Squares Analysis

1 From the least squares solution, the average cost of gas, oil, tires, and maintenance for the year was 3 14 cents per vehicle mile on earth, 2 54 on gravel, and 1 55 on pavement

2 The average unit cost of gasoline was 1 35 cents per mile on earth, 1 40 on gravel, and 1 22 on pavement

3 The average unit cost of oil was 0 21 cent per mile on earth, 0 15 on gravel, and 0 09 on pavement

4. The average unit cost of maintenance was 1 24 cent per mile on earth, 0 61 on gravel, and −0 02 on pavement using the straight line solution After correcting these costs for a curvilinear relationship the average unit cost of maintenance was 1 28 cent per mile on earth, 0 74 on gravel and 0 23 on pavement.

5 The average cost of tires was 0 34 cent per mile on earth, 0 38 on gravel, and 0 26 on pavement Tire repair costs averaged 0 02 cent per mile and were the same on all three surface types.

6 The average gasoline mileage obtained on earth was 13 52 miles per gallon, 13 04 on gravel, and 15 02 on pavement

7. The oil used averaged 113 miles per quart on earth, 159 on gravel, and 264 on pavement

8 During the winter season the cost of gasoline averaged 1 58 cents per mile on earth, 1 54 on gravel and 1 50 on pavement, while during the summer these unit costs were 1 13 cents on earth, 1 24 on gravel, and 1 21 on pavement

9 During the winter season the cost of maintenance averaged 1.70 cents per mile on earth, 0 77 on gravel, and 0 28 on pavement while during the summer season these unit costs were 0 63 cent on earth, 0 38 on gravel, and 0 06 on pavement

10 When three separate makes of cars less than 2 years old were considered, the cost of gas, oil, tires, and maintenance for these cars averaged 2 70 cents per mile on earth, 2 47 on gravel, and 1.68 on pavement

11 The total annual cost of operating the "average" car in this study (annual mileage = 14,560) was $702 44 on earth, $615 06 on gravel, and $470 94 on pavement, or 4 83 cents per mile on earth, 4 23 on gravel, and 3 24 on pavement

12 The total annual cost of operating an "average" car based on the above costs, but using a mileage of 8,000 miles per year as a fair average for all cars in the country amounted to $496 46 on earth, $448 46 on gravel, and $369 26 on pavement, or 6 22 cents per mile on earth, 5 62 on gravel, and 4 63 on pavement

13 The multiple correlation coefficient obtained in the least squares solution was 0 89 for the total unit costs, 0 98 for gasoline costs, 0.95 for tire costs, 0 78 for oil costs, and 0 50 for maintenance costs using a straight line relationship and 0 60 for maintenance costs using a curvilinear relationship

Practical Applications

1 A traffic volume of 35 vehicles per day will justify an investment of $1,000 per mile and an extra maintenance expenditure of $40 per year in improving a county trunk earth road with a gravel surface based on the 0 6 cent per mile difference in operating cost If an additional charge is made to amortize this

investment over a period of 10 years, a traffic volume of 73 vehicles per day will justify the change

2 A traffic volume of 7 vehicles per day will justify the improvement from earth to gravel if the factors of mileage, age, extra help, and travel time are evaluated as for the cars in this study and if the extra charge for amortization of the investment is included

3. An expenditure of 0 50 cent per vehicle mile is justified for snow and ice removal during the winter months when the difference in operating cost alone is considered and 1 18 cents per mile when the time factor valued at 40 cents per hour is included

CONCLUSIONS

1 The unit costs for gasoline, oil, tires, and maintenance for cars operating on pavement, gravel, and earth as determined in this study are accurate average values for cars operating under the same conditions as those in this study

2 Accurate cost differentials on the various surface types for such items as oil, maintenance, and depreciation can best be determined by a combined study of the results of long time road tests and life time cost records of cars for which the miles traveled on each surface are known

3 The time factor is an important item related to cost which may easily be determined by means of speed surveys and delay studies of cars on each surface for each season during the year

4 A considerable increase in revenue for secondary roads is justified to eliminate mud roads and loose, dusty, washboarded gravel and macadam roads on which operating costs are from 1 cent to 8 cents per mile higher than on pavement or on stabilized roads

5 Highway departments in the northern states are justified in an annual expenditure for snow and ice removal at the rate of more than $500 per mile of road per 1,000 vehicles of traffic per day in view of savings in operating cost, time, and the reduction of accidents resulting from complete snow and ice removal

6 With unit operating costs ranging from 2 cents per mile to 12 cents per mile for passenger cars, an average saving of 1 cent per vehicle mile or a total annual saving of 50 million dollars in the state of Iowa and two-and-a-half billions of dollars for the country as a whole, is a goal worthy of the organized and well directed efforts of all engineers and car owners who control the vast expenditures for highway transportation

ACKNOWLEDGMENTS

The preliminary work on this project was carried on largely under the direction of Robley Winfrey, Research Engineer, for the Iowa Engineering Experiment Station By the time the project was actually under way and cost records were being sent in, Mr Winfrey was on leave with the Bureau of Public Roads, and the supervision of the project was turned over to the writer

Much of the detailed work in connection with the assembling and summarizing of the cost data has been done under the supervision of Edwin R Davis, Louis W Herchenroeder, and Clarence W Rice, research assistants of the Experiment Station Special credit is due Mr Rice for his assistance in bringing the data into their present form and in the preparation of this report A large portion of the detailed office work was done by a staff of N Y A student workers

Special thanks are due the rural mail carriers who cooperated in every way possible to provide us with the information and cost data which have made this report possible