# THE EFFECT OF HEAVY MOTOR VEHICLES ON HIGHWAY COSTS

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## SYNOPSIS

The more or less unrestricted use of the highways by the heavier types of motor vehicles has given importance to the problem of the effects of such vehicles upon the costs of highway construction and maintenance This paper is largely a discussion of the relative effects of heavy and light vehicles upon the various items that affect design and cost Included in the discussion are statistics on the number of vehicles in each class, taxes paid by motor vehicles, weights and dimensions of trucks and buses, mileage of roads and pavements, and freight ton-miles handled by the various transportation agencies

The conclusion of the author is that widths, gradients, alignments and all other elements of design of modern highways, except possibly the thickness of pavement, are determined by the requirements of private passenger automobiles which comprise over 80 per cent of all motor vehicles The heavier vehicles, having a rated capacity of 1½ tons or more, comprise about 2 5 to 3 per cent of all motor vehicles using the roads and city streets The presence of these heavier vehicles may require some additional thickness of pavement but it is probable that this increased thickness may be economically justified by longer life and reduced maintenance In any event the additional cost of the extra thickness for high type pavements cannot be estimated at over $2000 to $4000 per mile

The writer recently had occasion to look into this phase of highway economics and was impressed by the conflicting testimony and the positiveness with which entirely different statements have been made and maintained He has therefore endeavored to ascertain and set forth herein as nearly as may be, what seems to him to be a reasonable statement of the situation as it now appears

It is specifically not the purpose of this paper to prove that the heavier motor vehicles pay or do not pay for a fair share of the road facilities which they use, but only to discuss the question of the effect of these heavy vehicles on highway costs

It is or should be evident, however, that such a discussion as is proposed cannot be confined to an isolated technical engineering opinion of the extra cost of this or that pavement due to the presence of certain types of vehicles It has been considered necessary, therefore, to include certain observations of the social, political and economic aspects of the problem that seem pertinent to a proper understanding of it

The survey of the Bureau of Railway Economics[1] says: "The problem of motor vehicle transportation affects the future economic welfare of the United States" If this be true, and the writer thinks it is, the problem should certainly be approached without bias and with a determination to ascertain if possible what the real economic factors are.

It is, of course, evident on the most cursory examination that the problem is in some degree, perhaps in large degree, indeterminate, especially as a whole Highways are of many different kinds, superhighways, city streets, improved main through routes, rural roads, etc, all of which carry all sorts of vehicles, the types of which are almost innumerable, and the conditions of operation extremely variable. In spite of all this, it is felt that there is a possibility of at least properly envisaging the problem, of showing what some of the important influencing factors are, and perhaps reaching some conclusions

Attention may here be called to the confusion which often occurs in statements as to costs of *highways*, which may be considered to include right-of-way, grading and drainage, as well as pavement, and as to the costs of *pavement* alone This makes for confusion in statements as to the proportion of total highway costs chargeable or possibly chargeable to heavy vehicles

*The Tax Burden*

As already indicated, it is not the intention or purpose of this paper to discuss governmental policies of taxation or regulation of commercial motor vehicles or the policies which have motivated the very heavy expenditures for highway construction in recent years, or how these costs should finally be met or distributed It does seem worth while, however, to try to examine impartially one phase of that problem, namely the question of the effect of these heavy commercial vehicles on highway costs, as this item, affects their distribution between motor vehicle taxpayers of different classes and other taxpayers who may or may not benefit thereby.

Practically everyone is a taxpayer and therefore interested in the equitable distribution of the tax burden. The railways are interested both as large taxpayers and because of the competition of trucks in the haulage of freight, and many of the large commercial and industrial corporations have an important interest as every branch of business is affected in greater or less degree by transportation.

*General Highway Uses*

In one sense, of course, every highway is a feeder to the railways, heavy trucks must use these highways to connect the railways with the

[1] An Economic Survey of Motor Vehicle Transportation in the United States Bureau of Railway Economics, 1933

original source of supply and ultimate destination, hence highways must be capable of accommodating heavy vehicles whether they compete with the railways or not They are today an integral part of the business life of the nation

The Minnesota highway law has for many years provided that all structures shall be designed to carry safely a theoretical farm tractor having a load of 5 tons on the front axle and 15 tons on the rear axle This is an essentially farming country and generally speaking this bridge loading was in common use prior to the advent of the motor vehicle. There is therefore nothing new in the use of highways by heavy vehicles.

In regard to the general problem, the National Transportation Committee headed by the late Calvin Coolidge, former President, stated:[2]

> "The Committee found the problem of the automobile 'very difficult' . . Nevertheless automotive transportation is seen as an advance in the march of progress, something which is here to stay "

They recommended certain regulation, but with that, the present discussion is not concerned, the interest is in the statement that we must consider automotive transportation as an advance in progress which is here to stay.

*Use of Heavy Motor Trucks by Private Corporations*

The railways are making more and more use of the highways as auxiliaries The Financial Chronicle of September 1, 1934, lists 125 large corporations which employ 154,966 trucks. These range from 13,600 of the American Telephone & Telegraph Co to 1197 of the Western Dairy Products Co , 320 of the Postal Telegraph Co , to 130 for the Boston Elevated Railway Co , etc.

It seems probable that most of these trucks are employed in local haulage, many on city streets, although some are undoubtedly direct competitors of railways and users of through highways.

It is difficult to see just how this affects the problem but it is a factor because, of course, these large industrial corporations are general taxpayers as are the railways and the effects of any vehicles on highway costs are due to their number as well as their weight.

*Military Use*

One other phase of the situation must be borne in mind when considering the apportionment of costs among the users or the general taxpayers and that is the military aspect Mobility and transportation have become factors of the very highest importance in military operations and there is no doubt that in the design of main highways and even secondary highways, some consideration, in some cases even a great deal of consideration, should be given to the possible use of the highways for military purposes. This, of course, is a matter for general taxation

[2] Report of National Transportation Committee, Feb 1933

*Rights of Light Vehicles*

The "Community use" of highways and the inherent rights of persons and certain types of vehicles to their use is generally recognized. In a brief[3] submitted to the Interstate Commerce Commission on behalf of the Louisville and Nashville R R Co and the Nashville, Chattanooga and St Louis Ry in re co-ordination of motor transportation, Counsel for the railways stated:

"It is recognized that the private passenger car (automobile) as an agency of transportation has added much to the pleasure, comfort, health and welfare of the public

"The small privately-owned and privately operated motor truck (not engaged in the business of regular transportation), fills a definite need especially in rural communities and on farms "

In an editorial in the Railway Age of March 11, 1933 it is stated that: "The use of a highway by an automobile or a farmer's or merchant's light truck is an ordinary public use It's use by the operator of a heavy bus or truck, who engages in transportation for hire is private use for private profit."

NATURE OF THE PROBLEM

The relation of truck haulage to railway traffic is indicated by the recent report of the Federal Co-ordinator of Transportation, the Hon Joseph B Eastman, who gives (N Y Times, March 13, 1934) the following figures, showing the percentage of freight ton-miles handled by the various transportation agencies in the United States in 1929 and 1932:

| | Ton miles 1929 | Per Cent 1932 |
|---|---|---|
| Steam Railroads | 72 9 | 73 9 |
| Great Lakes | 15 8 | 7 8 |
| Pipe Lines (petroleum) | 5 2 | 6 2 |
| Inter-City Trucks | 4 2 | 9 4 |
| Inland Water-ways | 1 4 | 2 5 |
| Elec rep and airplanes | 0 5 | 0 2 |

The increase in the percentage attributed to the railways is accounted for by the considerable decline in Great Lakes traffic, and it is pointed out that while trucks handled a comparatively small percentage of the "ton-miles" they handled 23 8 per cent of the total "tons" moved, their usual field of action being less than 300 miles

Some other figures of interest in this connection are the following: The total appropriations (receipts) for highway purposes in the United States for 1929, '30, '31, were as follows:

| | |
|---|---|
| 1929 | $1,646,030,433 |
| 1930 | 1,860,741,853 |
| 1931 | 1,819,643,556 |

[3] Interstate Commerce Commission Docket 23400

Of the above (and for some subsequent years), there was appropriated by the Federal Government:

| | |
|---|---|
| 1929–30 | $ 75,000,000 |
| 1930–31 | 125,000,000 |
| 1931–32 | 125,000,000 |
| 1932–33 | 125,000,000 |
| 1933–34 | 400,000,000 |

The total mileage of highways in the United States is given as:

| | | |
|---|---|---|
| Non-surfaced | 2,315,507 miles | 76 9% |
| Low type pavement | 567,851 miles | 18 9 |
| High type pavement | 125,708 miles | 4 2 |
| | 3,009,066 miles | 100 0% |

*Amount of Taxes Paid by Motor Vehicles*

The total fees and taxes paid in 1932 by all motor vehicles in the United States, were[4] very close to $983,488,934, which as will be noted is about half the total "receipts" from all sources The vehicles which paid these taxes are classified as follows·

| | Proportions of Various Types of Vehicles |
|---|---|
| Passenger, including taxi-cabs | 20,836,362 |
| Busses | 49,452 |
| Trucks | 3,229,315 |
| Trailers | 415,276 |
| Motorcycles | 89,197 |
| | 24,619,602 |

Of the trucks, 2,681,985 or 83 05 per cent were of 1½ tons or less About 2 25 per cent were of 5 tons or over (See "rating" further on.)

There are indications that these percentages of types of vehicles do not vary greatly in different sections of the country, close agreement being shown in such widely separated and differing states as Missouri, New York, and Arizona

A recent survey of trucks entering the State of Kansas during May, 1934, showed that they carried an average load of 2 6 tons each The average load of the trucks crossing the State was 3 8 tons per vehicle and the average for all trucks observed was 2 8 tons

Adding together the number of busses (49,452) and the number of trucks over 1½ tons (547,330) and assuming that 10 per cent of the trailers (41,527) might be rated as over 1½ tons, we have a total number of 638,309 heavy vehicles or 2 6 per cent of the total (A different

[4] "The Taxation of Motor Vehicles in 1932," T H MacDonald, Report of Committee on Highway Finance, Proceedings Highway Research Board, Vol 13, p 27.

classification of the trailers would change these figures but would not materially affect the general argument )

The problem seems to be, therefore, what effect 2 6 per cent of the total number of registered motor vehicles have on the costs of highway construction And probably this may be confined to a consideration of what effect these vehicles have on the costs of the 4 2 per cent of the total mileage of highways with high type pavements. See also further note as to the use of many of these heavy vehicles on city streets, page 81.

*Truck Ratings—Gross Weights*

Considerable confusion exists in the relation between the so-called "rating" of trucks and their actual carrying capacity and gross weight "Overloading" is often cited as the difference between the "rating" and actual loads carried Manufacturers' catalogues, however, usually quote the so-called "Rating" and with it the "Gross allowable weight " The latter figure takes care of the differences in weights of the different types of bodies, and is the allowable weight of chassis, body and load combined. The following table shows approximately the relation between the so-called "Rating" of trucks and their total weights:

| Rating Tons | Gross Allowable Weights Pounds |
|---|---|
| 1½ to 2 | 11,000 to 13,000 |
| 2½ to 3 | 14,000 to 16,000 |
| 3 to 4 | 17,000 to 24,000 |
| 3½ to 6 | 30,000 |
| 7 to 9 | 34,000 |
| 9 to 11 | 40,000 |

It is seen that "gross allowable weights" or "gross maximum recommended weights" vary greatly with the kind of truck, character of body, etc , but these figures give at least an approximation of the actual total weights of each class Further overloading which is not uncommon, is not considered

The distribution of weight between the front and rear axles of fully loaded trucks appears to vary from 30–70 to 20–80 per cent depending, largely on the design

Trucks with trailers for special purposes with capacities as high as 30 to 35 tons are in use. It seems somewhat doubtful, that such abnormal vehicles should be allowed on the roads even though these enormous moving weights are distributed so as to keep the individual axle loads within the limits of a so-called 10-ton truck with a maximum of 15 tons on the rear axle Consideration of these extremely heavy vehicles would probably confuse the issue, as it is proposed to discuss it here, that is to say, the effect on highway costs of trucks from 1½ tons to 10 tons rating

*Dimensions of Trucks and Busses*

The general dimensions of ordinary trucks are:

| | |
|---|---|
| Widths | 7 to 8 ft |
| Lengths | 30 to 40 ft |
| Heights | 10 to 12 ft |

Regulation of dimensions of motor vehicles, especially widths, is in effect in most States, but there are considerable variations as follows:

| | |
|---|---|
| Height limits between | 12 ft and 14 ft 6 in |
| Width limits between | 7 ft and 8 ft 6 in |
| Length of single vehicles | 28 ft and 40 ft |
| Length with trailer | 40 ft and 85 ft |

TABLE I

DIMENSIONS AND WEIGHTS OF YELLOW COACHES

(Product of General Motors Truck Corporation, Pontiac, Michigan)

| | Overall Dimensions—In | | | Loaded Weight—Lb | | | Weight Without Load—Lb | | |
|---|---|---|---|---|---|---|---|---|---|
| | Length | Width | Height | Front | Rear | Total | Front | Rear | Total |
| *City Service Coaches* | | | | | | | | | |
| 17 Transit | 238 | 84 | 106 | 5150 | 5250 | 10400 | 3960 | 3640 | 7600 |
| 21 Transit | 272 | 84 | 107 | 5080 | 6740 | 11820 | 4175 | 4525 | 8700 |
| 23 Transit | 301 | 84 | 107 | 6050 | 8300 | 14350 | 5110 | 5590 | 10700 |
| 30 Transit | 348 | 96 | 108 | 7000 | 11910 | 18910 | 5050 | 9080 | 14130 |
| 41 Transit | 396 | 96 | 106 | 8140 | 15700 | 23840 | 5040 | 12500 | 17540 |
| *Intercity Coaches* | | | | | | | | | |
| 20 Tr Parlor | 301 | 84 | 107 | 6500 | 8600 | 15100 | 5700 | 6250 | 11950 |
| 29 Pass Parlor | 365 | 96 | 113 | 9405 | 12795 | 22200 | 7125 | 9375 | 16500 |
| 33 Pass Parlor | 396 | 96 | 113 | 9835 | 13925 | 23760 | 7290 | 10110 | 17400 |

All coaches are equipped with pneumatic tires All but 17-passenger Transit have dual rear wheels

Governed speed of City coaches, 38–45 miles per hour

Governed speed of Parlor coaches, 50–60 miles per hour

Governed speed refers to coach speed mechanically possible with standard tires and gear ratio in direct gear at governed engine speeds

No data available as to coach performance on varying gradients

Most of these commercial trucks are capable of speeds of 35 to 40 miles per hour on ordinary good roads with light gradients. A truck capable of running 40 miles per hour on gradients up to 2 per cent can travel at about 20 miles per hour on 5 per cent and perhaps 10 miles per hour on 10 per cent grades. All these, of course, are very approximate and subject to variation

The general dimensions and weights, of busses of various traffic capacities are given in Table I.

BRITISH REPORT

CONFERENCE ON RAIL AND ROAD TRANSPORT

A very careful analysis of the factors entering into the use of roads by mechanically propelled vehicles of various types was made in England a year or two ago and is set forth in the "Report of the Conference on Rail and Road Transport" in Great Britain, made in July 1932

In passing, it may be noted that this report was unanimously agreed to by representatives of all the interests involved, railroads, merchants, manufacturers, all classes of road users, etc

After determining the annual road costs which it was considered proper that the motor vehicles as a whole should pay, a careful study was made of the reasonable allocation of these costs to the various types and weights of vehicles For this purpose, consideration was given to distribution of the costs according to—

Speed-tons
Petrol consumption
Ton-miles

The first of these (weight, times normal speed per hour) was rejected, and finally, equal weight was given to the last two, with some modifications in the way of extra taxes for the heaviest type, and also some increases for speeds and range of action, of some of the lighter vehicles

*British Vehicle Taxes*

Typical adjustments (increases), of the taxes on ordinary commercial freight trucks which resulted from this study are shown in Table II The money figures are pounds sterling, which may be roughly converted into dollars at $5 to £ 1.

It may be interesting to note the relative numbers of trucks of various weights in Great Britain as shown by this report:

| | |
|---|---|
| 12 cwt to 2 tons | 266,356 |
| 2 tons to 6 tons | 74,616 |
| Over 6 tons | 2,280 |

Of 46 trucks over 10 tons the average loaded weight was about 18 tons each and it will be noted that the proportion over 2 tons is about 20 per cent or approximately the same as in the United States

In discussing the effect of the heavier types of vehicles the report says:

"We have had evidence, though it is admittedly and necessarily based upon judgment rather than exact calculation, that the heaviest classes involve some extra expenditure in road construction and maintenance and some extra wear and tear beyond what would be involved in the passage of the same weight over the same distance in smaller units It was tentatively estimated with the aid of expert evidence from the Ministry of Transport that if there were no vehicles of more than four tons weight unladen, either for passenger or goods traffic, the annual road expenditure might be reduced by between 2 per cent and 3 per cent, and if this is true of the class as a whole it may be taken to be increasingly true with each increase of weight within the class Very heavy vehicles thus entail some greater expenditure in road construction and maintenance (and often by their bulk and shape some greater use and disturbance of the common amenities of the road), than the same weight in smaller units, when they travel long distances and are permitted to travel on unclassified roads over the whole country But this is not so when they are working within a narrow radius over roads or streets that would in any event, be eminently suitable for such traffic For transport, for example, from docks through congested streets to a factory in the same town, it is probably better from every point of view that a given weight should go in large units"

TABLE II

| Description of Vehicle Unladen Weight | Annual License Duty Recommended | | Present Annual License Duty | |
|---|---|---|---|---|
| | Vehicles Fitted with | | | |
| | Solid Tires | Pneumatic Tires | Solid Tires | Pneumatic Tires |
| | £ | £ | £ | £ |
| *Other goods vehicles—internal combustion* | | | | |
| Not exceeding 12 cwts | 10 | 10 | 10 | 10 |
| Exceeding 12 cwts but not exceeding 1 ton | 14 | 14 | 15 | 15 |
| Exceeding 1 ton but not exceeding 1½ tons | 20 | 20 | 20 | 20 |
| Exceeding 1½ tons but not exceeding 2 tons | 26 | 26 | 25 | 25 |
| Exceeding 2 tons but not exceeding 2½ tons | 41 | 33 | 35 | 28 |
| Exceeding 2½ tons but not exceeding 3 tons | 45 | 36 | 40 | 32 |
| Exceeding 3 tons but not exceeding 4 tons | 67 | 54 | 48 | 38 |
| Exceeding 4 tons but not exceeding 5 tons | 91 | 73 | 54 | 43 |
| Exceeding 5 tons but not exceeding 6 tons | 135 | 108 | 60 | 48 |
| Exceeding 6 tons but not exceeding 7 tons | 156 | 125 | 60 | 48 |
| Exceeding 7 tons but not exceeding 8 tons | 189 | 151 | 60 | 48 |
| Exceeding 8 tons but not exceeding 9 tons | 229 | 183 | 60 | 48 |
| Exceeding 9 tons but not exceeding 10 tons | 282 | 226 | 60 | 48 |
| With an additional duty for each additional ton unladen weight in excess of 10 tons of | 40 | 32 | | |
| With an additional duty, in any case, if used for drawing a trailer of | 16 | 16 | 6 | 6 |

Some of the conditions under which roads are used and which affect a fair allocation of charges against the users, are indicated in the following paragraph

"Motorcycles, with a franchise over the whole road system, with an unlimited speed, a tendency to concentrate upon weekends in the summer when congestion is at its worst, and involving a noise which seriously diminishes the amenities of the roads and the peace of those who live near them, enjoy a use of the roads which is not fully measured by combining their light weight and the low-average mileage that results from comparative disuse during the less crowded seasons and days The greater average distance of the commercial vehicles on the other hand is spread more evenly over more days in the week and more weeks in the year, and though this does not affect wear and tear, it certainly makes a difference to the use of the road and makes them a smaller factor in the congestion which largely necessitates widening, straightening, etc These considerations must not be ignored But at the same time they must not be put very high in view of the more manageable and adaptable character of small vehicles "

These quotations from the report of the British Conference seem to the writer to be an eminently fair summing up of the situation and are worth careful reading and consideration.

## WIDTHS OF PAVEMENTS

In the early days of roadway improvements made necessary by the development of motor vehicles, 20 to 25 years ago, pavement width of 16 ft wide (two 8 ft lanes) was considered sufficient This, however, was soon found to be inadequate for comfortable and safe operation of ordinary private passenger automobiles traveling at speeds in excess of 15 to 20 miles per hour

Further improvement provided hard dirt, or lightly paved shoulders two feet or more in width outside of the pavement, and for a good many years few, if any, two-lane roads have been built with pavements less than 18 ft. wide, (two 9-ft lanes). In many cases they have also hard shoulders two feet or more wide on both sides See also notes under Highway Costs page 96.

Recent practice on roads of any importance, that is to say, with a traffic of 500,000 to 1,000,000 vehicles per annum, tends toward the construction of 10-ft lanes with shoulders 2 to 5 ft. in width outside the pavement and this width may now be considered standard for roads of the first class, say with a traffic of over 1,000,000 vehicles per annum There is a general tendency to make 20 to 30 ft the standard effective width of all roads

Professor Breed[5] states his opinion that where the traffic density is less than 500 vehicles per day and there are no heavy vehicles, a width of 16 ft. is sufficient and where the density of the traffic is between 500 and 3000 vehicles per day 18 ft, suitably widened on curves, is sufficient In considering this statement, it must be borne in mind that any and all roads may be traversed by some heavy vehicles.

Professor Breed's comparison is based entirely on the static relation of width of vehicle to width of pavement He shows by a diagram (Fig 1) that two passenger cars, each 5 7 ft wide, on an 18 ft pavement, have clearances of 1 2 ft. from the edges of the pavement and 4.2 ft. between the vehicles On the diagram this looks ample and comfortable.

[5] Relative Road Costs for Heavy Motor Vehicles as Compared with Automobiles and Light Trucks." By C B Breed, A Report to the Associated Railroads of Pennsylvania, 1933

Anyone who has driven at 35 to 40 miles per hour, to say nothing of the not unusual speeds of 50 to 55 miles per hour, in open country even on 20 ft pavements will, however, realize that to the drivers of such cars

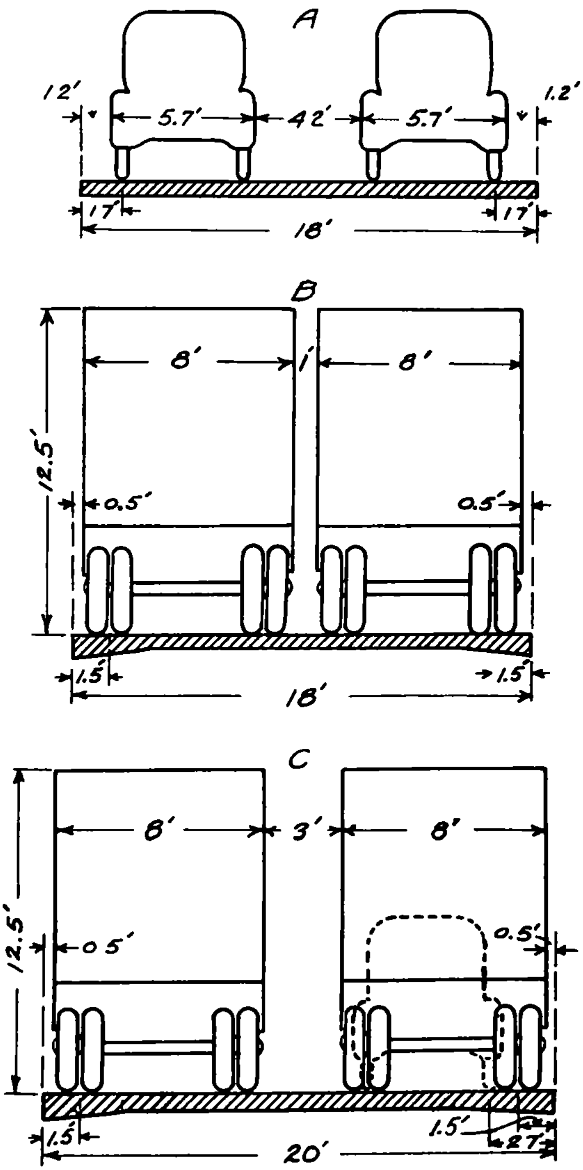


**Figure 1. A Passenger Cars Passing on an 18-ft. Pavement. B. Trucks of Maximum Allowable Size Passing on an 18-ft Pavement. C. Trucks of Maximum Allowable Size Passing on a 20-ft. Pavement. The outline of the passenger car shown in its normal position and superimposed upon the truck outline indicates how the maximum size truck obstructs the view for the passenger car.**

this theoretically ample space does not appear to be so generous. (See also the following notes on "Accidents ")

*Speed*

The effect of speed on highway design and construction is developing into a most important factor In Oregon,[6] the highway authorities have decided to locate and design their roads for speeds of 90 to 100 miles per hour

A speed census in Connecticut,[6] covering 45,000 timed cars has shown a maximum speed of 75 miles per hour with an average for all cars of 41 2 miles per hour

It is very evident, therefore, that a static diagram such as that of Figure 1, of the relation of widths of stationary vehicles to width of paved roadways does not tell the whole story.

*Accidents*

The width of roadway is also influenced by safety of operation Certain limited investigations were made a few years ago by the Highway Department of the University of Michigan of the accident records on the 20-ft road from Ann Arbor to Ypsilanti and another nearby parallel road, the width of which is 18 ft

These investigations apparently were not conclusive but did tend to show that the accident risk was quite a little greater on the 18 ft than on the 20 ft road The traffic on the 20 ft road was slightly greater than that on the 18 ft road

Prof R L Morrison of Ann Arbor stated (June 1934), in this connection· "The maximum difference in width between the ordinary farm truck and the widest trucks and busses appears to be only one foot and with millions of men, women and children, competent and incompetent, experienced and inexperienced, sober and drunk, driving cars up to 70 or 80 miles an hour and killing 30,000 people a year and injuring 1,000,000 a year, it seems to me absurd to say that 20 ft roads are being built because 1 or 2 per cent of all vehicles are a foot wider than ordinary farm trucks "

In an article in Engineering News Record of Sept 20, 1934 Harry Tucker, Professor of Highway Engineering at North Carolina State College reviews the effect of highway design on accidents He says "It is doubtful if the design of streets and highways has kept pace with the wise use of motor vehicles . the location of and defects in streets and highways are contributing factors in about 30 per cent of all fatal accidents The design of the [cross] sections should be undertaken with proper consideration for the safe operation of vehicles This has particular reference to width of pavements and shoulders etc "

[6] "Highway Design on Travel Speeds," An Editorial, Engineering News Record Sept 27, 1934

The National Safety Council at it's meeting on Oct 1, 1934 listed "the greater speed of the new cars" among the four main causes of the recent increase in accidents on the highways

It is of interest to note that in England a record of the accidents on the roads of that country shows that 80 to 85 per cent were due to the "human element," and that they were about evenly divided between drivers and pedestrians This points to the need for making some adequate provision for pedestrians Walking as a pastime is much more popular and prevalent in England than in the United States, but its popularity is growing in this country

*Traffic Density*

In considering the effect of traffic densities as expressed in vehicles per day, attention should be called to the quite uneven distribution of traffic throughout the 24 hours An accepted formula, ordinarily applicable, estimates the daily traffic at 12 2 times the maximum hourly traffic and the yearly traffic at 340 times the daily It is the maximum hourly traffic which affects the design

There are variations also, between Sundays, holidays and weekdays, between summer and winter, and also, of course, in the character of the vehicles, proportions of trucks and busses, etc

At one extreme are such roads as New Jersey State Highway Route 25 where the estimated capacity of four operating lanes, of a 50-ft paved roadway, is 5440 vehicles per hour, equal to 66,400 per day or 22,560,000 per annum At the other are rural roads with light traffic of perhaps 500 vehicles per day or 170,000 per annum. Roads with 3000 vehicles per day or 1,000,000 vehicles per year may be considered intermediate or feeder highways while main through highways may carry 5000 vehicles and upwards per day.

It may be of interest to note as indicating the considerable variations in relation of traffic capacity and traffic densities, that a count made on the Buffalo-Niagara Falls Road on one day in October 1924, showed a total of 24,000 vehicles passing over it This road was estimated at that time to have a normal comfortable capacity of 10,000 cars per day

The following estimate[7] of the number of vehicles which would use New Jersey State Route 25 based on actual counts on other highways in the vicinity, illustrates the fluctuation in hourly traffic

| A M | Cars per Hour |
|---|---|
| 12–1 | 2,520 |
| 1–2 | 1,440 |
| 2–3 | 360 |
| 3–4 | 360 |
| 4–5 | 360 |

[7] "Highways as Elements of Transportation," F Lavis, Transactions Am Soc C E Vol 95 (1931), p 1025

| A M | Cars per Hour |
|---|---|
| 5–6 | 360 |
| 6–7 | 360 |
| 7–8 | 720 |
| 8–9 | 1,080 |
| 9–10 | 1,440 |
| 10–11 | 1,800 |
| 11–12 | 2,160 |
| P M | |
| 12–1 | 2,520 |
| 1–2 | 2,880 |
| 2–3 | 3,240 |
| 3–4 | 3,600 |
| 4–5 | 3,600 |
| 5–6 | 3,600 |
| 6–7 | 3,600 |
| 7–8 | 3,600 |
| 8–9 | 3,600 |
| 9–10 | 3,600 |
| 10–11 | 3,600 |
| 11–12 | 3,600 |
| *Total* | 54,000 |

*Ten-Foot Lanes Necessary for Private Automobiles*

The opinion seems to be quite generally held that 10-ft lanes are necessary for even non-commercial vehicles when there is any considerable density of traffic

Maj William G Sloan, Chief Engineer of the New Jersey State Highway Department states. "There can be no question as to the advisability of providing at least 10-ft lanes, and in my opinion this is more necessary on account of fast moving automobile traffic than would be the case for the slow moving truck traffic "

Mr. J. T Ellison, Chief Engineer of the Department of Highways of the State of Minnesota states: "The width of roadway or structure is governed by the amount of traffic rather than by the character of it . . From observation and experience it is the opinion of most highway engineers that 10 ft is the minimum traffic lane which can be used safely by automobiles "

The Westchester County Parkway Commission and its Chief Engineer Mr. Jay Downer, with some 15 years' experience in building roads, exclusively for non-commercial vehicles, have found by experience that while 4-lane roads were originally built 40 ft wide, it was later necessary to widen them to 42 and 44 ft in order to keep the rapidly moving (35 to 40 m. p. hr permissible speed) vehicles on the outer lanes. The minimum radius of curvature is 1500 ft The usual speeds of vehicles on these parkway roads is probably at least 45 to 50 miles per hour.

The standard roadways of France are now 10 ft for each lane, but on two-lane roads carrying many high speed vehicles, the width is increased to 23.5 ft.

Reference has already been made to the investigations made by the Highway Department of the University of Michigan which tend to show that for main roads of fairly heavy traffic, accidents are more frequent on 18-ft roads than on roads with 10-ft lanes

Perhaps it is reasonable to allow the conclusion that while 10-ft lanes may be justified by non-commercial traffic alone on roads of primary importance with traffic densities of 3,000 per day or over, for rural roads, 16-ft pavements are adequate This 16-ft width for rural highways, however, may be admitted as reasonable only if we allow the assumption that speeds in excess of 20 or 25 miles per hour should not be permitted or would not be usual on such roads and provided there are adequate shoulders of hard material on both sides. Here again, it is sometimes difficult on rural roads to distinguish between pavement and shoulders, so that a minimum width of 20 ft of surfaced roadway is practically necessary to meet present day conditions

Mr M W. Torkelson, Director of Regional Planning of the Wisconsin Highway Commission, makes the following comment:

> "To obtain full benefit of any roadside improvement, the road must be properly built The old practice was to build narrow roadbeds and deep ditches with no right-of-way if it could be avoided The new standards require
>
> 1 A roadbed, on most main roads, 40 ft wide, for a 20 ft pavement and 10 ft shoulders This affords safety for pedestrians, permits vehicles to stop clear of traffic and also permits horse drawn traffic on the shoulders
> 2 A roadbed high enough so that snow can be readily removed In building the grade, the side ditches, if any, must be wide and shallow with very flat slopes The flat slopes are safer, more favorable to planting or seeding, and are cheaper to maintain
>
> To carry out these standards, the right-of-way must be wider than formerly In general, the minimum width is 100 feet, in many cases it is 120 feet, and in case of cheap land, the width may be much more"

The question of shoulders is important as there seems to be a disposition in some instances to charge the heavier vehicles with certain costs due to additional widths of roadbed as well as widths of pavements On the French roads previously referred to the—

> "Shoulders are wide enough to take an automobile They are usually planted with trees at a minimum distance of 18 ft from the centre line of a 20-ft roadway (pavement)"

## TYPES OF PAVEMENT

### ECONOMIC VALUE

Much of the literature referring to the effect of heavy motor vehicles on road costs tends to convey the impression that while 5 or 6 in. of concrete or the equivalent macadam pavement is sufficient to carry a traffic of ordinary passenger automobiles 2 or 3 in additional is necessary because of the heavy vehicular traffic.

It is known, that the heaviest types of trucks are habitually used on construction work where there is not only no pavement but where often the earth surface over which they operate with full loads is of the roughest character Heavy pavements are not, therefore, a necessity for the operation of heavy trucks nor is, as a matter of fact, any pavement a sine qua non for the operation of any motor vehicle

The fact is that pavements of one kind or another are a convenience and an economic necessity and are both convenient and economically required to a much greater extent for the 24,000,000 passenger automobiles and light trucks than they are for the 650,000 heavy trucks and busses which are now operating

Again quoting Mr J T Ellison, Chief Engineer of the Department of Highways of Minnesota, he says· "There is no doubt but that on the main highways of Minnesota the people who make use of the roads are no longer satisfied with a plain gravel surface They are demanding a road which will be free of dust in dry weather and from mud and slush in wet weather."

It is a function of the government, federal, state, county, municipal, to provide highways and in meeting the demands of highway traffic it is of course, the ultimate aim of the government, to produce such highways at the lowest annual cost

This annual cost is a function of the original investment, combined with costs of maintenance and renewal

There is also another factor seldom taken into consideration—the relation of the surface, pavement, cross-section, gradient and alignment to the cost of operation of the vehicles using the road

In the study of this problem consideration must be given to the question of annual costs and furthermore to:

A The relation of cost of pavement to the total cost of the highway including, rights-of-way, drainage, grading, formation and consolidation of roadbed

B The relation of first cost of pavement to its life and maintenance cost including in the latter, costs of maintaining shoulders and drainage

C Relation of pavement surface to costs of operation of the vehicles using it

*Effect of Location on Operating Costs*

It is quite probable that the entire cost of improved roads is saved by reduced costs of operation of the vehicles using them This is represented by savings in time, very often savings in distance, reduced costs of operation due to improvements in gradient and alignment as well as improvements in the surface and reduced costs of repairs and maintenance of these vehicles

It is claimed that the costs of these improvements, inasmuch as they benefit the road users, should be borne by them, but the assessment of all these costs solely against the motor vehicles hardly seems to be entirely equitable

The land owners and farmers benefit because improved roads enable them to get their produce to a market They may or may not own the motor vehicles which do the transporting The general public benefits, at least in theory, due to the lower cost of transportation It has been noted that tank cars for milk, operated as trailers on the highways at both ends of the route, are carried part of the way on specially designed railway flat cars. Improved highways increase land values by increasing the accessibility of the land [8]

Highways are a part of our general economic and social development and perhaps to some extent part of our scheme of military operations. These and many other items indicate some reasonable distribution of the costs of these highways between the vehicles which use them and the general taxpayers, and this is particularly true in the United States where we are still at the beginning of our program of highway improvement as contrasted with Great Britain which has probably reached or nearly reached a fixed cycle of highway expenditures In the United States also, that part of these modern improvements, namely the right-of-way, roadbed, and part at least of the drainage structures, which may be supposed to have a long useful life, possibly 50 to 100 years or even more, can fairly be assessed against the future generations which will use them

The calculation of these savings in operating costs is difficult because of the great variety of types of vehicles, various percentages of each class, etc , but in connection with the studies of economic factors governing the location of Route 25, New Jersey, the following estimates were made for the traffic which was expected to use that route [7] The items of operating cost, assuming 50 per cent of heavy trucks, 25 per cent of medium weight trucks and 25 per cent passenger automobiles which are affected by distance, were estimated to amount to 12 cents per mile per vehicle, on this route on a first class pavement This, of course, is high owing to the large percentage of commercial vehicles, and probably 8 or 9 cents per mile is a fair average for ordinary traffic on fairly good pavements

For the conditions on this highway it was estimated that the average savings in operating costs on account of distance were 2 2 cents per vehicle for 1000 ft Assuming an average traffic of 1,000,000 vehicles per annum, the decreased operating costs for a saving of 1000 ft. in distance would be $22,000 a year which capitalized at 6 per cent indicates that $360,000 might profitably be expended to save this distance. Here again the values are high owing to the large percentage of heavy trucks assumed but if private passenger cars and light trucks alone were

[8] An interesting present day study of the relative benefits and usefulness of road and rail transport in the development of new territory is presented in a paper, No 158 (1934) of the Institution of Civil Engineers of Great Britain entitled "Transport Problems in Western Australia" by Stileman and Young

considered the savings would be quite considerable, perhaps one-third of the amount indicated.

The effect of curvature on operating costs is difficult to estimate and possibly for highways with light gradients and curves of 1000 ft. radius or over may be negligible Where sharp curvature is used and visibility is reduced, especially where this may be combined with heavier gradients, the accident risk is increased and the traffic capacity of the road reduced by the slowing up of the traffic. The time element in increasing operating costs may also be a factor

Ascending gradients have been estimated to increase operating costs by 0 1 cent per foot of rise for ordinary trucks and, as noted above, steep gradients and sharp summits are both dangerous and costly.

The money value of delays or time was evaluated for the vehicles using route No 25 as follows

| | |
|---|---|
| For trucks | 2 3¢ per car minute |
| Busses .. | 2 2¢ per car minute |
| Private Autos | 1 0¢ per car minute |

These figures are only approximations and will vary according to locality, type of vehicle, operating costs, costs of fuel and lubricants, wages, etc They are sufficient, however, for the present purpose which is to show that road conditions or locations have a decided effect on costs of operation of the vehicles which use them

*Effect of Pavements on Operating Costs*

The effect of road surfaces on the costs of operating ordinary passenger automobiles is estimated by Messrs Agg and Carter (Bull 91 Iowa State College p. 20), to be as follows.

| | Cost of Operation cents per mile |
|---|---|
| High type roads | 5 10 to 8 00 |
| Intermediate roads .. | 6 02 to 9 45 |
| Low type roads | 7 03 to 11 00 |

## HIGHWAY COSTS

In considering the highway costs which may be affected by heavy motor vehicles, consideration must be given to the fact that many of the most important highway construction projects of recent years have been made necessary by the general increase in all highway traffic

Of course, part of this increase is in heavy trucks but it seems entirely reasonable to say that many of the most costly projects, the so-called super-highways, parkways, grade-crossing eliminations and the reconstruction and improvement of highways generally, have been made necessary largely by the needs of passenger automobiles in large numbers traveling at high speeds

The construction of that part of Route 25 in New Jersey between

Jersey City and Elizabeth, a length of about 13 miles, which cost approximately $40,000,000, was necessitated primarily, by the need of relieving the congestion on the principal business streets of Jersey City, Newark and Elizabeth, and partly by the concentration of much of this traffic due to the construction of the Holland Tunnels

The construction of the Westchester County Parkways was made necessary in large part by the need of expediting the large volume of traffic through a more or less narrow area between New York City and the North The expenditures for this purpose totaling around $50,000-000 for construction alone, were for roadways carrying only passenger automobiles

The new parkway route in New York and Connecticut paralleling the Boston Post Road has been made necessary by the increase in the Post Road traffic, which, while it has at times a fairly large percentage of trucks, has also a very heavy traffic of passenger automobiles This is true also of the new so-called super-highway between Worcester and Boston, Mass , and of the super-highways of Detroit

Most of the eastern states have spent and are spending very large sums of money for the entire reconstruction of most of their main highways, for revised alignments and gradients as well as for heavier, smoother and wider pavements and it is undoubtedly true that most of this work has been necessary or has been considered economically sound because of the large volume of passenger automobile traffic which has to be accommodated

In considering also, what part of highway costs is chargeable to heavy trucks, consideration must be given to the fact that as shown in the early part of this discussion and aside from their use on inter-city routes, such vehicles are today almost a necessity in the conduct of much of the business of the country

It is a fact, that a not inconsiderable proportion of the freight handled by the railroads is brought to them, and carried away from their terminals by the heavier types of vehicles If, therefore, these heavier vehicles do involve additional highway costs the extra expenditure is not wholly for the benefit of trucks in competitive traffic

*Allocation of Highway Costs*

Perhaps a rough idea of a possible allocation of highway costs may be obtained by application of the statement made in the British Report of the Conference on Rails and Road Transport which says that "such investigations as they have found it possible to make indicate that the annual road costs in Great Britain might be reduced by 2 or 3 per cent, if there were no vehicles of more than four tons unladen "

The total highway expenditures in the United States for the past few years, as previously given herein, have been about $1,800,000,000 per annum It is probably true that at least half of this is for "Land Service

Roads " Some of it, probably a very considerable part of it, is for new construction of what may be called "Permanent Works"—right-of-way, grading and much of the drainage, and for development of highways.

Just how much of this should be included as an established cycle of "annual cost" chargeable against motor vehicles is difficult to estimate but, assuming that this amount may be as much as $1,250,000,000, and that 3 per cent of this is caused by the presence of the heavier vehicles, we then have chargeable to them, in addition to other taxes, say $37,500,000 per annum or an average of about $50 or $60 per vehicle, which necessarily would have to be pro-rated on some sliding scale

A much closer analysis than the above is, of course, necessary for a reasonably careful determination on this basis, but this is at least an indication of one way to look at it

*Annual Costs*

In order to determine the additional cost, if any, due to the use of these heavier vehicles, it is necessary to determine not only the initial cost of highways but also their annual cost That is, first cost, interest on the investment, costs of renewals (life), costs of maintenance and also their effect on operating costs of the vehicles using them

This problem is complicated because of the relation of the cost of pavement to the cost of roadway, i e , right-of-way, drainage, grading on old roads-regraded, partially re-located, partially widened, entirely rebuilt, etc The fact must be borne in mind that the costs of much of the right-of-way, grading, drainage, etc , have long ago been absorbed in the national economy

Estimation of costs is also made difficult by differing systems of accounting, and in reporting costs, and also by the fact that the life, and consequent estimation of costs of renewal, varies so much with conditions, methods and quality of construction, climate, supporting roadbed, and traffic Professor Breed points out that "One can find in State Highway reports cost figures to fit almost any assumed premise "

The more modern types of concrete and bituminous pavements have not yet been in use long enough to permit authoritative statements as to their probable future life, but it seems not unreasonable to assume that this may be well over 20 years The writer knows of at least one fairly cheaply constructed bituminous macadam pavement which is and has been in constant use in a residential district with the usual proportion of trucks of various kinds, some fairly heavy, for nearly 30 years It has never had major repairs, very little patching, a coating of oil and sand at 3 or 4 year intervals, and today is in fair condition

*Thickness of Pavement*

In the survey of the Bureau of Railway Economics[1] it seems to be assumed that 6 in. of concrete is sufficient for lighter vehicles, that 8 in is required for heavier vehicles, and that the extra 2 in in thickness of concrete costs $10,000 per mile

On page 83 of the report,[1] however, it is stated that 8 in of reinforced concrete pavement costs about $21,000 per mile It is, of course, evident that a 6-in slab will cost more than 75 per cent of the cost of an 8-in and it is difficult to see, therefore, even on the basis of this statement. how the extra cost of the additional two inches of concrete can be more than, say, $5,000 per mile

Professor Breed shows in his report[5] that a difference of one inch in thickness of 20-ft. reinforced concrete pavements in Pennsylvania at 1929-30 prices amounts to $2,286 per mile He also states that using 1931–32 prices for a 20-ft pavement, the difference between "medium cost" bituminous macadam and high type bituminous macadam (omitting excavation), is about $4,000 per mile

Leaving out of consideration for the moment, therefore, the probable lesser maintenance costs, longer life, better riding qualities, and lower operating costs of the thicker concrete and higher type macadam, the most that could be charged against the heavier vehicles according to these figures is about $4,000 per mile

It seems to be hardly necessary in a discussion of this kind to point out that whether 6 or 8 inches of concrete be laid, the costs of certain items such as forms, preparation of sub-grade screening, etc. will be the same in either case and that some items such as plant charges, overhead, and costs of placing will be less per cubic yard for the 8-in. pavement than for the 6-in. It is, therefore, quite probable that the cost of an extra two inches will not exceed $3,000 to $4,000 per mile and it is further entirely probable that this may be justified by lower maintenance charges and longer life

The writer is of the opinion that the preparation of the sub-grade is quite as important, if not more so, for a 6-in slab even for non-commercial traffic alone, as it is for an 8-in slab for any purpose

Professor Breed's report to the Railroads of Pennsylvania[5] states that if flexible pavements are built instead of the rigid concrete pavements, "Highways adequate for passenger automobiles, and other motor vehicles weighing not in excess of 6,000 pounds gross or 4,000 pounds per axle, can be constructed and maintained for from one-third to two-thirds the cost of highways required for vehicles having maximum gross weights ranging from 20,000 to 40,000 pounds or axle loads of from 16,000 to 18,000 pounds."

It seems quite doubtful, although this is at present a matter of opinion only, that these lighter types of flexible pavements render the same service as do concrete pavements The writer is aware of the high quality of the bituminous pavements built in Massachusetts but there does seem to be a question as to their costs of maintenance, their life, and their riding qualities after they have been some time in use The question arises as between the effect of the heavier vehicles in permitting the use of a higher or less expensive type of bituminous macadam rather than that of permitting its use instead of concrete There is probably a large body of opinion in favor of the concrete from the point of view of operating costs, cleanliness and riding ease

Attention has already been called to the need of providing for a certain number of heavy vehicles even in purely farming communities and Mr. Ellison, Chief Engineer of the Department of Highways of the State of Minnesota notes that "The State Law of Minnesota[9] requires that all highway bridges constructed in that State shall be designed to carry safely a theoretical tractor having a load of 5 tons on the front axle and 15 tons on the rear axle "

I think it is generally true that most highway bridges were designed to carry vehicles with 15 tons on the rear axle even before the advent of the trucks.

It is a fair inference from this, that the pavements and roads must be designed to carry these same vehicles and Mr Ellison further states that their concrete road slabs are seven inches at the centre and nine at the sides, that this is sufficient for the legal loads in Minnesota, that "it would not be safe to build a slab of less than 6 in minimum thickness on the soils which exist in Minnesota" and that "much of the destruction of concrete highway is due to weather and soil conditions rather than to traffic "

Major William G Sloan, State Highway Engineer of New Jersey states:

"It is difficult to assign any additional cost in our highway construction as being entirely due to heavy truck traffic As regards the thickness of the pavement, it is my opinion that frost action is the most destructive force we have to contend with, and it is necessary to design a slab which will not break up and crack under these forces Such a slab is amply sufficient to carry any traffic which may move over it "

Mr Arthur W Brandt, Commissioner of Highways of the State of New York, says.

"I am not sure that the cost of a concrete pavement could be decreased very greatly if all trucks were to be removed from it because there is a certain minimum in the State of New York which must be built to take care of frost conditions Our minimum concrete pavement is 8 in on the edge and 7 in in the center In bad soils we use a considerable amount of stone or gravel foundation course Our maximum concrete pavement is 9 in uniform This is used in the neighborhood of New York City and one or two of the other larger cities where trucking is especially heavy I don't believe we would want to use a pavement less than 7 in thick on the edge even though there was no trucking because I don't believe a pavement thinner than that will withstand frost conditions "

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[9] Section 2601 General Statutes of Minnesota dated 1923

Mr E G Sumnei, Engineei of Bridges and Structures of the Connecticut State Highway Department, makes the following comment:

"Since the truck traffic is here and apparently here to stay, it has never seemed to be worth while to make any calculations on the assumption that it was not here However, we believe that if we could restrict our highways to the use of pleasure vehicles it would be possible to make some changes, especially in the thickness of the pavements For example, our standard concrete pavements have a depth of either eight or nine inches, depending upon the volume of traffic If the traffic were confined to pleasure vehicles only, we believe that seven inches would be adequate As to width, there are undoubtedly many places where it would be possible to use a two-lane road where we now find it desirable to construct four-lanes I am afraid our investigations have not been carried far enough for us to make any statement as to the additional cost of construction due to the presence of truck traffic "

Attention has already been called to the fact that on the Westchester County Parkways designed for private passenger automobiles only and restricted to that class of vehicles, after 15 years experience during which several different types of pavements have been tried out, the latest roadways are built of eight inches of concrete with double reinforcement

Before leaving this phase of the subject it seems only fair to quote the following from a latter of Mr L C Frohman, Chief Engineer of the Florida East Coast Railway, referring to statements of Clifford Older who testified before the State Railroad Commission of Florida in the early part of 1933 in regard to damage by trucks to the Florida highways·

"The roads inspected by Dr Older and referred to by him in his testimony were high class, well-built roads I am especially familiar with one of the roads in question, it being State Road No 4 extending from the Georgia line, through Jacksonville, along the East Coast to Miami and to Key West In the distance of approximately 360 miles between Jacksonville and Miami at the time Dr Older testified, only 9 miles of paving was more than nine years old—as the original paving was practically destroyed and the road rebuilt for that distance, beginning in the year 1924 and subsequent to that time 9″-6″-9″ concrete paving of high-grade concrete carefully placed in 1926 and 1927 on a well-built and thoroughly cured and properly drained sub-grade had developed serious ruptures of the paving slab and distortion of the surface when inspected by Dr Older in the first part of 1933 None of the grading required for highways along the East Coast is heavy and embankments are all very low and cuts very shallow The drainage provided under the practice of the State Road Department is really more than adequate, as they pay special attention to this feature The grades are all well cured for a period of approximately one year before paving is started On the road in question I know the quality of the work was as good as can be obtained, yet these slabs ruptured under the live loads The location of fractures, the extent of the fractures, etc , were all factors considered by Dr Older in arriving at the conclusion that the damage was due to excessive loads

"On all of the principal highways in Florida, including this particular roads between Jacksonville and Miami, the direction of traffic is north and south—with all heavy loads southbound up until approximately two years ago when extensive northbound movement of citrus and vegetables was started on these highways The southbound traffic runs on the west side of the paving Measurements taken at intervals along the highway from Jacksonville to Miami disclosed that the paving slab whether of concrete, or of compacted lime rock base with a wearing surface, was tilted for the entire distance so that the west edge of the paving was from 1" to as high as 4" and 5" lower than the east edge of the paving Furthermore, on paving other than concrete, a longitudinal depression was developed on the west side of the paving in the location of the outside wheels of the southbound vehicles This depression is from 2" to 6" in depth A similar depression developed more slowly and to less extent on the east side of the road The seasonal northbound movement of heavy loads will probably cause a change in these conditions I do not believe that the slab will tilt back but expect longitudinal fractures to develop near the center of the paving

"These roads were well-built and without excessive loads should have continued in service for many years All evidence indicates that the failure of the paving is due to the imposed loads Gross loads of 20,000 pounds to almost 30,000 pounds on two axles and axle loads of 16,000 pounds to 18,000 pounds on paving we now have in service will cause the failure of that paving This is not only in Florida but is demonstrated by results in paving in other Southeastern States The damage does not appear in the first, or second year of traffic but, with the repeated application of excessive loads and the increase in number of applications, the damage appears and generally after a period of three or four years, is very marked When it starts it continues at a slowly accelerating rate "

At this distance it is difficult to understand these failures, inasmuch as roads of this thickness in the north, properly constructed but having heavy frost conditions to contend with, successfully carry traffic of heavy trucks, (See further notes as to costs and types of highways in New Hampshire and Virginia and previous notes on thickness of pavements, particularly in Minnesota)

*Pavement Costs as Part of Total Highway Costs.*

In discussing the costs of highways there is much confusion in the statements and often no distinction is made between total costs of highways and costs of pavements and often no distinction between the two is made in discussing annual costs

The records of some 70,000 miles of Federal-aid highways built between 1917 and 1928 show[10] that the items of grading, drainage structures and bridges, constituted about 40 per cent of the total expenditures

As a further check, the writer has obtained some statements of costs of roads constructed during the last year or so which can be fairly definitely allocated between the three or four major divisions of costs.

In Massachusetts in the towns of Amesbury and Salisbury a new road was constructed in 1933. The length is 4240 ft of which 2600 ft. is entirely new, with cuts and fills up to 15–20 ft , the balance is re-grading and widening of an old road The pavement is 30 ft wide with 5-ft shoulders, making a total roadway width of 40 ft. The surface consists of 12 to 18 inches of gravel as sub-grade The base course of the pave-

[10] Bus Transportation—January 1933

ment is $4\frac{1}{2}$ in of broken stone bound with sand and there is a $2\frac{1}{2}$- in. top course of broken stone bound with $2\frac{3}{4}$ gal. of asphalt per sq yd

The costs of this 4240 ft section are given as follows.

| | | Per cent |
|---|---|---|
| Right of Way | $2,419 50 | 6 0 |
| Grading | 22,663 53 | 56 6 |
| Drainage (no Bridges) | 3,537 91 | 8 8 |
| Paving | 11,174 40 | 27 8 |
| Traffic Officers | 382 25 | 8 |
| | $40,177 59 | 100 0 |

On a continuation of this same project which was the widening, with very little straightening and some light grading, and complete re-paving of 2 6 miles, the costs were as follows

| | | Per cent |
|---|---|---|
| Right of Way | $13,612 25 | 18 5 |
| Grading | 15,059 67 | 20 5 |
| Drainage | 9,264 14 | 12 6 |
| Pavement | 34,628 51 | 47 1 |
| Traffic Police | 933 54 | 1 3 |
| | $73,498 11 | 100 0 |

These two sections of the same road are interesting as showing in one case the grading costing twice as much as the pavement and in the other, the grading costing less than half as much as the pavement In one case, also, the pavement cost nearly half the total, in the other a little over a quarter

The bituminous macadam of which these roads and many others in New England are built, is of a high type which produces a good pavement with flat cross-section and would seem to promise low maintenance costs and fairly long life The writer has no knowledge of how the particular road referred to may be classified from a traffic point of view but from his own observation and knowledge he would consider it to be secondary to the main through routes of the country although it carries at times a fairly heavy traffic, principally of private passenger automobiles

In Virginia, an entirely new highway has been built (1934) on Route 29 north of Charlottesville, the costs of 10 4 miles of which are given as follows:

| | | Per cent |
|---|---|---|
| Right of Way | $17,347 | 7 5 |
| Excavation | 89,467 | 39 1 |
| Drainage, including two Bridges, 163 and 237 ft spans | 65,944 | 29 |
| Pavement | 43,325 | 19 |
| Guard Rail | 12,617 | 5 4 |
| | $228,700 | 100 0 |

This road had fairly heavy grading, and runs straight across rolling country with no towns The pavement is 20 ft wide with 5-ft shoulders and is a compacted earth road with a surfacing of ¾ gal of bituminous material and 40 lb of stone chips per square yard

The Chief Engineer of the Virginia Highway Commission writes: "We have built roads of this type since 1926 and many of the through roads of this type stand up exceptionally well under heavy traffic "

Here is a road surface apparently capable of carrying a certain amount of heavy truck traffic and yet could not be of lighter or less expensive construction for a traffic exclusively of private passenger automobiles The surface appearance of these roads when new is not unlike that of the bituminous macadam roads built in Massachusetts, but of course, the Massachusetts macadam may be expected to give a much longer life

On eight contracts awarded between September 1933 and August 1934 for widening, straightening and paving roads in the State of New Hampshire, the proportions of costs (low bids) of the four main divisions were as follows

| | | Per cent |
|---|---|---|
| Grading | $229,720 | 27 |
| Pavement | 520,711 | 60 |
| Drainage | 29,115 | 3 5 |
| Miscellaneous | 79,576 | 9 5 |
| Total | $859,122 | 100 0 |

All these roads have a 20-ft pavement with 3-ft shoulders on each side

They have a 12-in gravel sub-grade, the cost of which is included in that of the pavement The cost of this is approximately 10 per cent of the pavement cost

The pavements are generally six inches of reinforced concrete, thickened on the outer 2 ft to 9 in at the edge On newly made fills a macadam pavement is built (on the 12-in gravel sub-grade) consisting of a 4-in base course and a 3-in bituminous top of trap rock with 2½ gal of bituminous material per square yard

The costs of certain State highway improvements in the State of Connecticut in 1933 are given as follows:

4 09 miles of concrete pavement 8 in thick with one layer of reinforcement, 20 ft wide, 5-ft shoulders

| | | Per cent |
|---|---|---|
| Right of Way | $72,944 | 26 |
| Drainage | 36,133 | 13 |
| Grading | 83,951 | 30 |
| Pavement | 86,324 | 30 |

16 87 miles of bituminous macadam, carried out under six contracts, 20 ft. wide, 5-ft shoulders, 7½ to 9½ in thick

| | | Per cent |
|---|---|---|
| Right of Way | $47,114 | 11 |
| Drainage | 89,621 | 20 |
| Grading | 132,073 | 30 |
| Pavement | 174,914 | 39 |

It will thus be seen from these examples that the costs of these pavements vary between 20 and 60 per cent of the costs of the improvements.

## MAINTENANCE

The effect of heavy vehicles on maintenance, or in fact the effect of traffic of any kind on maintenance, is a matter on which it is difficult to obtain anything like definite, reliable information We know, of course, that climate is an important factor and there is no doubt that construction methods have important effects

We have statements that the heavy vehicles have ruptured concrete slabs which would have been sufficiently strong for lighter vehicles We also know of six inch concrete slabs properly constructed and light macadam successfully carrying miscellaneous traffic, including some heavy trucks

It has been pointed out in the early part of this discussion that pavements are not a necessity for the movement of motor vehicles and are especially not necessary for the movement of heavy trucks They are, however, convenient and in general have economic justification

The assumption has been frequently made, however, that heavy expensive pavements are made necessary by the operation or for the operation of heavy trucks The cost of good pavements may, however, be justified—may even be wholly justified—by reduced maintenance costs and lower costs of operation of all vehicles using them

The following figures quoted from an article by A C Benkelman, in Civil Engineering for July 1933 are not given as a definite answer to this part of the problem but they do, at least throw some light on it·

The cost of concrete roads in Michigan is stated to be $25,000 per mile and the cost of gravel roads $10,000 per mile The annual costs of maintenance, however, for a traffic in both cases of 3000 vehicles per day is stated to be $695 per mile for concrete and $1710 per mile for gravel The author then quotes the data published by the Iowa Engineering Experiment Station that considering the cost of operation on earth roads to be indicated by 100, the costs on gravel are 85 and on smooth hard pavements 72

The Chief Engineer of the Westchester County Park Commission states (May 1934) "Nowadays, we find that the cost of a first-class eight inch reinforced concrete pavement is so reasonable that we can scarcely afford to gamble on the higher maintenance required for the cheaper types " This it will be remembered, is on roads for noncommercial vehicles exclusively

The following figures prepared by Prof. C B Breed[5] will show the very wide differences in costs of highway maintenance They give the maintenance costs on 26 separate sections totaling 41 4 miles of roads in Massachusetts, all on Route 12, and are averages for five years and for pavements of differing ages, back to 1911 They are as follows

| | Annual Maintenance Cost Per Mile | | |
|---|---|---|---|
| | High | Low | Average |
| Surface | $988 | $5 | $210 |
| Right of Way | 600 | 183 | 380 |
| Snow Removal | 446 | 134 | 215 |
| Registration | 830 | 195 | 314 |
| Traffic Police | 572 | 134 | 216 |
| Engineering | 241 | 78 | 121 |
| | | | $1456 |

The following is quoted from the Minnesota Highway News of March 5, 1932 and indicates very considerably reduced maintenance cost on paved highways not only per mile but per vehicle

"Paved trunk highways, carrying the heaviest traffic, require the smallest maintenance expenditure, according to highway department figures Maintenance of concrete slabs in 1931 averaged $97 61 per mile This included crack filling, lifting sags with a 'mud jack'—and replacing broken spots in the older pavements Adding shoulder repair, snow removal, mowing, repair of ditches and culverts, signs and miscellaneous, the total expense averaged $249 36 per mile The paved routes carried an average of 2,309 vehicles per day

"Gravel roads, with less than one-third as much traffic, cost more to maintain The average cost of maintaining 2,948 miles of untreated gravel road was $339 per mile for all items except re-graveling The maintenance division regraveled 1,601 miles at an average cost of $256 per mile

"The more heavily traveled gravel roads were bituminous treated The average cost per mile of 1,589 miles of new treatment or retreatment was $1,069 There were 291 miles of bituminous gravel on which retreatment was not required These showed an average expense of $176 per mile for maintenance of the roadway, and a total of $280 60 per mile with snow removal, roadside maintenance and all other items "

It is regrettable that there is so little really conclusive data now available on this question and it is suggested that the Research Board may perhaps ask highways officials for studies and cooperation in obtaining more information

### SUMMARY

It must be evident from the preceding discussion that there can be no definite answer to the question: what is the effect of heavy motor vehicles on highway costs

Bearing in mind, that this present discussion does not attempt to allocate these costs between general taxpayers and the owners and operators of the vehicles using the roads, the following general statements and conclusions seem to be warranted

By the term heavy motor vehicles is meant trucks heavier than those with a rated capacity of 1½ tons, weighing with loads, about 10,000 lbs, and busses weighing with loads over 10,000 lbs

These heavy vehicles comprise about 2 5 to 3 0 per cent of all vehicles using the roads and City streets

All kinds of vehicles use all kinds of highways

It is generally recognized both in this country and in Great Britain that private automobiles are an important part of the national economic life and that adequate provision for highways and for their safe, proper and convenient operation, is an obligation of the State

Roads of so-called "High Type" surface or pavement comprise only 126,000 miles out of a total mileage of over 3,000,000 in the United States or about 4 per cent of the total All paved highways of every type comprise less than 25 per cent of the total mileage of all the highways in the United States

Most of the other roads may be considered to be "land service" roads, their main purpose being to make land accessible and their cost and upkeep are, therefore, principally a charge against the land

It seems to be evident, therefore, that motor vehicles should not be called upon to pay all the costs of highways

Some part, possibly a fairly large part of the heavy motor vehicles are used locally as farmers' wagons, for service between factories and railroads, in construction operations, and on city streets

There is evidence to indicate that farm trucks, farm wagons, trucks for local use, etc, make it necessary to build all bridges with a capacity equal to that required for a so-called 10 ton truck having a gross weight of 40,000 lbs with 15 tons on the rear axle

It seems probable that less than two, possibly not over one per cent of the total registered motor vehicles are used in through trucking operations in competition with the railways

It also seems to be quite evident, that the main use of all the highways is by the 20,000,000 private passenger cars which constitute over 80 per cent of all the registered motor vehicles

It is undoubtedly true that the number of vehicles, that is traffic density, is a far more important factor in the design, use and maintenance of highways than is the presence of a comparatively few heavy vehicles.

There is a good deal of evidence to indicate that the privately owned cars, on account of the speeds at which they are operated, the varied character of the operators, the condition of the cars, and their large numbers, require roads with 10-ft lanes and ample shoulders

This appears to be true of all types of roads and road surfaces

*It seems evident, therefore, that the heavier motor vehicles cannot be charged* *exclusively with additional costs on account of widths of roads, bridges or pavements*

While it may be true that a concrete slab capable of carrying a 10 ton truck without rupture may cost more, even perhaps twice as much as a pavement capable of carrying a $1\frac{1}{2}$ ton truck without similar failure, it is evident that this alone is not sufficient evidence of the additional "cost" of highways due to the heavier vehicles

*There is some evidence to indicate that if there were no heavy vehicles at all, one or possibly two inches in the thickness of concrete slabs might be saved This evidence is not, however, conclusive*

If it be assumed that there might be this saving of one or two inches in thickness of concrete slabs, *the value of this saving in first cost of pavements would be possibly $2,000 to $4,000 per mile but this does not take into consideration the effect of the extra two inches in possible longer life and longer continuation of good riding properties*

In discussing highway expenditures and their allocation between taxpayers, it is necessary to carefully distinguish between costs of roadbed, i e , right-of-way, grading, and drainage structures and the cost of the pavement High class pavements may be assumed to cost from 40 to 60 per cent of the total cost of ordinary highways, not including so-called super-highways with grade crossings eliminated and other very costly works of construction

It is doubtful if the heavier motor vehicles are responsible in themselves for any increase in costs of rights-of-way, drainage or roadbed construction

In computing annual costs, the roadbed must be considered as having a fairly long life, perhaps 100 years or more, whereas the pavement may have a life of only 10 to 25 years, or in some cases of modern high-class pavements, somewhat longer

In considering annual costs, also, it seems probable that values should be assigned only to expenditures on roadbeds within recent periods, say perhaps within the past 20 or 25 years It seems reasonable to assume that the costs of roadbeds in use over 25 years have been pretty well absorbed in the National economy

The annual costs of highways must take into consideration interest on first cost, cost of renewals or annual amortization, maintenance, and effect on the operation of the vehicles using the highways It is well known that smooth pavements of ample width, on highways laid out with proper gradients and alignment, tend to reduce the operating costs of the vehicles using them

These benefits largely accrue to the 20,000,000 private automobiles, which comprise 80 per cent of the vehicles registered

One of the indeterminate factors of importance in this problem is the effect of modern pavements and traffic on costs of maintenance and periods of necessary renewal These modern high type pavements both concrete and bituminous, have been developed to their present high standards only within the past ten years and there is no definite information available as to their life. It does, however, seem reasonable to expect that this will exceed 20 years

CONCLUSIONS

It seems reasonable to state that the width, gradients, and alignment of modern highways are determined almost entirely by the requirements of private passenger automobiles

The presence of the heavier vehicles may require some additional thickness of pavement, but it is probable that this increased thickness may be economically justified by longer life and reduced maintenance It may be justified by the requirements of private automobiles In any event, the additional cost of this extra thickness for high type pavements cannot be estimated to be over $2,000 to $4,000 per mile

So-called high type pavements constitute only 4 2 per cent of the total highway mileage of the United States and only part of these, probably only a small part, have a thickness of concrete over seven inches or the equivalent thickness of high class macadam

## DISCUSSION ON EFFECT OF HEAVY MOTOR VEHICLES ON HIGHWAY COSTS

PROF J TRUEMAN THOMPSON, *The Johns Hopkins University* I am sure Mr Lavis will be the first to recognize that many of the points which he touches upon are based upon the experience and opinions of various individuals Unfortunately, in the past we have had to depend almost entirely upon this kind of information in the allocation of highway costs to the several weight classes of motor vehicles rather than upon specific factual information In search of such factual data, I have been working in cooperation with the U. S Bureau of Public Roads, the State Roads Commission, and the Commissioner of Motor Vehicles of Maryland The full report on this data, "A Study of the Weights and Dimensions of Trucks" will appear in *Public Roads* (See *Public Roads*, Vol 16, No 3, May, 1935, pages 37 to 52 )

The study was made to secure answers, at least in part, to the following questions

1 How do the over-all dimensions of loaded motor vehicles vary with manufacturer's rated capacity?
2. How are the gross loads of motor vehicles distributed to the various axles?
3. To what extent do operators exceed the manufacturer's recommended loading, and how does prevalency of this "overloading" vary with manufacturer's ratings?
4 To what extent are tires being similarly overloaded?

From June 15 to November 15, 1934, commercial vehicles were weighed and measured at two stations, operated alternately for approximately two week periods One station was on Route U S 40 between Baltimore and Philadelphia and one was on U S 1 between Baltimore and Washington During the entire period, 7,100 loaded and 3,600 empty vehicles were observed It is believed that the data represent a fair sample of truck traffic on main highways in this area

The capacity of the truck was not an indication of overall width When the vehicles were classified by overall widths, (5 0, 5 2, 5 4, etc , to 9 0 feet) it was found for single units that 1½ ton vehicles were more numerous than the 5 ton vehicles in each width class up to and including the legal limit, 8 feet Less than one per cent of all the vehicles were more than 8½ feet in width and practically all capacities from 1½ to 5 ton were represented in this class

Over 56 per cent of all trucks higher than 11 feet and 63 per cent of trucks higher than 12 feet were of 1½ ton capacity Only three trucks were measured which were over 12½ feet high

Of single vehicles of determinable capacity only 8 exceeded 33 feet in overall length and only 121 or 2 6 per cent, exceeded 30 feet The longest semi-trailer was 52 feet long Eighteen, or 2 5 per cent, were over 45 feet long, and 63, or 8 7 per cent, were over 40 feet More than 33 per cent of the semi-trailers were over 35 feet long Only 10 combinations with full trailers were observed The longest and heaviest of these was 58 7 feet long with a gross load of 77,000 pounds, transporting gasoline in a tank truck and tank trailer

For single vehicles, an average of approximately three-fourths of the gross load was carried on the rear axle In semi-trailer combinations, about 45 per cent was carried on the tractor rear axle and 45 per cent on the trailer axle, leaving about 10 per cent for the front axle of the tractor The largest wheel loads are not always found on the vehicles of largest capacity

The weight of the load carried was determined by 1,429 single vehicles and 219 semi-trailers As found in the analysis of gross weights, it was here also definitely shown that loading in excess of rated capacity is far more prevalent for small trucks than for large ones On the average, the 1½ ton trucks carried 1⅔ times as much as the recommended load while 5 ton trucks averaged just about their rated capacity In extremes, the smaller truck is loaded to 4, 5, and even 6 times its rated capacity, the larger one is seldom loaded more than twice its capacity

The rated tire capacity was not exceeded to the same extent as vehicle capacity probaby because oversize tires were used on many of the smaller vehicles The extreme overloading of the smallest and largest tires did not respectively exceed 2 75 and 1 50 times the rated load of the tires

To limit the gross weight of vehicles, the American Association of

State Highway Officials has recommended use of the formula W = C (L + 40), where W is gross weight, C a coefficient, and L the length in feet between extreme forward and rear axles A value of 700 for C is recommended by the Association as the lowest value to be used Values of C were calculated for the vehicles as actually loaded The following table shows the frequency distribution of values of C in the gross load formula, percentage of total observations:

| Group | Total Observations | Value of C | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Under 100 | 100 to 200 | 200 to 300 | 300 to 400 | 400 to 500 | 500 to 600 | 600 to 700 | Over 700 |
| Single vehicles | 4,956 | 5 9% | 33 6 | 36 1 | 17 1 | 5 5 | 1 1 | 0 5 | 0 2% |
| Tractor semi-trailer combinations | 1,551 | 0 1% | 5 2 | 23 1 | 35 4 | 23 6 | 11 4 | 1 1 | 0 1% |

The primary purpose of this formula is the protection of highway structures It accomplishes this by preventing the concentration of excessive load in a too limited length Meanwhile the pavement slab is protected by limits placed upon wheel loads

As an example of the desirability of some such weight-distribution regulation it is noteworthy that of the single vehicles which exceeded C = 700 all were 6 wheel trucks of unusually short wheel base, whose wheel loads did not exceed 9000 pounds They would not, therefore, have been prevented from operation by wheel load limitations such as have been recommended by the American Association of State Highway Officials

Dean Anson Marston, *Iowa State College* Mr Lavis' paper is extremely interesting and it seems to me that the data which he has presented, prove his conclusion at the end of his paper which is, that it seems reasonable to state that the width and gradients of modern highways are determined almost entirely by the requirements of private passenger automobiles. Also it seems to me that in general he has proven fairly well, that the presence of the heavier vehicle will require some additional thickness of pavements, but that it is possible this additional thickness may be economically justified by longer life and reduced maintenance Mr. Lavis comes to the conclusion, that the construction of pavements on our highways to carry weights greater than those of passenger automobiles is required irrespective of the use of those highways by commercial buses and trucks and I agree very completely with that conclusion The present opinions of those responsible for the design and construction of pavements in Iowa, is that if there were no commercial buses and trucks using those roads at all for hire, we would still build about the kind of system we have at present so far as thicknesses go Now the question still remains as to how the charges for that system should be distributed between the owners of private automobiles and owners and operators of trucks and buses of various weights Mr Lavis' implication that we can arrive at a correct conclusion by discussing the possible increase in the cost of construction per mile, is not very well supported It seems to me we should look beyond that—perhaps use that factor and use additional factors which have not yet been properly studied It may be that the ton-mile basis gives a pretty good measure of the contribution which the owners of the trucks and buses should make in comparison with those of other vehicles, and it seems to me that it is entirely possible that we should take into account the frequency of repetition of these loads upon our highways In engineering we are accustomed to use a larger factor of safety for frequently repeated stresses than for stresses which occur only seldom I see no reason why that should not apply to pavements

MR H S FAIRBANK, *U S Bureau of Public Roads*: I would like to refer very briefly to two of Professor Breed's statements In one he refers to the transverse distribution of vehicles in passing on the road, and shows a diagram said to be based upon the results of the studies of the Bureau of Public Roads made a number of years ago in Washington and in Cuyahoga County, Ohio I simply want to say of that diagram that it does not represent the transverse distribution of vehicles in passing It does represent the transverse distribution of vehicles as observed on the road whether they are passing or not These observations were made at selected stations and the transverse distributions recorded in the diagrams represent the position on the pavement of all vehicles passing the fixed station Very rarely did two vehicles pass a station at the same time Therefore the transverse distances recorded on the diagram represent generally the placement of the vehicles on the road when they are not passing

My other comment has reference to Professor Breed's feeling in regard to the necessity of considering the bituminous road as well as the concrete road in determining the probable costs of accommodating heavy trucks I agree that the bituminous type of construction is quite adequate for passenger vehicles and I also agree that it can be made quite adequate for the heaviest trucks There is ample demonstration that this is correct

The objection, if any, that we might take to the analysis of costs which was presented in his report is that he attempts to show that the additional cost of truck operation is represented by the difference between the least cost of a bituminous type and the greatest cost of a concrete type Now, obviously, if we are going to determine the difference in cost caused by the operation of trucks we must compare the differences in cost of the same type of pavement designed for the passenger vehicle on the one hand and the truck on the other We cannot cross from one type to the other because, as he suggests, either one can be adequate for either type of traffic

Mr C S Pope, *California Division of Highways*: I have for a long time held the view that the weight of vehicles using the road is not the only characteristic which should be considered in road design I have a very clear opinion that the time and space occupied by a vehicle on the road should be a measure of its obligation toward the time space capacity of the road In other words, any section of highway of a given width may be said to have a certain maximum time space capacity which might be divided into units and the number of units of this time space which are appropriated by any one vehicle would be a measure of how much they owed to the community which financed the construction The simplest case, of course, would be that of a truck and trailer operating on a grade at a low rate of speed and thus restricting the passage of possibly nine or ten times the number of high speed vehicles which could normally use the same road The mathematics of the obligation appear to be quite simple, and would, I believe, give us a better basis for fixing the charges to be borne by trucks and heavy vehicles than is now available from the studies which have been made

Prof C B Breed, *Massachusetts Institute of Technology*: In approaching this highly controversial problem it is obvious that the premise adopted will greatly influence the conclusions reached If one is to first formulate the pavement requirements for passenger vehicles and then charge to the heavier motor trucks and buses the cost of all additional construction and maintenance required to make pavements adequate for these commercial vehicles, the result will be greatly different from that obtained if the investigator is going to assume that roads must of necessity be constructed and maintained for use of these heavy commercial vehicles (and consequently are suitable for the use of lighter vehicles) and then attempt to allocate the values of the advantages of the roads to each class of vehicle Obviously this latter method opens the door to favor the truck or the passenger car, depending upon the opinion or prejudice of the writer

This problem, and many others, was studied by the Joint Conference of Railroads and Highway Users published January 30, 1933 The result of their deliberations was published in a report which for the most part was printed in parallel columns, in one of which the opinions of the railroad group were set forth and in the other the opposing views of the motor interests When these two interests agreed, their joint opinion was printed in the middle of the page On the subject of equitable taxation of motor vehicles this conference agreed on the following:

"The basic cost of constructing, improving and maintaining a given highway should be determined from a highway designed for private passenger vehicles and other vehicles commensurate therewith All vehicles using such highways should pay their proportionate share of that total as a base tax The total additional cost of construction, improvements and maintenance to make a road suitable for a type of vehicle requiring such additional cost should be shared by each vehicle of that type and each vehicle of greater size Thus, each group should share in the base cost plus all increments of cost up to and including cost required by it "

The above agreed statement of opposing interests appears on the face of it to be equitable and it is the opinion of the writer that this has been pretty generally accepted as a fair basis for taxation. If this principle be applied to Mr Lavis' paper, it is obvious that roads which are adequate for the passenger car and for equivalent trucks is a joint use and should be so considered in an analysis of this problem of determining the costs which should be borne by each, and that any and all costs that are the results of providing for roads suitable for all vehicles which are heavier than this basis vehicle should be wholly borne by the heavier vehicles These added costs therefore should not be treated in any way as *joint* costs but as costs chargeable *wholly* to the heavier vehicles

In this paper Mr Lavis repeatedy discusses the added costs of the heavier types of pavements as chargeable jointly to the basic vehicle and to the heavier trucks which is the main reason why he reaches what seems to me to be an inequitable conclusion.

Throughout Mr. Lavis' article, there are several statements with which I am inclined to take issue, of which a few only are here mentioned.

For example, Mr Lavis repeatedly states that the stronger, wider and more durable pavements required by motor trucks bring likewise benefit to passenger cars These benefits he chooses to consider in nearly every case equal benefits, charging only to the trucks the cost of two or three additional inches of high type pavement, implying the cement concrete pavement type, which of course is only one of the higher types of pavements

With this point of view I cannot agree All highways can be built for passenger cars at a much lower cost than is required for mixed traffic Because an expensive pavement which is necessary for heavy commercial vehicles happens to provide a luxury for the passenger vehicle seems not to be adequate reason for assigning to the passenger vehicle a large part of the additional cost In many localities passenger car traffic, no matter how dense, would not require the cement concrete pavement at all Mr Lavis appears to doubt the economy of bituminous types because of their higher maintenance costs, shorter life, and higher vehicle operating cost There is no proof that these costs would be higher if these roads were used only by passenger cars In fact, experience in Massachusetts indicates that even with mixed traffic the bituminous type competes favorably with concrete For example, the surface maintenance costs for 7-in. bituminous macadam for the years

1933 and 1934 were practically the same as for 8-in reinforced cement concrete In fact, the bituminous type showed a slightly lower cost than the concrete In Massachusetts there are about 900 miles of bituminous type and about 300 miles of concrete in the state system, carrying from 3,000 to 10,000 mixed traffic per average day

A paper by Robley Winfrey in these *Proceedings*[1] shows that it is the smoothness and condition of the pavement surface which control power requirements Recent tests quoted in Winfrey's paper show the power requirements on good pavements to be very nearly the same regardless of the surface type There is no reason why, with proper subgrade treatment and careful inspection, bituminous types cannot be laid and kept smooth

I also take exception to Mr Lavis' belittling of the problem by emphasizing the fact that roads with a high type of surface comprise only four per cent of the total U S mileage It is upon this four per cent of roads that more than half of State and Federal funds have been spent

Mr Lavis refers to a diagram showing the relation between vehicle spacing and pavement width, which I included in my report to the Associated Railroads of Pennsylvania This diagram was based on a study, conducted by the Bureau of Public Roads, of the transverse distribution of moving traffic on different widths of pavements The diagram is not a "static" diagram as Mr Lavis calls it It is a diagram which shows the positions occupied by vehicles while moving along the road

In discussing the allocation of highway costs to commercial vehicles, Mr Lavis uses as his premise a quotation from the British Report of the Conference on Rails and Road Transport to the effect that annual road costs in Great Britain might be reduced by 2 or 3 per cent, if there were no vehicles of more than four tons unladen The amount which Mr Lavis estimates as chargeable to heavier vehicles in the U. S on this basis is $37,500,000 per year, which he divides by 638,309, (the number of trucks and buses over 1½ tons capacity) and obtains an additional charge of $50 to $60 per year to be levied against this group of vehicles. If I read the British report correctly, this seems to be inconsistent with the findings of the Ministry which referred to trucks over four tons unladen, which is roughly equivalent to a 3½ ton capacity truck. If Mr Lavis had divided $37,500,000 by the number of trucks over 3½ tons capacity (estimated at 65,000) he would have gotten $577 per year per truck over 3½ tons capacity, which is more nearly what the British Ministry report appears to say It may be of interest to note here that this same British report suggests a charge of £20 for a 1½ ton unladen truck and £226 for a 10 ton unladen truck on pneumatic tires.

[1] Page 23.

The two Massachusetts highways (in Salisbury and Amesbury) referred to by Mr. Lavis carry an average daily traffic of from 2000 to 3000 vehicles per day This is secondary traffic for Massachusetts, but it would be major traffic for many of the less densely settled states of the Union The construction cost of pavement only on these two projects reduced to a per mile basis is as follows

| | |
|---|---|
| For the 4240 ft section | $13,900 per mile |
| For the 2 6 mile section | $13,300 per mile |

If a concrete pavement of Massachusetts standard design (8 in. uniform thickness) had been laid the cost for this pavement would have been about $26,000 per mile at prices prevailing in 1933, that is, the additional investment would have been about $12,000 per mile, or about twice as much as the bituminous pavement which was laid

The maintenance costs quoted by Mr Lavis from my paper in the 13th Proceedings require a word of explanation The last three items in his tabulation are overhead items not usually included in published maintenance costs The low surface maintenance of $5 per mile was for a bituminous macadam pavement of the same type as those built in Salisbury but carrying slightly heavier traffic The high maintenance cost of $988 per mile there recorded included extensive repairs to an obsolete 2-lane bituminous type which was carrying an average daily traffic of 6400 vehicles per day including about 16 per cent of trucks A section of this road has since been replaced with four lanes of concrete

It will be noticed that the British Report of the Conference on Rails and Road Transport came to the conclusion that equitable taxation should place a much heavier burden on the heavier trucks than on the lighter Apparently this Conference used as a basic principle for taxation one similar to that adopted by the Joint Conference of Railroads and Highway Users

When one attempts to analyze annual road costs for different classes of vehicles, he is immediately confronted with the fact that, while dependable construction costs are readily obtainable, maintenance costs are anything but dependable since they have different bases in different states and even different bases in the same state from year to year It is perfectly easy to quote maintenance costs from state reports to prove any type of pavement to be cheaper to maintain than others These are some of the reasons why on the subject of this paper it is so difficult to reach a general conclusion which applies to the country as a whole If the problem is confined to an individual state where costs can be broken down into individual items which may then be properly placed in the construction, maintenance and operating divisions, it is possible to arrive at a reasonable conclusion as to the added annual cost of highways chargeable to the heavier commercial vehicles for that state system.

PROF W S DOWNS, *University of West Virginia*: Much research work is necessary before there will be available sufficient information to determine more than approximately the effect of heavy motor vehicles on highway costs

Preliminary to the apportionment of highway costs between the classes of vehicles is the question of a division of the costs between social and economic uses, that is, the part that should be paid by general taxation and the part that is chargeable to motor vehicles

THE EFFECT OF VEHICLE LOADS The effect of the vehicle load may be to require greater thickness of pavement or it may influence the selection of pavement type including the materials which enter into the pavement

*Flexible Pavements* Flexible type pavements must be constructed with sufficient thickness to distribute the load over the sub-soil in proportion to its carrying capacity Whatever is done to make the flexible pavement safe from load failure must bear a relationship to the maximum wheel load The depth of the macadam, soil stabilization, or what not will be found to increase approximately in proportion to the square root of the unit wheel load, according to tests involving the distribution of pressure through soils and granular material and in accord with actual experience in the construction and maintenance of flexible type roads These tests show that earth pressures are not only proportional approximately to the square root of the unit load but also, with equal unit pressure, are proportional approximately to the square root of the contact surface area Hence the square-root relationship applies even though the larger tires may possess the same unit pressure on the surface as the small tires

The theories derived from these tests may have little value for actual design purposes because of the unknown variations in the sub-soil conditions and the materials used, but the problem is not one of actual thickness but deals only with relative values It is only necessary that a *ratio* be found for comparative thicknesses which will apply for any given sub-soil condition or material Hence the ratio based upon the square root of the wheel load will meet all requirements and, though it be approximate, like the Older Theory of design for concrete slabs, it is nevertheless more accurate than many other factors which are accepted in the apportionment of highway cost

The difficulty in the general use of macadam or flexible type pavements for all classes of vehicles lies in the fact that the stone which composes the macadam is often of insufficient strength or hardness to withstand the crushing and shearing forces when the wheel load reaches large proportions Not infrequently greater strength may be imparted to the stone if it is surrounded by a stronger matrix as an asphalt mix When portland cement is used to form cement concrete, the strength of the stone in this respect is greatly increased In some sections of the country where exceptionally strong stone is available, as in the case of the granites and trap-rocks of New England, the macadam or flexible type pavement can be constructed to carry successfully the heaviest loads now using the highways, it being necessary to use asphalt or tar to bind the surface course, only Such conditions, however, do not exist in many states Thus, the macadam pavements are commonly used for comparatively light loadings, but where truck traffic prevails it is generally necessary to resort to a more expensive type in order to avoid the crushing and shearing effects caused by such loadings upon the stone aggregates

In accordance with these principles the writer has constructed flexible pavements composed of very inferior materials which successfully served large volumes of traffic consisting of light automobiles, but when trucks began to use such roads as the result of increased industrial activities, two things became necessary First, additional pavement thickness was needed to maintain a proper distribution of the load over the subsoil base in order to meet subsoil conditions and thus preserve the smooth surface contour, second, a tougher and harder stone was required for the top course to prevent crushing and internal disintegration

*Rigid Pavements* When rigid cement concrete pavements are used, it is the universal practice to consider the design from the standpoint of flexural strength Hence, the thickness of the slab for various loadings will be in proportion to the square root of the unit wheel load, other things being equal Opinion may differ about the advisability of building cement concrete pavements only 4 in thick because of the so-called action of the elements, but there is nothing to support a theory that the elements have any different effect upon slabs 4 in thick than upon slabs 6 or 8 in thick under similar sub-soil conditions, so long as the load factor is inoperative If, however, a greater thickness than that indicated by the design formula is desired to meet such objections, it can not be denied that the safety factor of the pavement structure will be proportionally increased Since surface wear is an unimportant consideration with pneumatic tires even under great frequency of traffic, the service life is largely a matter of structural strength With the proper design respecting expansion joints, drainage, etc , the forces produced by the elements, in the absence of a load factor, are minimized except as to the natural disintegration of the materials Portland cement concrete, properly built, is a very durable material and it is not unreasonable to expect it to last 40 or 50 years under adequate maintenance provided it is not structurally damaged by the weight of the loads traveling the highway To ensure against load failure engineers recognize that the design factor of safety must not be less than two That such requirement concerning the safety factor may be occasionally violated without causing perceptible damage when an occasional extra heavy truck passes over a pavement of inadequate design gives rise to a belief in some quarters that pavements which are adequately designed for light weight vehicles can be safely used at infrequent intervals by heavier vehicles without causing any extra cost Indeed, an analysis of the designs for concrete pavements in many states will show that many pavements possess a factor of safety less than two for wheel loads of 8,000 pounds, yet these pavements are actually carrying wheel loads much in excess of that limit In doing so, however, in accordance with the theory of fatigue, the pavement's useful life is being shortened in proportion to the frequency of such overloading Frank T Sheets, Consulting Engineer for the Portland Cement Association, gives an apt illustration of the principles of fatigue applied to concrete pavements in his booklet entitled "Concrete Road Design"[1] He shows, for instance, that for a concrete pavement with the thickness 8-5 3-8 in , assuming the concrete to possess a modulus of rupture of 700 lb per sq in , the safety factor is two for a moving wheel load of approximately 7,000 lb For a wheel load of 8,000 lb the safety factor is 1 8 Hence such pavement will safely sustain an indefinite number of repetitions of wheel loads not exceeding 7,000 lb, but approximately 40,000 applications of a wheel load of 8,000 lb will induce failure

The average portland cement concrete pavement possesses a comparatively short service life, (often estimated at less than 20 years) because most pavements heretofore constructed are not designed adequately for the present-day maximum wheel load and they are often overstressed by the occasional passage of extra-heavy trucks It will not do, therefore, to say that these heavy trucks entail no extra highway costs simply because they are using a pavement that was designed for lighter loads, without perceptible signs of failure at the time of vehicle passage So long as the maintenance crews are able to maintain a smooth surface by filling the cracks or depressions with bitumen, no great concern is felt; but when ultimately, reconstruction becomes necessary, then it is appreciated how disappointingly short was the service life If the heavy trucks serve to shorten the pavement's useful life, are they not responsible for an increased annual cost just as they would be if the first cost had been sufficiently increased to provide a thicker pavement slab to meet the demands of such wheel loads?

If, therefore, portland cement concrete is considered the type for all classes of vehicles it seems logical to assume that the true comparative pavement costs are in proportion to the cost of providing a thickness of slab that will conform approximately to the ratio expressed by the square-root of the wheel loads The same ratio will apply to the flexible type when that pavement is considered for all classes of vehicles, provided suitable stone is available

[1] Published by the Portland Cement Association, Chicago (1934)

Therefore, with respect to the factor of pavement depth, which enters into any study of pavement costs as between the basic vehicle and the heavy truck, it must be concluded that it costs at least twice as much and often more, per surface unit, generally speaking, to provide pavements for wheel loads of 8,000 or 9,000 lb as it does to provide pavements for private automobiles with wheel loads of 2,000 lb

WIDTH, GRADE AND ALIGNMENT The writer can not agree with the conclusion that "the width, gradient and alignment of modern highways is determined almost entirely by the requirements of private passenger automobiles "

*Width* In general, the proper width of a pavement is largely a matter of opinion based upon the ease and comfort of travel The actual width of present-day pavements is largely a compromise of conditions coupled with economic considerations Comparable widths for different classes of vehicles depend upon vehicle width, other things being equal In the writer's opinion a 10-ft traffic lane is not too wide for passenger automobiles, nor is 12 ft too wide for buses and trucks when the traffic density is great A popular criticism of present highway conditions is with respect to the crowding of the traffic lanes by buses and trucks It is conceivable that vehicles 8 ft wide will require no greater width of pavement than vehicles only 6 ft wide, other conditions being the same

Some trucks, and most buses, travel at a speed equal to that of the average automobile when such vehicles are not required to ascend grades in excess of two or three per cent While skilled operators may generally be found at the wheel of the public carrier buses, and perhaps on some commercial trucks, yet no higher qualifications are needed to secure a truck driver's license, than are required for an automobile license, nor are all the careless, incompetent and drunken drivers restricted in their operations to automobiles There is no reason to assume under such conditions that the driver of the ponderous truck can be depended upon to exercise greater skill and precaution upon the highways than will the driver of the privately owned automobile who is likely to sustain much greater injury in the event of a collision It is therefore difficult to understand why the same differential in highway width that is so apparent when the vehicles are static will not apply to moving vehicles Traffic studies, moreover, indicate that these differentials do apply, as was shown by the writer in a paper entitled "The Cost of Providing Highways Suitable for Various Classes of Vehicles," published in September, 1933

It appears that if an 18-ft width is required for automobiles only, then to afford the same ease and comfort when automobiles are required to pass trucks that are 8 ft wide it is necessary to have 20 ft of pavement When trucks are required to pass other trucks 2 ft. more of pavement is required than when trucks pass automobiles, and the comparable width becomes 22 ft

A very important factor in pavement width is the volume of traffic As the necessity of passing becomes more frequent there is greater need for adequate passing width It is this fact, as well as the extra vehicle width and the speed of locomotion which has caused highway engineers to increase gradually the width of pavements If vehicles were all of uniform width, a difference would still exist in the required width of pavements, based on low and high frequency of traffic The fact that a relatively few extra-wide trucks may use widths that are generally considered no more than is necessary for automobiles is because they pass infrequently As the trucks increase in number and truck passing becomes more frequent, it is apparent to the automobile driver that extra pavement width is needed to compensate for the extra truck-width

There is another phase of the question of pavement width which needs mention It relates to highway capacity On a two-lane highway the presence of slower-moving trucks in mixed traffic slows down the speed of other vehicles It is more difficult to pass trucks of great length and width than vehicles which conform to the basic dimensions Hence, the condition is reached in dense traffic when all vehicles must move slowly at the rate of speed set by the trucks Consequently the highways reach a stage of premature congestion and additional traffic lanes are demanded which would not be necessary if vehicles were free to move with greater speed

When the additional lanes are provided that will permit the segregation of the slow from the fast moving vehicles, or to facilitate passing, the average lane capacity is increased about 50 per cent This fact is clearly shown in the traffic studies of Dean A N Johnson, who found the practical capacity of two-lane pavements was approximately 1,000 vehicles per hour, but four-lane pavements showed 3,000 vehicles per hour [2]

*Gradient and Alignment* On open rural roads where the speed of vehicles is of prime importance, the alignment is generally influenced by automobile rather than truck requirements Alignment, however, is generally dependent upon the gradient restrictions The problem of the engineer is to find a location where the highway gradient requirements may be fitted economically to ground conditions without too great sacrifice in alignment The more freedom he has in the permissible gradients the less occasion there will be to make deep cuts and high fills Thus, in hilly country the grading costs necessary to secure a low rate of grade are generally more than for steeper grades

The maximum economical rate of grade for automobiles is not less than 8 per cent That for trucks varies, but for the heavier vehicles

[2] Proceedings Highway Research Board, Vol 11, Part I, p 409 (1931)

is less than 4 per cent Any extra cost, therefore, which might be incurred in order to reduce highway gradients below 8 per cent may properly be considered to be primarily for the benefit of the heavier buses and trucks If the grade is more than 3 or 4 per cent, and of appreciable length, many buses and trucks must shift gears from direct drive and thus travel at a reduced rate of speed, which requires the automobile traffic either to reduce speed or pass the trucks Thus, highway hazards are increased and the road efficiencies are impaired In view of these conditions the American Association of State Highway Officials, much in the nature of a compromise, recommends 5 per cent as the maximum grade for main highways carrying heavy traffic, and for lighter traveled highways 6 per cent where feasible, but otherwise 8 per cent

In the approaches for the George Washington Bridge over the Hudson River in New York City, the Engineering Staff of the Port Authority, in criteria to meet the demands of modern traffic, specified "All grades shall be as flat as possible consistent with the drainage and in any event should not exceed 4 per cent on main approaches and connections carrying truck traffic, and 6 per cent on connections with Riverside Drive carrying passenger automobiles only "

It is evident, therefore, that it is the performance of the heavy truck rather than the automobile which demands the lower rates of grade for which the engineer must strive in the economical design of highways To meet such requirements will generally necessitate more excavation and perhaps add to the highway distance with a consequent increase of curvature Failure to meet the truck demands impairs the efficiency of highway operation