REPORT OF COMMITTEE ON ECONOMIC THEORY OF HIGHWAY IMPROVEMENT

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The committee presents three progress reports on projects now under way under the direction of members of the committee Three of these will merely be mentioned, while the fourth, which contains some data that are new and very significant, will be read by the author

The first is a statistical report on automobile and truck operating costs and some conclusions based on a study thereof.

The second is a report on some researches that have been made with a specially designed tire tester, which includes some hints of possible errors in some of the assumptions heretofore made with reference to the measurement of rolling resistance

The fourth is a report on air resistance of automobiles based upon a new method of observation It will be presented by the author.

In previous reports it has been pointed out that the major function of the committee is to segregate the elements of cost involved in the general item of cost of highway transportation. In attempting to segregate the several items of cost the committee has been particularly interested in those items that are affected by road conditions, and consequently our studies have led us into investigations in the field of coefficient of friction between tires and road surfaces, tractive resistance, which is usually thought of as consisting of rolling resistance and air resistance, and similar studies that have to do with the relation between the physical characteristics of roadway surfaces and the cost of operating vehicles over those surfaces

Three years ago reports were presented indicating some progress in arriving at conclusions with reference to the way in which some of these factors affect transportation costs Investigations that have been under way since that time and upon which progress reports have been presented have gone a good way toward upsetting some of the ideas that had previously been formed Two years ago, Prof. W. C. McNown of the University of Kansas presented a report showing the relation between road surface conditions and tire wear. A similar report was presented by Professor Waller of the State College of Washington, and those two reports check each other fairly well It happened that the two investigations were made entirely independent of each other, and the investigators knew very little about the work done at the other place until the final reports were pretty well along toward completion Those

investigations were made with high pressure tires, types such as are at present used on commercial vehicles and not used to any great extent on automobiles. Following the completion of this first series, a new series of studies was made with low pressure tires such as are at present generally employed for automobiles

The present status of that work indicates that the tire wear relations that prevailed with the high pressure tires did not prevail with the low pressure tires, and that some of the types of roadway surface and some certain conditions of roadway surface that contributed to a high rate of wear with the high pressure type of tires, do not contribute to a high rate of wear with the low pressure types Consequently some assumptions with reference to the relation between tire wear and cost of transportation had to be revised Further studies of the relation between type and condition of roadway surface and the rate of wear with the low pressure types of tires are under way and will have to be completed before it will be possible to draw final conclusions with reference to that matter

It was recognized that there is a definite relation between the factor called tractive resistance, and the cost of transportation In the early years of the work engineers were thinking specifically of the differences that exist in the rolling resistances of various types of roadway surfaces, and more especially the difference that exists between the low types of roadway surface and the high types It is quite well understood that the rolling resistance of a muddy earth road is considerably higher than that of a high type pavement That needs no particular investigation The magnitude of that difference however, needed to be measured, and was measured However, this factor of tractive resistance is made up of two kinds of effects One is the effect that we call rolling resistance which is the interaction between the tire and the roadway surface The other is air resistance Three or four years ago air resistance was considered in terms of average speeds around 30 to 35 miles per hour and on that basis the factor of rolling resistance had considerable significance, since it might be as much as 50 or 60 per cent of the total force to be overcome by the mechanism of the vehicle Today tractive resistance must be thought of in terms of top speeds of 50 miles per hour and upwards There are bus systems operating upon schedules that require top speeds in excess of 50 miles per hour Nothing need be said about the speed of the privately owned automobile One cannot sell an auto nowadays unless it will demonstrate up to 70 miles an hour or thereabouts So the factor of air resistance has become exceedingly important in this problem and what is of more significance, the residue of tractive resistance has shrunk from around 50 per cent to around 25 per cent Therefore that portion of the total resistance that can be affected by anything the highway engineer does is around 25 to 30 per

cent, and even if he were able to cut in two that 25 or 30 per cent, the aggregate effect on the cost of transportation would be relatively small

In view of these changes in the situation the researches of the last year or two have led into blind alleys and the reports that are submitted today are in the nature of progress reports on projects intended to bring out some of the factors that are developing along with this change in the traffic situation 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

In discussing road costs heretofore the committee considered that the total cost of a highway is made up of the following factors (*a*) interest on investment, (*b*) depreciation, or as some prefer to state it, the amortization cost, (*c*) maintenance and interest thereon and (*d*) operating costs The item of operating cost has been neglected in most statements of road costs, because it is an exceedingly small factor Of the other items the one that has the most significance is maintenance cost In attempting to determine the relative merits of two systems of construction, such as intermediate type and high type, it is necessary to make an estimate of the probable cost of these types, under the traffic conditions assumed, throughout the useful life of the surface, and account must be taken in connection therewith of the probable maintenance cost of the surface

The only criterion by which to judge the maintenance cost of a given type of surface is the record of what the maintenance cost has been in cases where the road has been used under known conditions The committee has checked up on records of cost of maintenance as they have been reported by various agencies and has found that with almost every type the curve of maintenance cost is concave upwards, that is, the maintenance costs tend to increase with age and, in most cases, rather rapidly towards the end of the useful life of the road Some studies made on the basis of reported costs yielded results that were evidently incorrect, even absurd A little further investigation of the reason for the peculiar form of these curves revealed the fact that in part the increase in maintenance cost was due to an increase in the traffic, not to an increase in the ton mile rate of deterioration of the road surface It therefore became necessary to find out the relation between traffic density and maintenance cost, and it is upon that point that several members of the committee are working at the present time The only way in which to arrive at useful facts is through reported costs that have been prepared by agencies in charge of road improvement

TABLE I

Average Cost of Automobile Operation

Based on detailed cost records covering about 1200 automobiles operated in various parts of the United States and an average of 11,000 miles per year. The reports were largely from fleet operators who purchase supplies at wholesale and the items of gasoline and tires have been converted to retail price basis

Type of car / Gross weight tons (approx.)	Light 4[b] Average 0 86		Medium 4[c] Average 1 08		Heavy 4[d] Average 1 4		Light 6[e] Average 1 41		Medium 6[f] Average 1 66		Heavy 6[g] Average 1 86	
Item[a]	Dollars per year	Cents per mile	Dollars per year	Cents per mile	Dollars per year	Cents per mile	Dollars per year	Cents per mile	Dollars per year	Cents per mile	Dollars per year	Cents per mile
1. Gasoline at 20 cents per gallon	147 40	1 34	125 40	1 14	144 10	1 31	149 60	1 36	167 20	1 52	157 30	1 42
2 Oil	27 50	25	18 70	17	17 60	16	19 80	18	22 00	20	18 70	17
3 Tires and tubes	66 00	60	71 50	65	77 00	70	82 50	75	88 00	80	99 00	90
4 Maintenance	170 50	1 55	210 10	1 90	227 70	2 06	214 50	1 95	236 50	2 14	278 30	2 53
5 Depreciation	137 50	1 25	154 00	1 40	172 70	1 57	192 50	1 74	229 90	2 09	282 70	2 57
6 License	12 00	11	15 00	14	22 00	20	22 00	20	26 00	24	30 00	27
7. Garage at $4 00 per month	48 00	44	48 00	44	48 00	44	48 00	44	48 00	44	48 00	44
8. Interest at six per-cent	30 00	27	42 00	38	60 00	55	60 00	55	78 00	71	95 70	87
9. Insurance (Fire, theft, tornado, liability)	23 00	21	22 00	20	23 00	21	23 00	21	28 00	26	30 00	28
Total	661 90	6 02	706 70	6 42	792 10	7 20	811 90	7 38	923 60	8 40	1039 70	9 45
Annual mileage	11,000		11,000		11,000		11,000		11,000		11,000	
Average miles per gallon gas	14 95		17 53		15 29		14 68		13 19		14 02	

[a] 1 From reported costs reduced to uniform price per gallon
2 Average reported
3 Based on average retail prices of tires
4 and 5 Reported for vehicles that had been operated for a period and then sold
6 At the Iowa rate, i e , 40 cents per cwt plus 1 per cent of list price

[b] Light 4—Fords all types
[c] Medium 4's—Chevrolet, Star, Overland
[d] Heavy 4's—Dodge, Nash, Maxwell, Chrysler, Oldsmobile, Hupmobile
[e] Light 6's—Essex, Chrysler, Oldsmobile, Studebaker, Oakland
[f] Medium 6's—Chrysler, Buick, Jewett, Studebaker, Nash, Chandler
[g] Heavy 6's—Buick, Studebaker, Hudson, Paige, Reo

and who are keeping their costs in such terms that they are useful in such a comparison That means a report of the maintenance cost of a given type of road per annum and a record of the traffic, so that maintenance can be expressed in terms of the cost per unit of traffic per annum. Some of the state highway department organizations are now recording their maintenance costs in those terms, and those that have been most useful have come from these sources Some of the cities are doing the same thing and before long there will be enough information of this character to enable satisfactory conclusions to be reached with reference to the general subject of road costs as related to traffic

. The situation with reference to automobile operating costs, or more properly, vehicle operating costs is somewhat the same. The higher speeds that are becoming common, the lowered cost of the vehicle itself, the better mechanical construction of the vehicle, and the betterment of road surfaces, have all contributed to decrease the average cost of operating an automobile, and that decrease over the past five years has been quite material Records have been studied by the committee covering a period of about five years and some recent statistics have been prepared that may be summarized as follows in Table I.

The statistics showed that a great many people are unable to operate their vehicles at anywhere near the general average cost for careful operators of individual vehicles or fleets There were many reports in which the cost reached as much as twelve cents per vehicle mile Taking account of these costs and the various factors of tire wear, gas consumption and similar items, the present indication is that for composite traffic—as our automobile traffic is made up of all weights and sizes and ages—but making no allowance for the drivers' time value, (which some people think we ought to include but which we have not included up to this time), the value of changing from a low type surface to an intermediate type surface ranges from three-quarters of a cent to a cent per vehicle mile If you consider the average cost the year round on a low type surface under all conditions in which that surface may be found and compare that with similar operations over an intermediate type, the difference is likely to lie somewhere between three-quarters of a cent and a cent per vehicle mile A similar comparison between intermediate type surfaces and high type surfaces indicates that the difference is likely to lie between three-quarters of a cent and one and one-quarter cents per vehicle mile.

DISCUSSION

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CHAIRMAN UPHAM I would like to ask Professor Agg if the difference in cost of three-quarters of a cent and one cent was vehicle operating costs?

PROFESSOR AGG That was the difference in vehicle operating costs between the two types

MR W H ROOT, *Iowa Highway Commission,* Our costs on low type, four cylinder cars, on maintenance work, operating about 40,000 miles in a year and a half, run three cents or less

MR W B CATCHINGS, *North Carolina* I would like to ask if this cost includes depreciation and interest on equipment

PROFFESSOR AGG It does The depreciation was arrived at in this way We took records showing what was paid for a car to start with and what was received when it was turned in We assumed that the difference between the trade-in value and the original price was depreciation and distributed it over the period of operation of the vehicle

MR CHARLES B WOOSTER Were these differences in operating costs based on busses or cars?

PROFESSOR AGG These figures I gave you as comparisons of operating costs were all on automobiles While we have had costs ranging around three cents per mile the average is upward of six cents per mile, and this three-quarters of a cent to a cent saving is on the general average of automobile operating costs, per vehicle mile Undoubtedly a similar saving is made by the bus but we do not have the data