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Line-Haul Trucking Costs and Weighing Vehicles in Motion

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Foreword

The two papers presented in this Record are of particular interest to those in highway transportation concerned with comparative operating costs of highway freight vehicles and/or basic data on operating truck axle loads and gross weights. The importance of sound economies in highway planning and operations is increasingly evident; the information in these papers should find direct application in this field.

The Highway Research Board Committee on Economics of Motor Vehicle Size and Weight reported in 1961 the results of a study conducted in 1955 and 1956 concerned with the relationship between the operating costs of trucking equipment in line-haul, highway freight service and the gross weights and cargo weights of highway freight vehicles. The report entitled "Line-Haul Trucking Costs in Relation to Vehicle Gross Weights" was later published in detail in HRB Bulletin 301.

In order to reflect the present level of economic development, Hoy Stevens updated HRB Bulletin 301 for the Committee in a report entitled "Line-Haul Trucking Costs Upgraded to 1964." The 1964 upgrading reflects for highway freight vehicles the line-haul operating costs for rural highway operations where quite consistent road speeds are attained for terminal-to-terminal operations. The operating costs are grouped into the following six subtitles: repair, servicing and lubricants costs; tire and tube costs; fuel costs; driver's wage and subsistence costs; indirect and overhead costs; and depreciation and interests costs. The report presents vehicle operating costs, in terms of vehicle-miles and payload ton-miles, and in relation to increases in gross weight trailer combinations.

Clyde E. Lee has conceived a unique axle weight transducer which is directly applicable to the dynamic weighing of vehicles. The transducer has distinct weight and size advantages over conventional scale pits and platforms; its operational advantages may also well favor its use in place of the standard loadometer.

When documentation is complete, the transducer may be shown to be more accurate than load cell supported platforms. At present this appears to be due to the transducer deflecting with the pavement instead of including the rigid discontinuity of pit walls.

Dr. Lee describes the construction of his transducer, the method of installation in existing pavements, and the accuracy evaluations which have been completed. He discusses the research data analysis and outlines his continuing development program.

A portable dynamic weighing device with inherent accuracy will stimulate the imagination of highway engineers to find applications for it in planning, design, and operation. The procurement of statistical data without stopping or delaying traffic will undoubtedly be one of the foremost uses. Pavement research, vehicle classification, vehicle use of lanes, traffic control operation, and law enforcement are some possible other uses.

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Line-Haul Trucking Costs Upgraded, 1964

HOY STEVENS, Highway Research Engineer, Traffic Systems Research Division, Office of Research and Development, U.S. Bureau of Public Roads, Washington, D.C.

The line-haul trucking costs in relation to vehicle gross weights, reported in Highway Research Board Bulletin 301, were developed from 1955 and 1956 cost data obtained by interviews with line-haul highway freight carriers.

In the present paper, these costs are upgraded to 1964 by three types of indexes, the methods of developing this information are described, and the resulting upgraded unit mileage cost data are given in a series of charts.

•IN STUDIES of the economics of prescribed and proposed size and weight limitations for highway freight vehicles and/or trailer combinations, there is a need for data relating operating costs to loaded gross weights. Such information was published in Highway Research Board Bulletin 301, "Line-Haul Trucking Costs in Relation to Vehicle Gross Weights" (1).

The information in this report was based on detailed cost data collected from 611 motor carriers during 1955 and 1956.

This type of cost information becomes dated in our present dynamic economic development, and after several years is not representative, except for overall trends, of operating costs. The present report is a percentage upgrading of the cost data reported in HRB Bulletin 301, and was made in 1964.

It was not difficult to upgrade these costs because in HRB Bulletin 301 the expense elements of motor vehicle operating costs were grouped under six subtitles which are described in the 1952 Interstate Commerce Commission Classification of Accounts (2). The totals of these six groups of accounts may be readily upgraded by using certain data from the Annual ICC "Transport Economics Reports, Part 7 Motor Carriers," (3) and additional data such as line-haul drivers' wage contracts, or other indices.

The line-haul operating costs in Bulletin 301 were grouped into six subtitles, which were assembled into the overall costs. The subtitles are

1. Repair, servicing and lubricant costs;
2. Tire and tube costs;
3. Fuel costs;
4. Driver's wage and subsistence costs;
5. Indirect and overhead costs; and
6. Depreciation and interest costs.

The expense account numbers and descriptions of the several accounts in each group are contained in HRB Bulletin 301, and were not changed in this upgraded supplement.

Reasonably consistent cost data can be obtained for line-haul highway freight vehicle operation, i.e., the costs from the time the line-haul trailer combination leaves one freight terminal until it reaches its terminus freight terminal. This consistency results from fairly uniform rural highway operation, where quite consistent road speeds are attained for terminal-to-terminal operation. In fact, with the increasing development of the Interstate highway system, line-haul highway road speeds will become more uniform.

Paper sponsored by Committee on Economics of Motor Vehicle Size and Weight and presented at the 45th Annual Meeting.

The opposite situation exists in urban areas, where operating costs are greatly affected by urban vehicle speeds, stops and starts, and waiting times, all of which influence primarily drivers' costs and fuel costs. For urban operating cost information, a different series of data and indices must be employed to develop urban pickup and delivery operating costs. The data in Bulletin 301 and this upgrading of them do not cover urban delivery costs, but relate only to line-haul operations, primarily of trailer combinations.

To have these cost data in tabular form in smaller increments of loaded gross weight, the equations of the upgraded curves were determined and used to calculate data for several tables of costs with smaller increments of gross weights (tables available from Robley Winfrey, U. S. Bureau of Public Roads).

LOADED GROSS WEIGHT

The term "loaded gross weight" used to designate the weight ratings of trailer combinations by which the operating cost data were distributed has been subject to some misunderstanding, although defined on pages 76 and 77 of Bulletin 301. For clarity, a shortened definition of loaded gross weight is given here.

Loaded gross weight is the tare weight of a vehicle or a trailer combination plus the most usually carried or typical payload when the vehicle or trailer combination is dispatched on a loaded trip. This term is used because the cost data were overall operating data obtained from motor carriers endeavoring to obtain optimum payloads for their typical freight under the operating and delivery conditions required by the class of freight. Further, only two groups of costs for a given vehicle or combination are significantly affected by the different operating services of full payloads in one direction and empty returns, as compared with payloads in both directions; these groups are fuel and tire costs, which are affected by gross weight. The other cost groups are affected predominantly only by time or miles of operation.

UPGRADING INDICES

Many data are available concerning the overall average cost of transporting freight in various sizes and capacities of highway freight vehicles on a nation-wide basis. Such data are contained in the annual reports of certificated motor carriers to the Interstate Commerce Commission (ICC), and to certain state transportation regulatory commissions. These data generally do not contain specific information regarding variations in type and capacity of the freight-transporting equipment, usual cargo weights, loaded gross weights, or amount of regular road travel without cargo. The exceptions to this generalized statement are the cost studies undertaken by the Truck Transport Division of the California Public Utilities Commission in connection with motor carrier tariff revisions for intrastate hauling of various commodities in California. However, these data are not published for general use, but are used in California state hearings.

Such data are of little value to highway engineers who wish to investigate the overall economic advantages which might result from permitting higher axle and gross weights for motor freight trailer combinations and to evaluate these advantages against the increased costs of providing highway facilities with greater load-carrying capacities.

A study of six groupings of the cost elements involved in owning and operating trailer combinations in line-haul service, in an increasing order of loaded gross weights, was reported for 1956 in HRB Bulletin 301. This study developed the increases in operating costs of trailer combinations per vehicle-mile as the loaded gross weights of the trailer combinations increased, and the resulting reductions in payload ton-mile costs. The range of loaded gross weights studied varied from approximately 20,000 to 195,000 lb. This study, which was made by interviewing the motor carriers, included for-hire carriers, private carriers, carriers of light commodities, and carriers of very heavy commodities in weight-limited loads on public highways, as well as private carriers hauling maximum gross loads on private roads.

Since 1956 several of the private toll roads have initiated the use of long double-trailer combinations approximately 100 ft in overall length, with permitted gross weights of approximately 130, 000 lb. In addition, 7-axle double-trailer combinations have been developed for use on Michigan public highways for hauling liquid commodities with permitted gross weights of 106, 000 lb. Also, 11- and 12-axle trailer combinations are in use on certain Michigan public highways for hauling crushed stone and sheet steel, with permitted gross weights of 148, 000 and 161, 000 lb. All of these types of very heavy gross weights operations take place on relatively level roads, but the permitted gross weights are approaching the present limits of automotive design, if desired level road speeds with full load are assumed to be not less than 50 mph (as is presently required on the toll roads). Although the range of gross weights considered in HRB Bulletin 301 adequately covers the vehicle gross weight developments since 1956, it is desirable to revise the older cost data to reflect current costs. The methods of upgrading the previous cost data, the indices used, and the resulting cost curves, constitute the balance of the report.

The data are reported under three headings: (a) gasoline and diesel engine powered trailer combinations, (b) gasoline engine powered trailer combinations, and (c) diesel engine powered trailer combinations. However, it is believed that the data for gasoline and diesel engine powered trailer combinations are most representative of the overall average costs of the mixture of types of trailer combinations in use on the highways of the continental United States.

UPGRADING TECHNIQUES

Several indices were investigated as means for upgrading the 1956 cost figures. However, the latter cost elements were assembled on the basis of the expense account definitions prescribed in the ICC's "Uniform System of Accounts for Class I Common and Contract Motor Carriers of Property—Issue of 1952" (2). The various individual expense accounts comprising each of the six groups of costs charted in HRB Bulletin 301 are described in that report.

Each year the Bureau of Transport Economics and Statistics of the ICC issues its "Transport Statistics in the United States" in several parts. In Part 7, which relates to motor carriers (3, 4), the specified ICC expense accounts and statistical information are tabulated and summarized by different groupings of carriers with similar operating characteristics. One group of carriers described as "Class I Common Carriers of General Freight Engaged in Intercity Service Operating With Owned Equipment Principally" has characteristics similar to the carriers reported in HRB Bulletin 301. The expense account and statistical data regarding these carriers are reported in Tables 5, 7, 8 and 14 in Part 7, Motor Carriers, ICC Transport Statistics (3, 4) for each year.

Although the number of carriers in this category has decreased because of mergers and redefinition of class I motor carriers, the number of vehicles and vehicle-miles has remained adequately constant, as is shown in the following schedule.

1. Total number of power units owned in intercity service—31, 424 (1956), 28, 609 (1962);
2. Total vehicle-miles operated in intercity service owned power unit vehicles—1, 609, 849, 389 (1956), 1, 958, 930, 439 (1962); and
3. Average vehicle-miles per owned power vehicle per annum—51, 230 (1956), 68, 473 (1962).

Power vehicles are being operated both more extensively and more efficiently, as can be expected of modern automotive equipment. Further indication of the comparative use of these carriers is shown by the following data developed from ICC (Table 14, 3, 4).

1. Average tons of freight hauled annually by line-haul power units (both owned and rented)—1, 964 (1956), 2, 326 (1962);
2. Average revenue per line-haul power unit (both owned and rented)—$37, 683 (1956), $59, 163 (1962);
3. Freight revenue per line-haul vehicle-mile (both owned and rented)—$0. 735 (1956), $0. 861 (1962); and
4. Costs per line-haul vehicle-mile (both owned and rented)—$0. 711 (1956), $0. 830 (1962).

For the reasons previously mentioned, the relative costs from the ICC Transport Statistics (3, 4) for 1956 and 1962 are used as the primary indices to upgrade the line-haul trucking costs for different loaded gross weights. Further, except for changes in driver wage rates, there were only small changes in the majority of the different cost elements during 1963. For this reason, the upgraded cost data are assumed typical for the first quarter of 1964. However, in January 1964 a new driver wage contract was negotiated, which resulted in a substantial increase in costs. The driver wage and subsistence costs are upgraded to reflect these 1964 wage rates. As a result of these factors, the revised cost data reported in this upgrading study are considered representative of trucking costs as of March 1964.

The revised cost data are presented in curve form on charts similar to the cost curves shown in Figures 18 through 23 of HRB Bulletin 301.

PRESENTATION AND METHODS OF UPGRADING VEHICLE-MILE COST DATA

Grouping by ICC Accounts

The ICC Uniform System of Accounts (2) was used as a guide in identifying and grouping accounts for the purpose of computing the major categories of costs, which represent costs directly related to line-haul operations.

To reflect the overall costs per vehicle-mile of operation, the individual expense accounts have been grouped under six general descriptive headings. Cumulative cost curves have also been developed under these general headings, using methods similar to those in HRB Bulletin 301.

Repair, Servicing, and Lubricant Costs

Repair and servicing costs included the costs of engine oil in the 1956 data. The total amounts spent for each of these two cost items by the selected group of carriers (class I common carriers of general freight engaged in intercity service operating with owned equipment principally) are reported in Table 8 of the 1956 and 1962 ICC Transport Statistics (3, 4). In both ICC reports, the amounts include the costs for line-haul revenue equipment (tractors, tractive trucks and trailers) and city pickup and delivery trucks. However, the expenses of city pickup and delivery trucks, because of fewer miles of travel and less severe daily service, account for only a small portion of the total cost of repair, servicing, and lubricants. Further, these combined costs for carriers' vehicles are the only ones available in published reports.

Table 14 of the 1956 and 1962 ICC Transport Statistics (3, 4) gives the total vehicle-miles of owned line-haul power vehicles, and Table 8 of these reports gives cost data for the same series of carriers. Vehicle-mile data for city pickup and delivery trucks are not reported. Hence, the vehicle-mile data for the line-haul power vehicles are considered as representative of the vehicle mileage for each year.

To develop an upgrading index factor to apply to the 1956 cost data, the total amounts spent by this group of carriers for repairs, servicing, and lubricants in the years 1956 and 1962 were divided by the appropriate line-haul power unit vehicle-miles to give an average cost for these expense items in terms of cents per power unit vehicle-mile for each year. The 1962 cents per vehicle-mile were divided by the 1956 cents per vehicle-mile to develop the upgrading factor of 1.077 by which the 1956 costs in HRB Bulletin 301 are multiplied to develop appropriate cost data for first quarter 1964.

The data given in the table on page 5 are derived from Tables 8 and 14 of the 1956 (3) and 1962 (4) ICC Transport Statistics.

The resulting upgraded cost data for first quarter 1964 are shown in Figures 1, 2, and 3.

Tire and Tube Costs

The tire and tube costs reported in HRB Bulletin 301 are for line-haul revenue vehicles only. The tire and tube costs reported for the same selected ICC Class I common

Item	1956	1962
Repairs and servicing, revenue equipment	$ 100,960,309	$ 133,038,261
Oil for revenue equipment	3,292,275	3,781,929
Total owned line-haul power units	31,424	28,609
Total owned line-haul power unit vehicle-miles	1,609,849,389	1,958,930,439
Repair and servicing per power unit vehicle-mile	0.0627	0.0679
Oil per vehicle-mile	0.0021	0.0019
Average repair and oil costs per vehicle-mile	$ 0.0648	$ 0.0698

$$\frac{\text{1962 unit cost}}{\text{1956 unit cost}} = \frac{0.0698}{0.0648} = 1.077 \text{ upgrading factor}$$

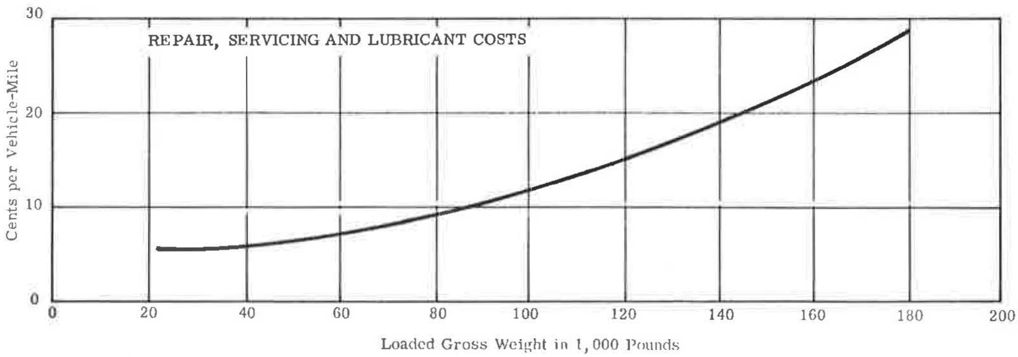

Figure 1. Gasoline and diesel engine powered trailer combinations.

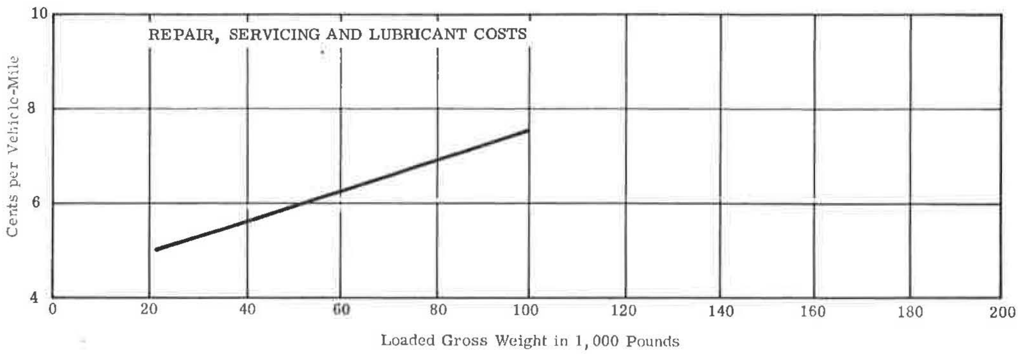

Figure 2. Gasoline engine powered trailer combinations.

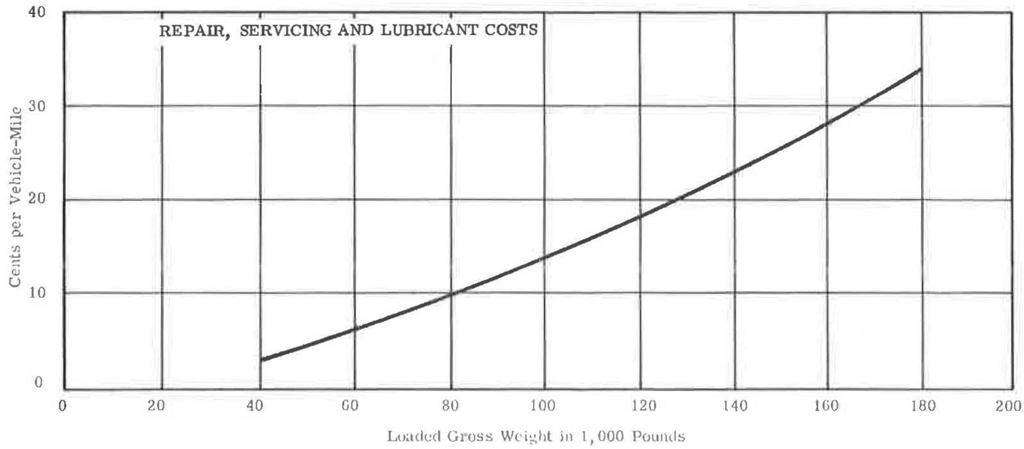

Figure 3. Diesel engine powered trailer combinations.

carriers in Tables 8 and 14 of the 1956 and 1962 ICC Transport Statistics (3, 4) include the costs of tires and tubes for city pickup and delivery as well as the costs of tires and tubes for line-haul revenue equipment. However, because of less annual travel and less severe service, the costs of tires and tubes for city trucks is only a minor part of the reported total tire and tube costs; hence, as these cost totals are published they are used to develop the upgrading index factors to be used with the tire and tube costs reported in HRB Bulletin 301.

The average vehicle-mile costs for tires and tubes for 1956 and 1962 were developed by dividing the total tire and tube costs for each year by the appropriate total owned power unit vehicle-miles. The average vehicle-mile cost for 1962 was divided by the average vehicle-mile cost for 1956 to develop the upgrading factor of 0.894 by which the 1956 costs are multiplied to develop appropriate cost data for first quarter 1964.

The following details of these data are from Tables 8 and 14 of the 1956 and 1962 ICC Transport Statistics.

Item	1956	1962
Tire and tube costs	$ 34,705,212	$ 37,894,275
Total owned vehicle-miles	1,609,849,389	1,958,930,439
Tire and tube costs per vehicle-mile	$ 0.0216	$ 0.0193

$$\frac{\text{1962 unit cost}}{\text{1956 unit cost}} = \frac{0.0193}{0.0216} = 0.894 \text{ upgrading factor}$$

The resulting upgraded cost data for the first quarter 1964 are shown in Figures 4, 5, and 6.

Fuel Costs

The data on fuel costs indicate a considerable reduction in fuel costs per vehicle-mile, undoubtedly as a result of the interaction of two developments in the industry. In line-haul, intercity service there has been a considerable transition from gasoline engines to the use of diesel engines with their better fuel economy. Also, there have been improvements in gasoline fuels and gasoline engines which have resulted in improved fuel economy for gasoline engines.

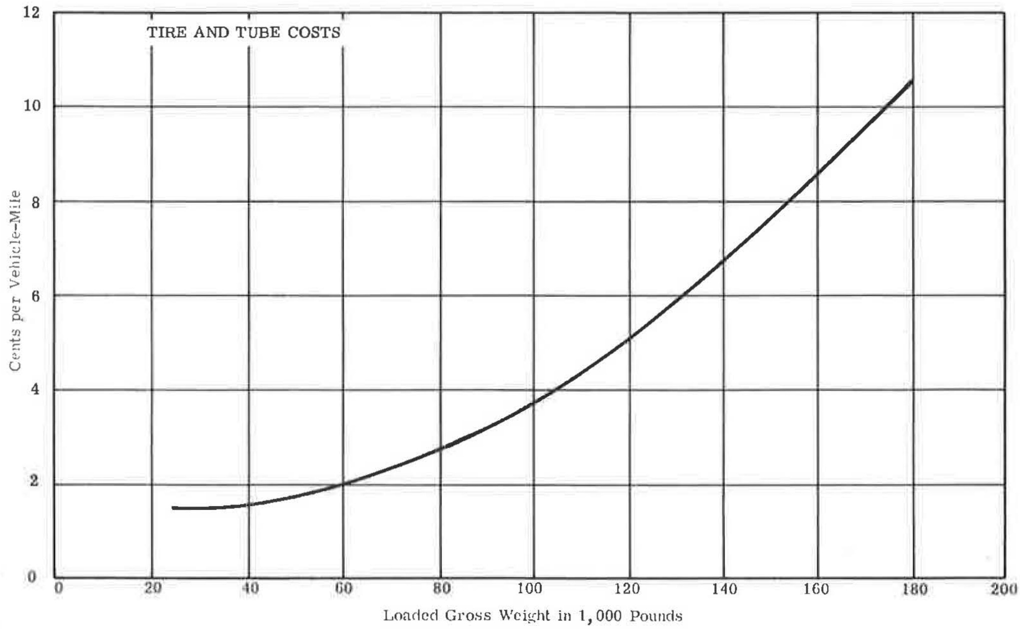

Figure 4. Gasoline and diesel engine powered trailer combinations.

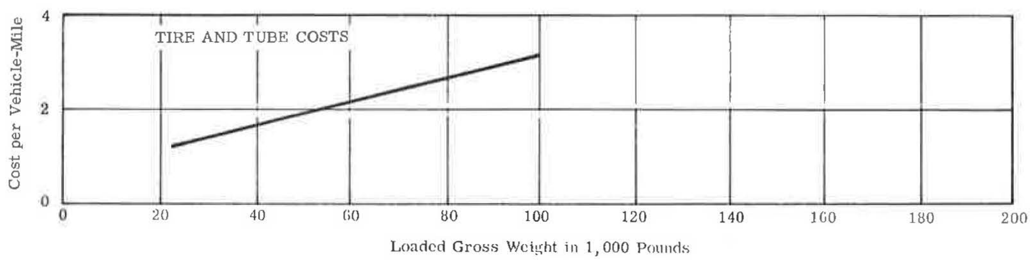

Figure 5. Gasoline engine powered trailer combinations.

For these reasons it is not surprising to obtain the reductions in fuel costs indicated by the changes in these cost items in the ICC Transport Statistics for 1956 (3) and 1962 (4). The total amounts reported under "fuel for revenue equipment" in the two series of ICC Transport Statistics (3, 4) include fuel for city pickup and delivery trucks. As was the case with tire costs, the fuel for city trucks is a small portion of the total fuel consumed. Hence, the average vehicle-mile cost for fuel, developed by dividing the total fuel costs from Table 8 in the 1956 and 1962 ICC Transport Statistics (3, 4) by the line-haul, intercity mileages obtained from Table 14 of the same reports, may be used to develop the upgrading factor for fuel costs. Dividing the average vehicle-mile fuel cost, so developed for 1962 by the similar average vehicle-mile fuel cost for 1956, gives the upgrading factor of 0.765 by which 1956 fuel costs are upgraded to first quarter 1964 costs.

The details of these data and calculations are given in the table on page 8; the original fuel cost data are from Tables 8 and 14 of the 1956 and 1962 ICC Transport Statistics (3, 4).

The resulting upgraded cost data for the first quarter 1964 are shown in Figures 7, 8 and 9. (Fuel costs do not include state and Federal fuel taxes because the latter are payments on the costs of providing highway facilities, and as such are not vehicular cost.)

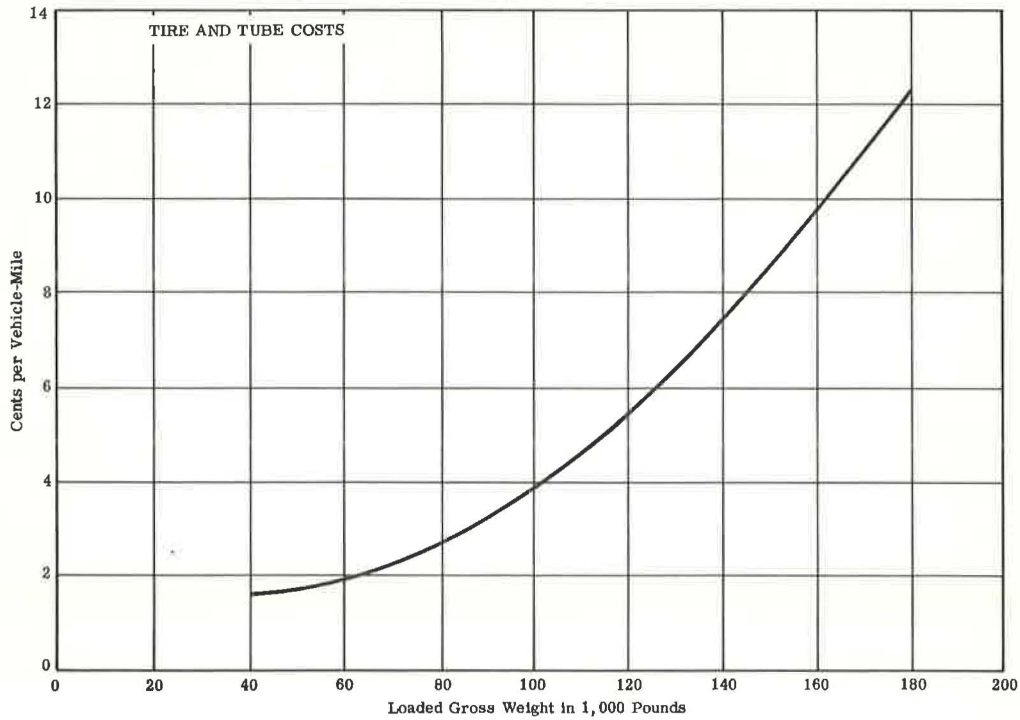

Figure 6. Diesel engine powered trailer combinations.

Item	1956	1962
Fuel for revenue equipment	$ 61,140,346	$ 55,730,201
Total vehicle-miles, intercity	1,712,129,255	2,040,395,692
Average fuel cost per vehicle-mile	$ 0.0357	$ 0.0273

$$\frac{\text{1962 unit cost}}{\text{1956 unit cost}} = \frac{0.0273}{0.0357} = 0.765 \text{ upgrading factor}$$

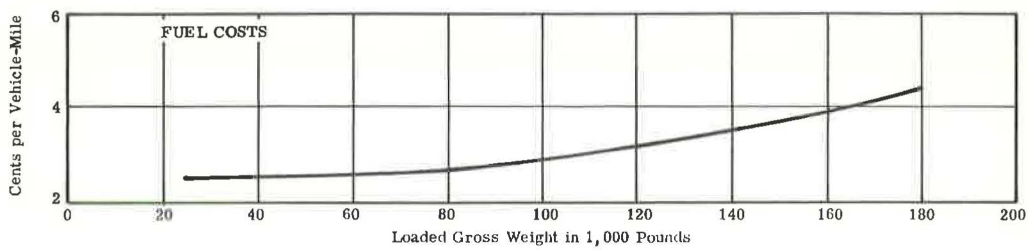

Figure 7. Gasoline and diesel engine powered trailer combinations.

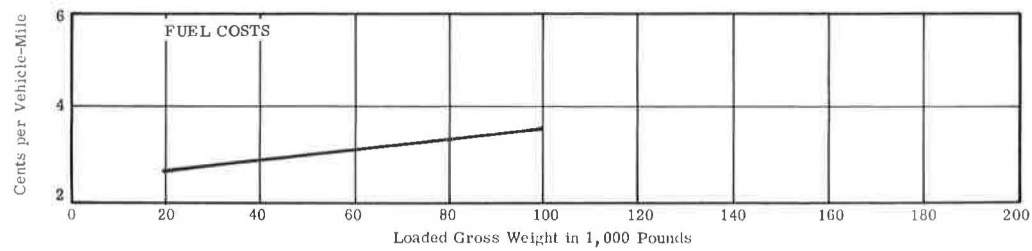

Figure 8. Gasoline engine powered trailer combinations.

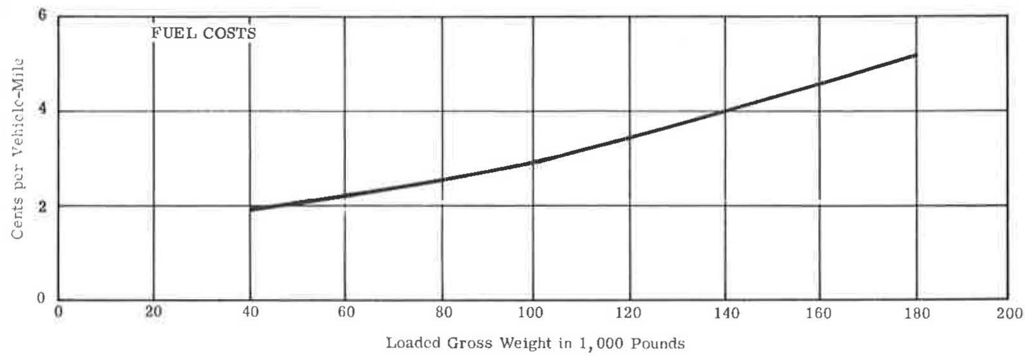

Figure 9. Diesel engine powered trailer combinations.

Driver Wage and Subsistence Costs

The greatest change in trucking costs occurred in driver wage rates. A new wage contract for over-the-road, line-haul drivers was negotiated in January 1964 (5), and the first increase became effective shortly thereafter. This year (1964) in 26 of the western and central states the wage contracts (5) are on a mileage basis, as compared with 23 states in 1956. The 1964 contract rates are given in Table 1.

These new wage rates are plotted in Figure 10, using the same procedure as in the 1956 study (1) to develop wage rates for trailer combinations with a range of loaded gross weights. This procedure recognizes the principle of productivity pay differentials that are indicated by the contract wage scales for the different trailer combinations having the typical loaded gross weights shown in the 1956 study (1).

Although the subsistence costs for away-from-home layovers were increased slightly in the new contracts, the apparently greater average annual miles per power vehicle probably offsets this subsistence allowance increase to such an extent that vehicle-mile costs for subsistence are not substantially changed from the estimates in the 1956 study.

The 1964 driver wage rates for different power unit vehicle-miles are plotted in Figure 10, using the same typical loaded gross weights of the specified trailer combinations as shown in Figure 10 of the 1956 study. The 1962 wage rates at the 20,000-, 40,000-, 60,000-lb, etc., ordinates for both the single cargo body combinations and the double cargo body combinations were divided by similar wage rates on the 1956 charts to develop upgrading factors for driver wage and subsistence costs. There

TABLE 1

1964 OVER ROAD DRIVERS' MILEAGE RATES PER VEHICLE-MILE

Vehicle	$/Veh-Mi
3-axle tractor semitrailer	0.1025
4-axle tractor semitrailer	0.1050
5-axle tractor semitrailer	0.10625
Double cargo vehicle combination	0.1165

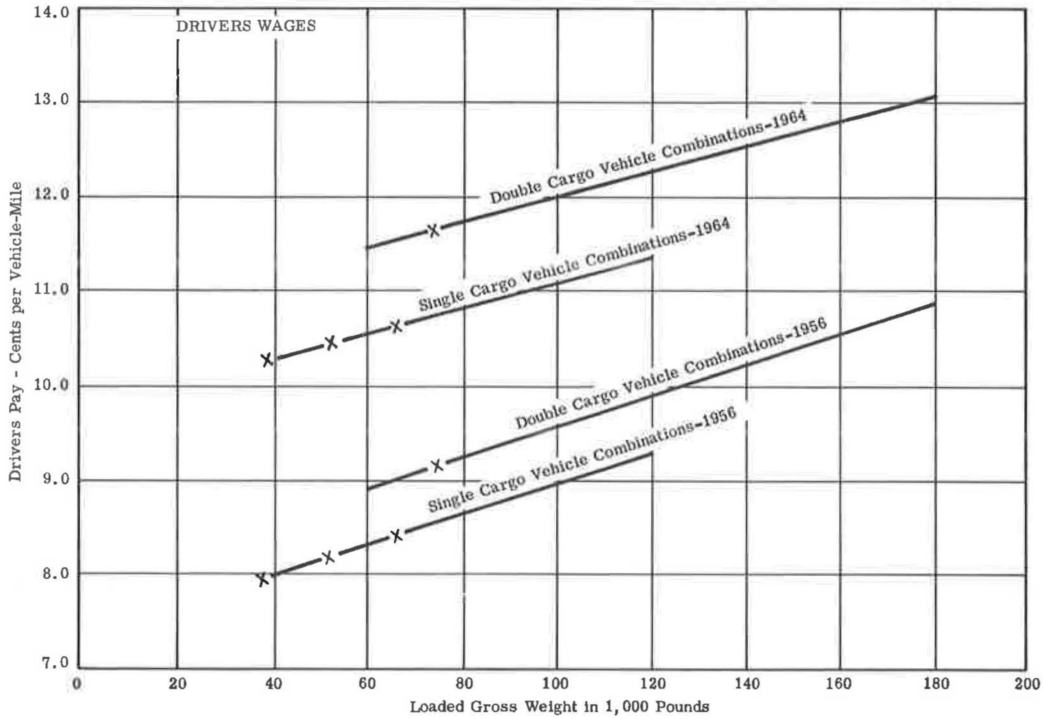

Figure 10. Drivers wage rates per mile by gross weight of trailer combinations.

appears to be a slight trend toward bringing together the mileage wage rates for different trailer combinations, as the increases were slightly smaller, percentage-wise, for the heavier vehicles than for the 2-S1 trailer combination. Hence it was necessary to develop an upgrading factor at each 20,000-lb ordinate on the Driver's Wage Rate Chart (Fig. 10).

Using these several upgrading factors with the vehicle-mile costs at the several 20,000-lb ordinates of the drivers wage and subsistence charts for 1956 (Figs. 21 through 23, HRB Bulletin 301), revised Driver Wage and Subsistence Costs for 1964 were developed as shown in Figures 11, 12, and 13.

Indirect and Overhead Costs

The Indirect and Overhead Costs indicated in Table 2 were tabulated from Tables 8 and 14 of the ICC Transport Statistics for 1956 (3) and 1962 (4). One change made in the 1962 ICC Table 8 is that Employees Welfare Expenses are shown under each department grouping, rather than only in the administration department, as in 1956. However, in Table 2 all related Employee Welfare Expenses are grouped under one heading, as was the case in the 1956 study. Employee Welfare Expenses are more commonly known as Fringe Benefits, and have increased in all industries, either as a matter of contract or management policy.

The calculations in Table 2 indicate an average increase in Indirect and Overhead Costs of $0.0149 per power unit vehicle-mile. Indirect and Overhead Costs are primarily "time" expenses and are not directly related to vehicle weights. Hence, these costs are uniformly increased $0.0149 per vehicle-mile over the entire range of loaded gross weights. The upgraded values for Indirect and Overhead Costs are shown in Figures 14, 15 and 16.

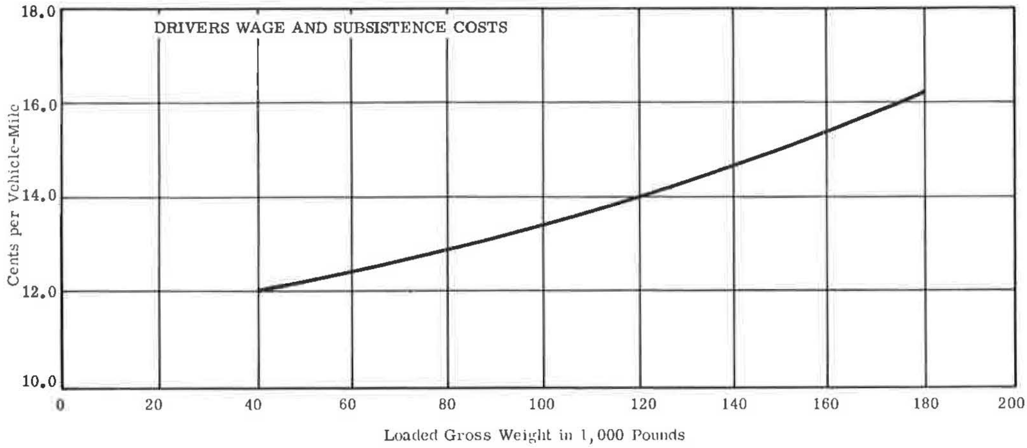

Figure 11. Gasoline and diesel engine powered trailer combinations.

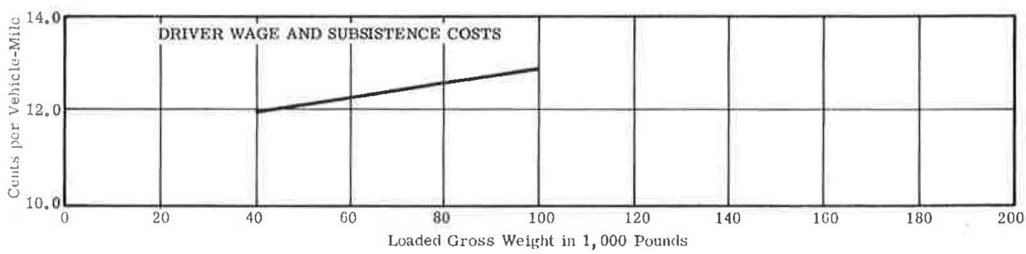

Figure 12. Gasoline engine powered combinations.

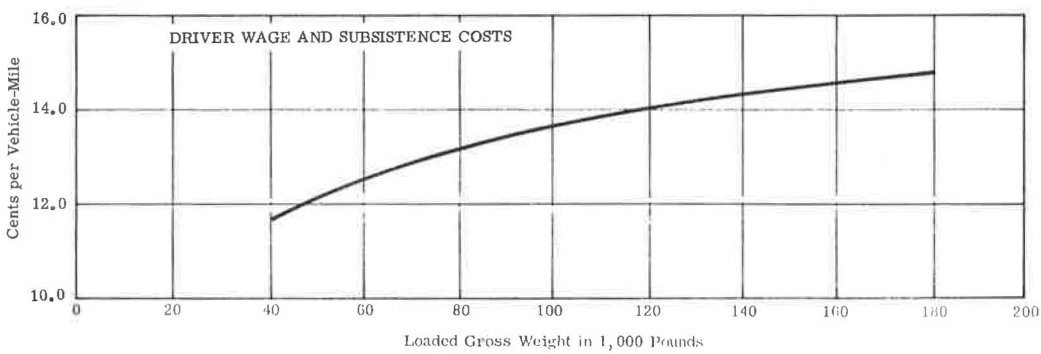

Figure 13. Diesel engine powered combinations.

Depreciation and Interest Costs

In the 1956 cost study (3), the depreciation costs calculated for the line-haul revenue trailer combinations constituted the major part of the expense. Each of the two general types of power vehicles, i.e., those with gasoline engines and those with diesel engines, were classified into three groups with different engine sizes. For gasoline engined tractors values developed for typical service lives to junk varied between 7.4 and 8.5

TABLE 2

LINE-HAUL, INDIRECT EXPENSES, COST PER TRAILER COMBINATION MILE[a]

Indirect Expense Account		1956 Total Amount ($)	1962 Total Amount ($)
Maintenance supervision	(4110)	5,257,228	9,639,848
Maintenance office and other expenses	(4120)	345,582	615,435
Other maintenance expenses	(4180)	6,252,057	9,968,123
Transportation supervision	(4210)	16,529,453	23,648,712
Transportation office and other expenses	(4220)	956,650	1,122,747
Insurance and safety supervision	(4510)	5,533,097	8,556,938
Insurance and safety office and other expenses	(4520)	1,899,737	2,241,596
Insurance and safety public liability and property damage	(4530)	17,468,047	18,593,080
Insurance and safety workmen's compensation	(4540)	9,212,062	13,131,496
Insurance and safety tire, theft and collision	(4560)	3,708,405	3,591,210
Insurance and safety other department expenses	(4570) (4580)	1,053,479	251,496
Salaries, general officers	(4611)	21,545,570	19,624,881
Salaries, other general office employees	(4613)	17,348,313	18,502,864
Salaries, expenses—general officers	(4621)	3,897,369	3,223,217
Salaries, general office employees	(4622)	711,290	715,331
Salaries, other general office expenses	(4623)	7,557,720	10,658,859
Employee's welfare expenses	(4145) (4245) (4545)	21,300,503	37,512,701
Social security taxes	(5240)	16,191,412	33,957,562
Real estate and property taxes	(5230)	3,804,967	6,298,191
Total		160,572,941	221,854,287

[a]Total owned vehicle-miles: 1956 = 1,712,129,225 mi; 1962 = 2,040,395,692 mi. 1962 expenses, $0.1087; 1956 expenses, $0.0938; constant upgrading unit applied to cost curves, $0.0149.

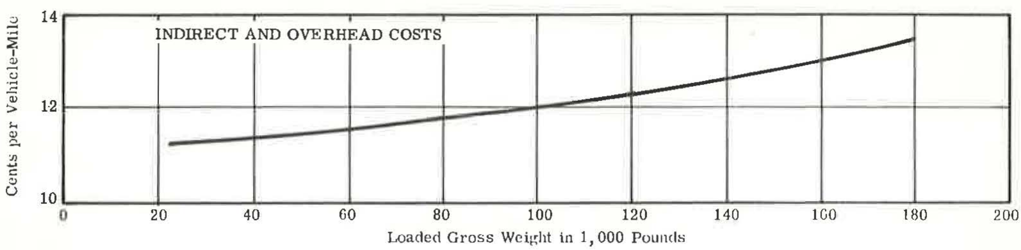

Figure 14. Gasoline and diesel engine powered trailer combinations.

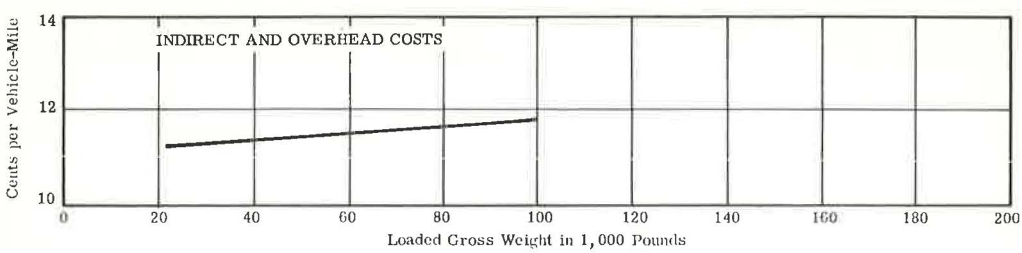

Figure 15. Gasoline engine powered trailer combinations.

yr, with the heavier gross combination weight tractors having the longer lives. Similar values developed for diesel engined tractors were between 7.9 and 10.6 yr.

These service lives are assumed unchanged for the 1964 study; however, because of increases in new purchase prices, the dollar amount of depreciation is somewhat greater. Other property subject to depreciation is assumed to have the same service life now as in 1956, but the current prices of new and improved shop and office facilities can be assumed to be higher than in 1956. Hence, depreciation costs may be higher now than in 1956.

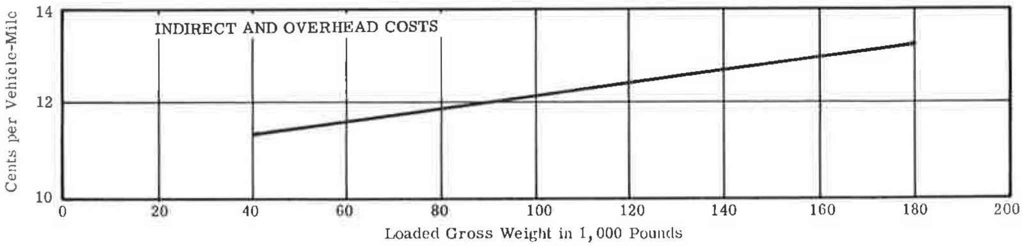

Figure 16. Diesel engine powered trailer combinations.

In the 1956 study (3), the charts showing Depreciation and Interest Costs included an interest cost for the undepreciated property which included interest paid on borrowed money and dividends paid to stockholders. It was assumed that funds to cover the undepreciated property of motor carriers came from these two sources, and therefore was paid for annually. The value of depreciated property was assumed as the amounts taken from the gross revenue and accumulated in depreciation accounts for the replacement of worn out and discarded property of any type, including motor vehicles and other real or personal property.

To upgrade the Depreciation and Interest Costs charts, the total amounts in the depreciation, interest and dividend accounts in Tables 5 and 8 of the ICC Transport Statistics for 1956 (3) and 1962 (4) were summarized (Table 3). The summary totals for each year are divided by appropriate power unit vehicle-miles from Table 14 of the ICC Transport Statistics to develop vehicle-mile costs for these three cost accounts.

The upgraded figures for Depreciation, Interest and Dividend Costs are shown in Figures 17, 18, and 19.

Summation of Costs

Figures 21, 22, and 23 of HRB Bulletin 301 include strata-type Summation of Costs charts in which the lowest curve represents the initial cost relationship, and each succeeding upper curve is an accumulation of the preceding groups of costs, leading to the topmost curve of the series which shows the Gross Operating Costs in relation to loaded gross weights of trailer combinations. Summation of Costs charts are made for the three major groupings of vehicles: (a) all trailer combinations (gasoline engine and diesel engined powered), (b) gasoline engine powered trailer combinations, and (c) diesel engine powered trailer combinations.

TABLE 3

DEPRECIATION AND INTEREST COSTS[a]

Item	1956 ($)	1962 ($)
Depreciation total	72,151,893	99,139,177
Interest total	9,324,471	15,892,166
Dividend total	6,315,219	11,201,447
Total	87,791,583	126,232,790
Average vehicle-mile costs	0.0545	0.0644

[a]Power unit vehicle-miles, owned vehicles: 1956 = 1,609,849,389 mi; 1962 = 1,958,930,439 mi.

$$\frac{\text{1962 unit cost}}{\text{1956 unit cost}} = \frac{0.0644}{0.0545} = 1.182 \text{ upgrading factor}$$

For the purpose of developing annual overall costs of highway freight transportation using the number of trailer combinations and loaded gross weights that may be predicted at any future time, the Summation of Costs curve for all trailer combinations (gasoline and diesel engine powered combined) provides the most accurate means of analysis, because the sample of data in the combined group is the largest. Further, a mixture of gasoline and diesel engine powered trailer combinations is more representative of the nature of the fleet actually in use in the United States. The distribution of trailer combinations by engine type has undergone noticeable change since 1956 because of the replacement of many gasoline engines by diesel engines in line-haul service. Detailed

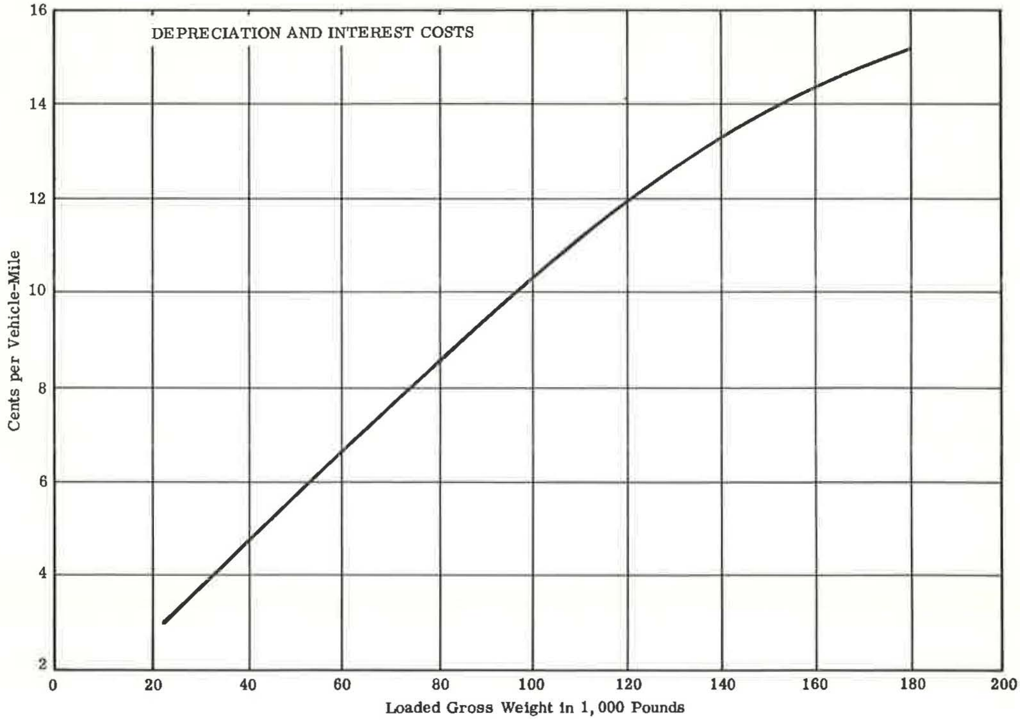

Figure 17. Gasoline and diesel engine powered trailer combinations.

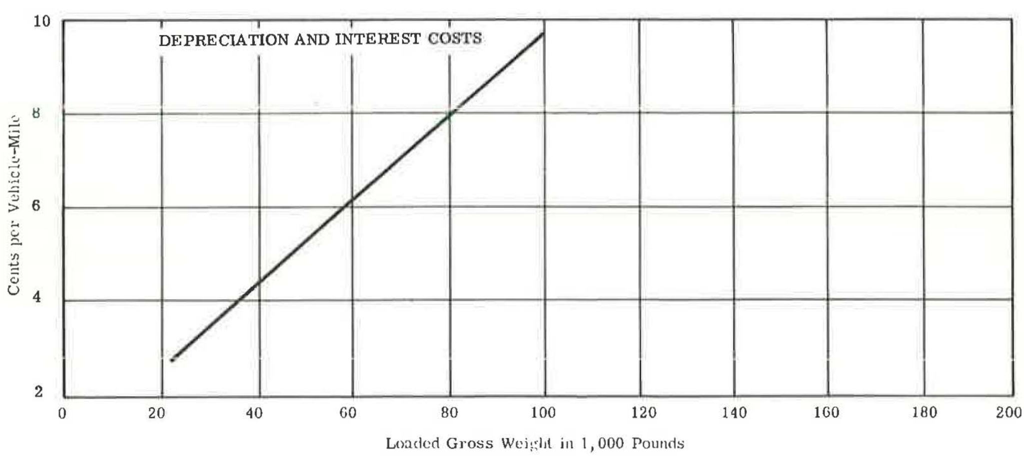

Figure 18. Gasoline engine powered trailer combinations.

statistics on intercity trailer combinations are not readily available to show the extent of this change. However, the differences in Summation of Costs between each engine type and the combined type costs are not substantial. Therefore, the numerical differences between gasoline and diesel engine combinations are not a critical factor. This supports the premise that the Summation of Costs for the combined fleet should be used in any prediction calculations.

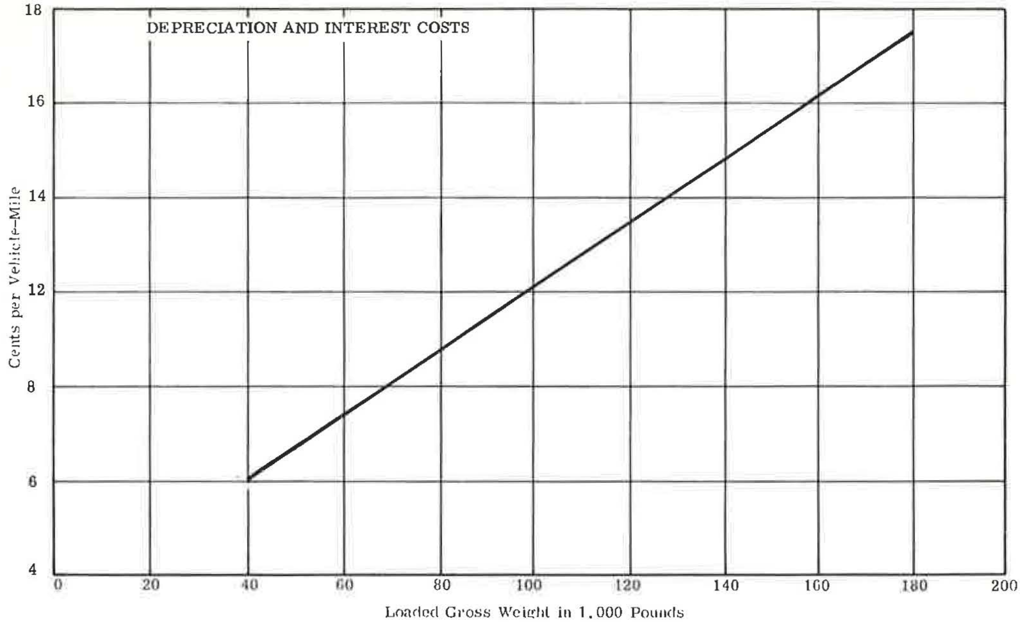

Figure 19. Diesel engine powered trailer combinations.

The Summation of Costs for 1964 are shown in Figures 20, 21, and 22. The cost elements included in each strata-curve are explained in pages 43 and 44 of the HRB Bulletin 301.

GROSS OPERATING COSTS AND TON-MILE COSTS FOR ALL TRAILER COMBINATIONS

Vehicle-Mile Costs

The upgraded gross operating costs per vehicle-mile for all trailer combinations (gasoline engine powered and diesel engine powered combined) shown in Figure 20 are replotted in Figure 23, which is similar to Figure 18 in HRB Bulletin 301. The new vehicle-mile costs were divided at each 20,000-lb loaded gross weight ordinate by the same payload weights (for given gross weights) shown in Figure 15 of HRB Bulletin 301.

The reported line-haul operating costs of trailer combinations are related to the loaded gross weights of the trailer combinations. The definition of loaded gross weight in HRB Bulletin 301 is as follows:

> The loaded gross weight is the predominant loaded operating weight of a vehicle or trailer combination. The loaded gross weight includes the empty (tare) weight of the vehicles, plus the payload (cargo) weight when the cargo body is fully loaded; that is, fully loaded in regard to the stowage capacity of the cargo body for light-density commodities, or to the maximum permitted gross vehicle weight when loaded with heavier commodities.

The payload weights are the typical or modal payloads as hauled by the individual carrier. This definition indicates that the loaded gross weights of each class of trailer combination may vary over a considerable range. The 2-S1 class of trailer combinations may have a wider range than the multi-axle trailer combinations that are usually

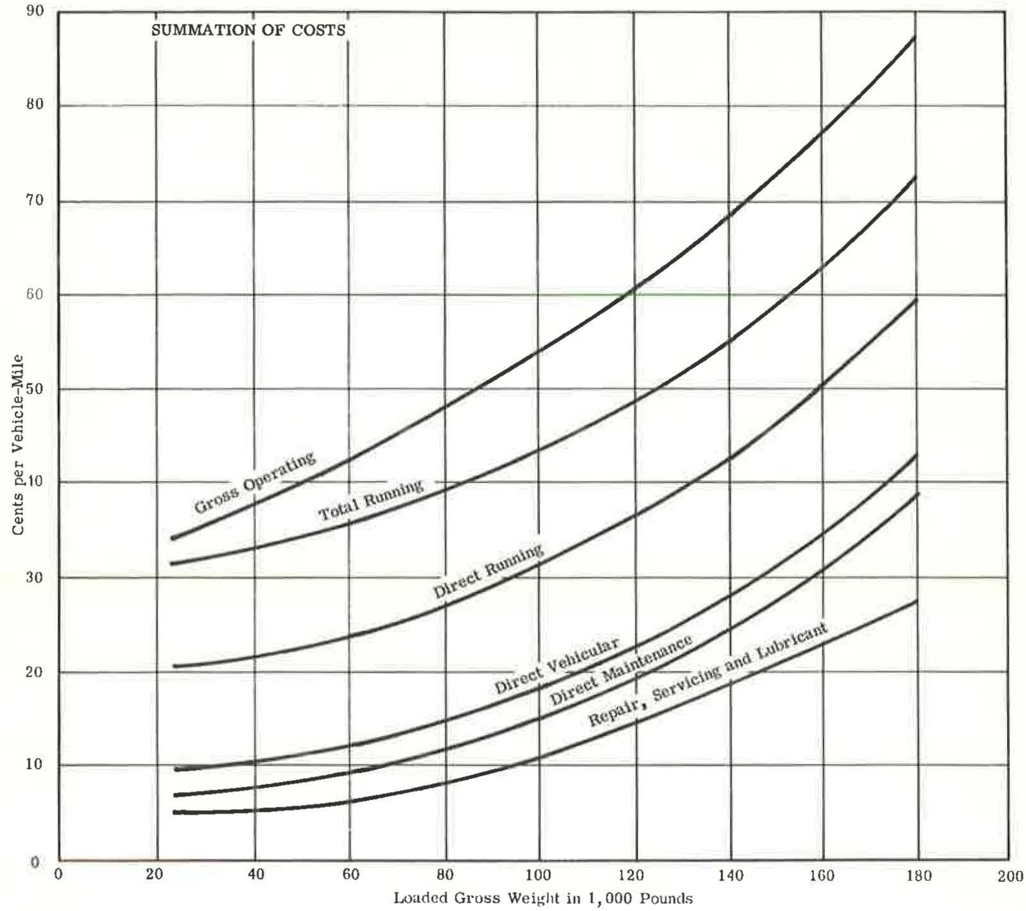

Figure 20. Various costs per vehicle-mile for gasoline and diesel engine powered trailer combinations, by loaded gross weight.

used for the heavier commodities. The original cost data were analyzed on the basis of the predominant loaded gross weights in each carrier's records.

The carriers' records were always investigated on the basis of round trips, which may include empty return travel, because it is customary in the trucking industry to domicile power vehicles at specific terminals to control maintenance, overhauls, and costs. It is always necessary to return the vehicle to its domicile terminal to have it available for the next outbound trip. Thus a consistent measure of work rate was the actual loaded gross weights regularly obtained in a fleet.

The main possible source of any differences in costs between loaded and empty operations is in fuel and tires. Other costs are affected to little or no measurable extent by the degree of cargo loading. However, as carriers' cost records are for round trip operation, the differences in travel measurable from carriers' records are (a) loaded in both directions (i. e., 2 loaded trips in a round trip), (b) loaded in one direction and empty on return trip (i. e., 2 trips, one loaded and one empty in a round trip), and (c) loaded in one direction with intermediate degrees of loading on the return trip (i. e., 2 trips in a round trip). The results of segregating fuel costs into five levels of trips between loaded in both directions and loaded in one direction with various degrees of loading or no load on the return are shown in Figures 40 and 41 in HRB Bulletin 301. There were insignificant differences in fuel costs for the different levels of trip loadings.

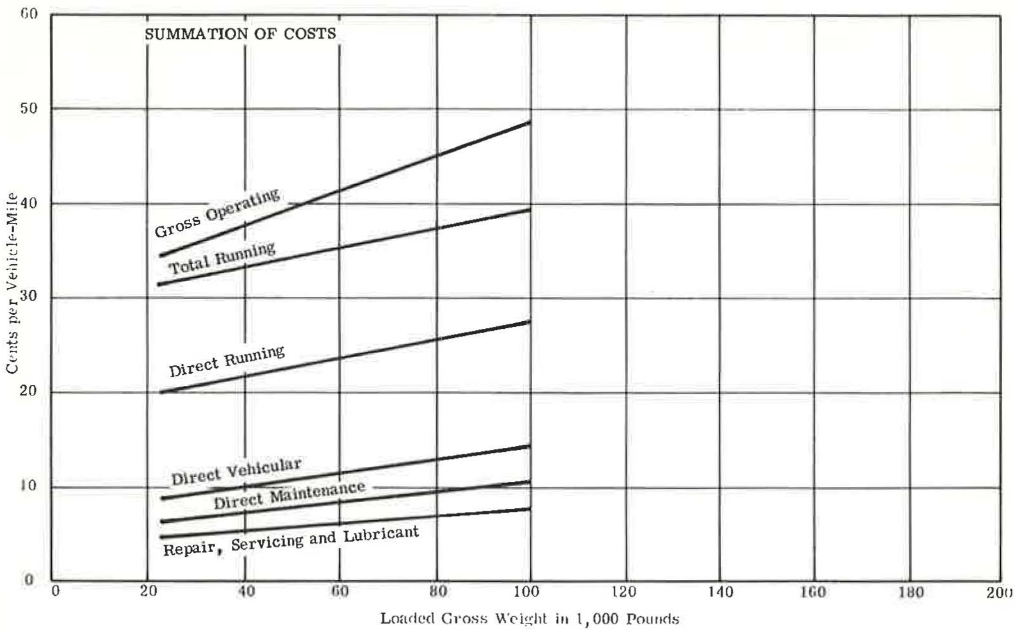

Figure 21. Various costs per vehicle-mile for gasoline engine powered trailer combinations, by loaded gross weight.

The most accurate data for operating costs are shown in Figure 18 of HRB Bulletin 301 and Figure 23 of this report, which include all trailer combinations for which data were obtained. The data for all trailer combinations include both gasoline engine and diesel engine power vehicles.

Other figures in HRB Bulletin 301 show, to a degree, cost differences between different classes of trailer combinations for certain cursory comparisons between classes of trailer combinations. However, these samples of trailer combinations and cost data are smaller and the curves are less reliable for estimating total overall freight transportation costs than the summation of costs for all trailer combinations.

Since the line-haul operating costs are related to loaded gross weights, there is a problem in developing operating costs for trailer combinations traveling empty, or with little payload. The seriousness of this problem can be appreciated from the annual U.S. Bureau of Public Roads-state truck-weight studies (6), which indicate that approximately 33 percent of all trailer combinations on the main rural roads are without payload.

For empty trailer combinations it is recommended that assumed loaded gross weights be assigned by axle classification of trailer combinations. Suggested loaded gross weights to be assigned for cost purposes to different axle classifications of trailer combinations are given in Table 4.

These loaded gross weights were selected arbitrarily to take into account the differences in axle and gross weights permitted on rural primary roads in various states, and on the toll roads permitting 95- to 105-ft long double trailer combinations.

Ton-Mile Costs

The lowest ton-mile curve in Figure 23 is the ton-mile cost when payload is carried in both directions. The upper curve, the cost values of which are twice that of the lower curve, shows the ton-mile costs when the payload is carried in one direction only and the cargo space is empty on the return trip. The vehicle-mile costs for different degrees of loadings lie between these two extremes.

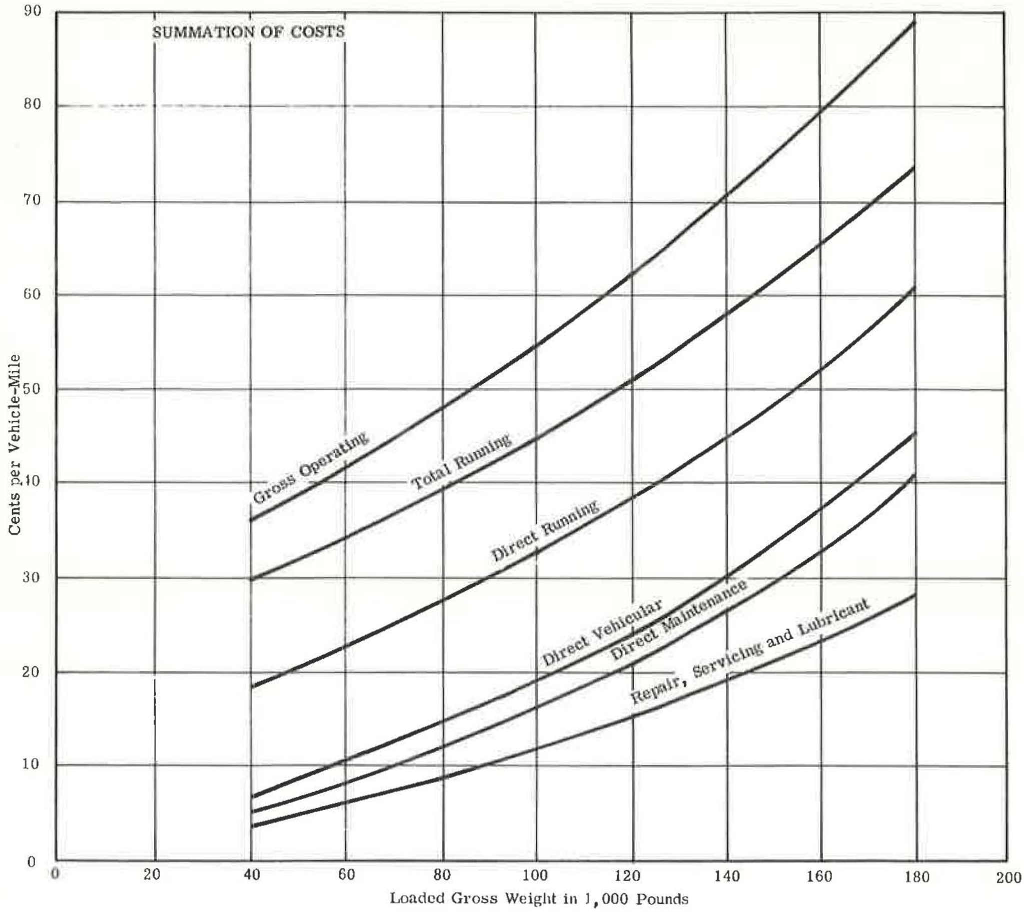

Figure 22. Various costs per vehicle-mile for diesel engine powered trailer combinations, by loaded gross weight.

The average ton-mile costs for the different loaded gross weight trailer combinations may be estimated using percentage values from the annual U. S. Bureau of Public Roads-state truck-weight data. For a number of years, truck-weight studies have indicated that approximately 67 percent of vehicles weighed were with cargo, and 33 percent were empty. Although there may be some error in assuming that all vehicles "with cargo" were fully loaded, this assumption is nevertheless supported, for practical purposes, by the discussion regarding directional characteristics of freight haulage as indicated in Tables 35 and 36 and adjoining text in HRB Bulletin 301.

Therefore, it is assumed that the averages of the loadings of all trailer combinations, as counted in the traffic stream, are 67 percent of the fully loaded payload for each level of loaded gross weight. Thus, taking this 67 percent of the maximum payload per loaded gross weight (Fig. 15, HRB Bulletin 301), and dividing this reduced payload into the gross vehicle-mile cost at each 20,000-lb ordinate gives a new curve of practical average ton-mile costs for trailer combinations of various loaded gross weights of vehicles in the traffic stream. These data are plotted as the ton-mile curve between the upper and lower ton-mile curves, and are labeled "payload ton-mile—average loading." This average cost includes all empty miles, and permits a calculation of total transportation costs from the number and mileage data for trailer combinations of various levels of loaded gross weights, length of haul, directional char-

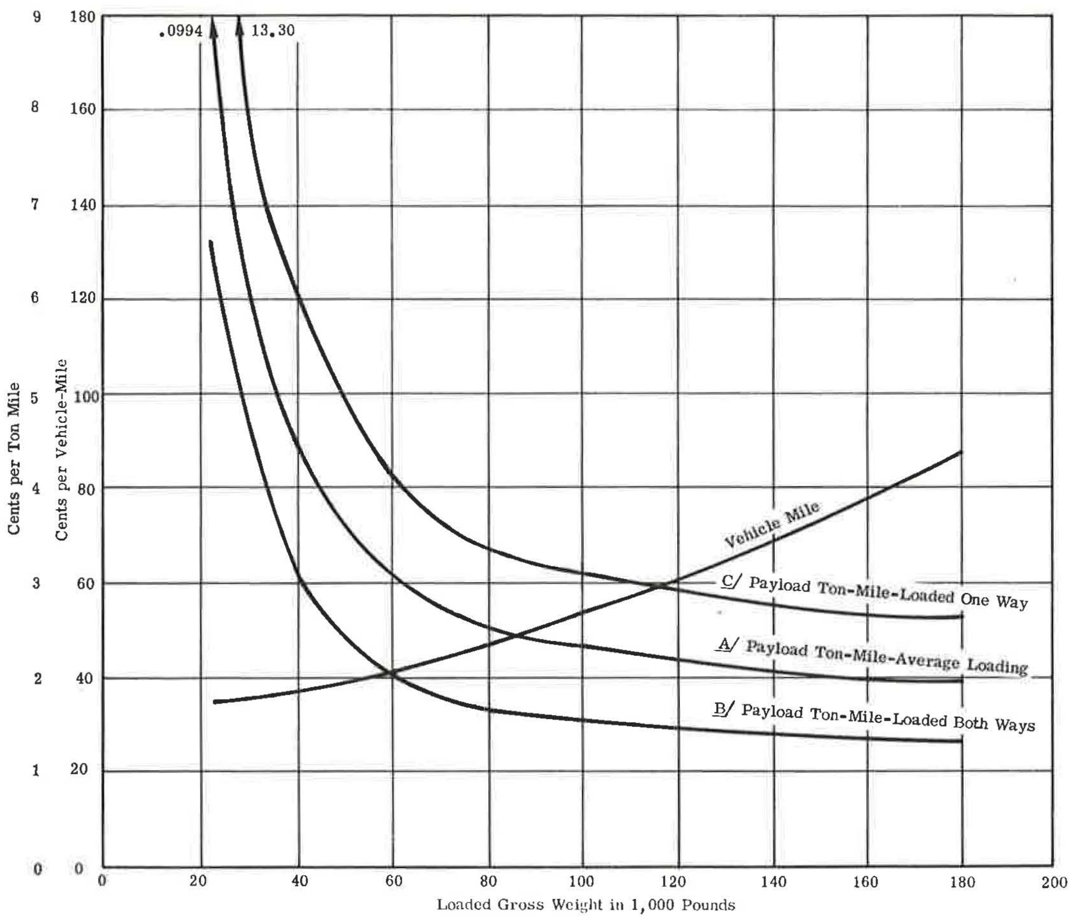

Figure 23. Gross operating costs for all trailer combinations, showing vehicle-mile costs and payload ton-mile costs in relation to loaded gross weights. Payload ton-mile costs are shown: A/ for average operations which include the ratio of payloads (empty) as found in present traffic rural roads, B/ for operations with payloads in both directions, and C/ for operations with payload in one direction and no-load (empty) on return.

acteristics of haulage, and the tonnages of freight and lengths of haul that may be predicted for the future.

TABLE 4

SUGGESTED LOADED GROSS WEIGHTS FOR ASSIGNING COSTS TO EMPTY TRAILER COMBINATIONS

Trailer Comb. Axle Class.	Sugg. Loaded Gross Wt (lb)
2-S1	44,000
2-S2	58,000
2-2	62,000
3-2	72,000
3-S2	72,000
2-S1-2	72,000
3-S2-3[a]	120,000
3-S2-4[a]	130,000

[a]For toll road service.

TRANSPORTATION SAVINGS RESULTING FROM HEAVIER GROSS WEIGHTS

In addition to savings in vehicle transport costs resulting from higher gross weights, heavier permitted gross weights and larger permitted cubical dimensions would also reduce the number of freight vehicles in the traffic stream. With the predicted increase in motor vehicles, especially passenger cars, the factor of highway space for vehicles will become increasingly important. There appears little likelihood of a reduction in the number of passenger cars, as they are a matter of individual and personal selection, comfort, and convenience. On the other hand, the number of highway freight trailer combinations, which primarily serve the needs of the general public and business, could be reduced by means of larger vehicles and greater cargo weights, both of which would increase the efficiency of highway freight transportation.

For example, for light-density commodities of under 25 pcf, the reduction in the number of trailer combinations for line-haul service would be almost directly proportional to the increase in cargo space.

For heavier density commodities, the reduction in the number of trailer combinations would be directly proportional to the increase in permitted cargo payload weights above the present permitted payload and gross weights.

The savings in transport costs to be gained by increasing permitted gross weights can be estimated by assuming a reasonable number of ton-miles as a possible day's work for a trailer combination. A typical large trailer combination is capable of handling approximately 10, 000 ton-mi a day in line-haul service. Therefore, a reasonable day's work for a line-haul trailer combination is assumed to be 10, 000 ton-mi. This amount of service may be calculated by assuming that a trailer combination having a gross weight of 60, 000 lb can haul 20. 5 tons of freight 488 mi in 24 hr. A ton-mile cost of $0. 0205 was selected from Figure 23 for a 60, 000-lb loaded gross weight trailer combination. This combination, loaded in both directions, with a payload of 20. 5 tons, was used for multiplying the ton-mile cost of $0. 0205 by 10, 000, the estimated daily ton-miles, which produced a cost of $205. 00. This figure becomes a basic cost against which other daily costs are compared.

Using the same procedure for an 80, 000-lb loaded gross weight vehicle hauling a 28. 0-ton payload, 358 mi, a daily cost for 10, 000 ton-mi is $168. 00. The difference in these costs represents the daily saving possible per trailer combination with increased permitted gross weight.

Table 5 gives similar calculations for loaded gross weight trailer combinations of up to 160, 000 lb. There is initially a significant reduction in vehicular operating costs, but as the permitted gross weights increase, the savings become less significant. At the 160, 000-lb level, the daily savings appear to reach the end point in diminishing returns and provide too little savings to offset increasing costs of highways of higher load-carrying capacity.

Future Highway Transport Potential

Personal observations this summer on the New York Thruway showed that 500 veh-mi were regularly attained on this divided expressway within a 10-hr driving shift, with double trailer combinations 98 ft in length and with gross weight up to 128, 000 lb.

TABLE 5

LOADED GROSS WEIGHTS OF TRAILER COMBINATIONS, AVERAGE PAYLOADS CARRIED, AND COST REDUCTIONS RESULTING FROM HEAVIER VEHICLE GROSS WEIGHTS

Loaded Gross Wt (lb)	Avg. Payload (tons)	Cost/10, 000 Ton-Mi ($)	Savings from Heavier Gross Wt ($/10, 000 ton-mi)
60, 000	20. 5	205	
80, 000	28. 0	168	37. 00
100, 000	34. 0	156	12. 00
120, 000	40. 0	150	6. 00
140, 000	49. 0	139	11. 00
160, 000	58. 0	133	6. 00

TABLE 6

NUMBER OF TRAILER COMBINATIONS OF VARIOUS LEVELS OF LOADED GROSS WEIGHTS REQUIRED TO MOVE 1,000,000 TON-MILES OF FREIGHT 488 MILES A DAY

Permitted Gross Wt (lb)	Avg. Payload (tons)	Avg. Daily Ton-Mi/ Trailer Comb. (ton-mi)	No. of Trailer Comb. Required	No. of Cargo Bodies in Trailer Comb.
60,000	20.5	10,000	100	1 40-ft
80,000	28.0	13,664	74	1 40-ft
100,000	34.0	16,592	61	1 40-ft
120,000	40.0	19,520	52	2 40-ft
140,000	49.0	23,912	42	2 40-ft
160,000	58.0	28,304	36	2 40-ft

One example was a turnaround from Syracuse, N.Y., to Suffern, N.Y., a distance of 508 mi, and with a 40-ton payload gave 20,300 payload ton-miles of freight transport. This run was accomplished in an 11.25-hr on-duty period, which included exchange of both trailers at Suffern, and necessary driver's business and personal stops en route.

Another way of estimating the advantages of various higher levels of loaded gross weights is to calculate the number of trailer combinations of higher loaded gross weights that would be required to haul 1,000,000 ton-mi of freight daily. Starting with a basic trailer combination of 60,000-lb loaded gross weight, which is assumed to be capable of hauling 10,000 ton-mi a day over an average length of haul of 488 mi, and would require 100 trailer combinations, the numbers of trailer combinations of higher levels of loaded gross weights are given in Table 6. These estimates apply only to the heavier commodities capable of heavier loads in the permitted sizes of cargo bodies.

Other measures of the operating advantages of heavier permitted loaded gross weights can be devised, but Tables 5 and 6 give two measures of the advantages which may tend to offset the higher construction costs of highways with greater load-carrying capacities.

REFERENCES

1. Line-Haul Trucking Costs in Relation to Vehicle Gross Weights. Highway Research Board Bulletin 301, 1964.
2. Interstate Commerce Commission. Uniform System of Accounts for Class I Common and Contract Motor Carriers of Property Issue of 1952.
3. Interstate Commerce Commission. Transport Statistics in the United States, Pt. 7, Motor Carriers as of December 31, 1956.
4. Interstate Commerce Commission. Transport Statistics in the United States, Pt. 7, Motor Carriers as of December 31, 1962.
5. 1964 National Over-the-Road Drivers Wage Contract. Jan. 1964.
6. U.S. Bureau of Public Roads. Table HT-1, Travel and Weight Characteristics of Trucks and Combinations. Highway Statistics, 1960 to 1962.

A Portable Electronic Scale for Weighing Vehicles in Motion

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The portable electronic scale consists of a pair of wheel load transducers and associated electronic recording instruments. The transducers, each of which is 50 by 20 in. in plan dimensions and only slightly over 1 in. thick, are simple in design, rugged, and portable. Inertial effects in the transducer are negligible, and the electrical output signals depend only on the magnitude of the load applied normal to the surface. Since only $1\frac{1}{2}$ in. of pavement must be removed, the transducers can be installed in any smooth roadway surface including rigid pavements and bridge decks. Initial installation requires approximately 3 hr, but subsequent installation at a previously occupied site requires only about 30 min.

Basic electronic equipment has been used in the experimental stage of the scale development. Signals are displayed on an oscilloscope, and Polaroid photographs made for permanent records. An instrument system will record in digital form on magnetic tape information regarding date, time of day, vehicle speed, number of axles per vehicle, axle spacing, and wheel weight. This system will be operative early in 1966.

Analysis of data on nearly 300 different vehicles, each of which was weighed both statically by a conventional loadometer and while moving at normal road speed by the portable electronic scale, indicates that static vehicle weight can be estimated from the weights obtained by the portable electronic scale with sufficient precision for planning and design purposes.

•ELECTRONIC scales for weighing moving vehicles are not new, but until now a portable scale capable of weighing highway vehicles moving at normal road speeds has not been available. Early attempts to weigh moving highway vehicles were reported by O. K. Normann and R. C. Hopkins (1, 2) in 1952. For their work, a massive reinforced-concrete slab about 3 by 10 ft in plan dimensions and 12 in. thick was supported flush with the adjacent road surface by four conventional load cells set in a pit beneath the road, and electrical signals from the load cells were recorded on appropriate instruments. This configuration, with minor modifications, has been used experimentally and commercially both in this country (3 through 11) and in Europe (12).

Although several expensive scales of this type have been installed during the past fifteen years, at least three inherent inadequacies in the design have hampered successful operation. The scale location is fixed; therefore, its usefulness is limited to one site. Construction of a pit beneath the pavement is necessary, and even with good drainage, moisture in the pit damages the equipment. And finally, the inertia of the heavy slab and its horizontal translation have adverse effects on the response of the system to dynamic loads.

A critical analysis of the vehicle weighing problem, performed in the light of experience, makes obvious the need for eliminating these and other inadequacies in the

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scale system if usable results are to be obtained. Certain basic criteria for the kind and quality of information required must be established before a suitable system can be developed. The fundamental question of whether static vehicle weight or dynamic wheel force information is desired must first be answered; then performance criteria for a weighing system can be defined.

Static vehicle weight is generally used for law enforcement and for planning purposes and dynamic wheel force data for structural design of pavements and bridges. A relationship exists between static weight and the forces exerted on the pavement by a moving wheel for any given vehicle operating under a specific set of conditions, but as yet the relationship is not clearly defined. Neither is the relationship precisely known for the general case of mixed traffic operating on different types of roadways. It may be reasoned, however, that the static wheel load and the dynamic wheel load are nearly equal for a vehicle operating at moderate speed on a perfectly smooth, level surface. From this, it follows that, in a practical sense, wheel loads of a vehicle moving over a smooth pavement can be sensed by a suitable dynamic scale and summed to give a good estimate of the static vehicle weight.

Factors such as pavement roughness, tire roundness, vehicle suspension-system characteristics, aerodynamic lift, weight sensing time or distance, and response characteristics of the weighing device all affect the accuracy with which this estimate can be made, but static vehicle weight can probably be estimated from dynamic wheel forces with sufficient precision for planning and design purposes by sampling vehicle wheel loads with a suitably responsive dynamic scale of finite length, set flush in a smooth pavement. The precision of the estimate can undoubtedly be improved either by measuring wheel loads continuously as the wheel moves over some relatively long finite distance, or by sampling it several times. In any case, a scale with good dynamic response is required.

Other criteria for a practical weighing system include portability, insensitivity to tractive forces or position of load, ruggedness, flexibility, and reasonable cost. The system should be such that a two-man crew can transport, install, and operate the scale for extended periods of time, using a station wagon or light truck as a working vehicle. Only the component of wheel force, acting normal to the pavement surface, should affect the scale output signal. Neither tractive forces nor position of the wheel load on the sensing device should affect the signal. Ruggedness and reliability are of prime importance since the scale is expected to operate for long periods of time under severe traffic and climatic conditions. The weight transducers should deflect in a manner similar to the pavement structure into which they are set so as not to cause a bump or depression in the roadway surface under load. A minimum amount of pavement should be removed for installing the scale. This is particularly important when transducers are installed in bridge decks and in rigid pavements. The total cost of owning and operating the system must compare favorably with the cost of procuring vehicle weight information by present techniques if the system is to be considered as a replacement for such techniques. Fortunately, this is not necessarily true of a system intended for research purposes. Although minimum cost is certainly desirable, progress depends to a large extent on research and on the successful application of the results of research; therefore, sizable investments are reasonably justified when the technology of planning, design, and operation of our vast highway system is advanced. Through advanced technology we can expect to effect long-range economies.

The only known portable scale used routinely for weighing moving highway vehicles is the one operating in Sweden, as described by Stig Edholm (13). This unit, although apparently successful, fails to satisfy all the criteria previously suggested in that the load detector is over 4 in. thick and the speed of the vehicles to be weighed is restricted to 12.5 mph. Also, data from the scale are recorded on paper tape in analog form; interpretation is tedious and expensive.

The criteria outlined are formidable, and past experience seems somewhat discouraging, but a portable scale system capable of sensing the dynamic forces exerted normal to the pavement surface by the wheels of highway vehicles moving at normal road speed has been developed through the cooperative research program of the Center for Highway Research at the University of Texas, the Texas Highway Department, and the U. S. Bureau of Public Roads. The basic configuration of the load transducer was first described in a thesis at Mississippi State College in 1956 (14). Transducers have recently been tested under actual operating conditions at three different field sites and have successfully weighed vehicles moving at speeds up to 70 mph.

WHEEL LOAD TRANSDUCER

The load-sensing element of the system is a special transducer which detects the component of wheel force acting normal to the pavement surface and converts this force into a corresponding electrical signal. Two transducers are required for each lane of traffic (Fig. 1). They are placed side by side and are proportioned so that the wheels of a vehicle traveling in the normal traffic lane will pass individually over a transducer. Each unit is 50 by 20 in. in plan dimensions and slightly over 1 in. thick.

A sheet metal diaphragm, welded to a rectangular steel frame, forms the top of the transducer (Fig. 2). The diaphragm transmits any tractive forces produced by the wheels of an accelerating or braking vehicle directly to the frame, and thus cancels their effect on the sensor. Vertical deflection of the diaphragm permits any forces applied normal to the surface to act, for all practical purposes, entirely on the structural steel plates immediately underneath. The three steel plates distribute this component of the wheel forces among a set of load cells arranged to support the corners or edges of each plate. The load cells supporting the corners of the outer plates are set in recesses to reduce the overall height of the unit. The middle plate rests directly on four load cells and supports one edge of each outer plate by means of a ledge-type joint. In this arrangement, the plates are hinged at the support, and no uplift occurs beyond the support when a single plate is loaded.

Load cells of unique design convert load to a usable electrical signal. The configuration of the cell is shown in Figure 3, and dimensions are shown in Figure 4. Each cell is machined from tool steel, heat treated, and stress relieved. A spiral etched-foil strain gage cemented to the plane surface of the circular restrained-edge diaphragm detects the tangential strain caused in this surface by a load acting against the boss on

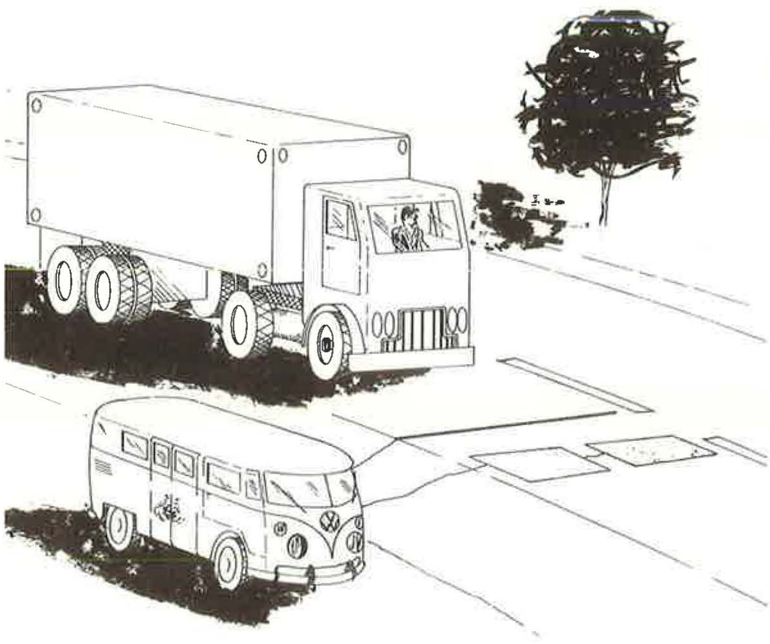


Figure 1. Typical installation of portable scale.

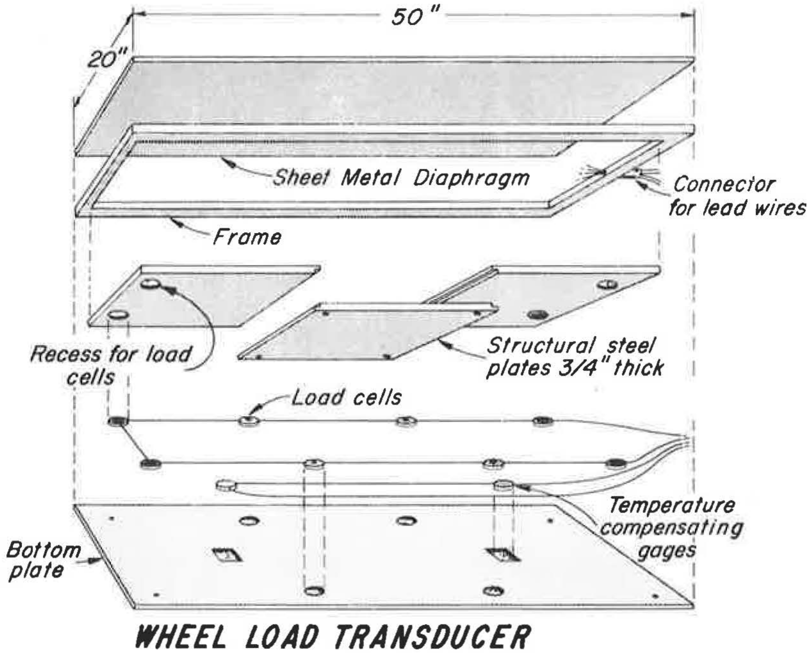


Figure 2. Exploded view of wheel load transducer showing arrangement of plates and load cells.

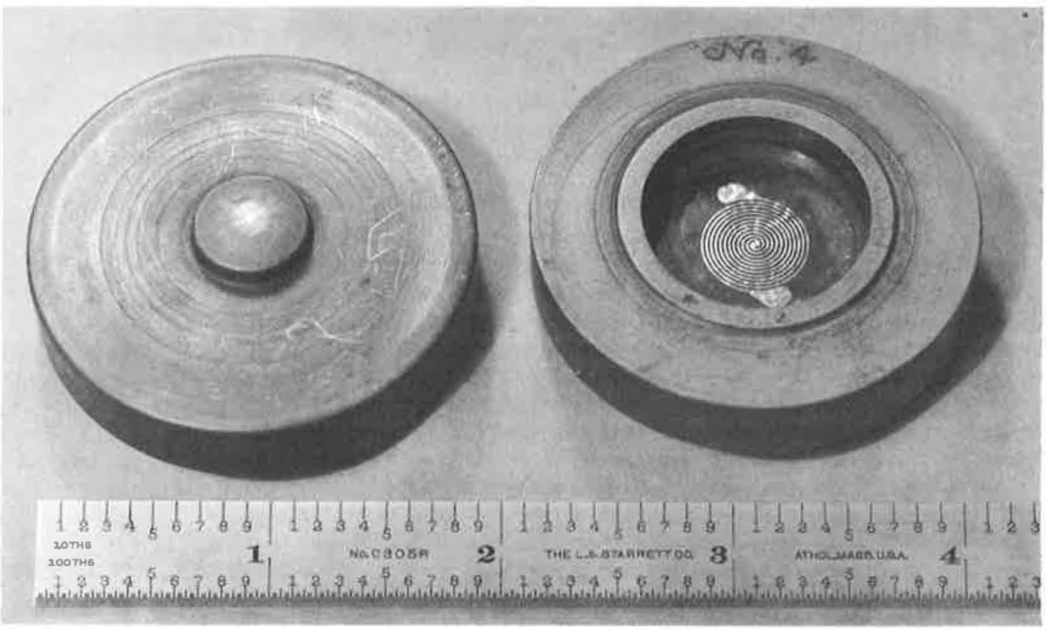


Figure 3. Load cells with spiral strain gage in place.

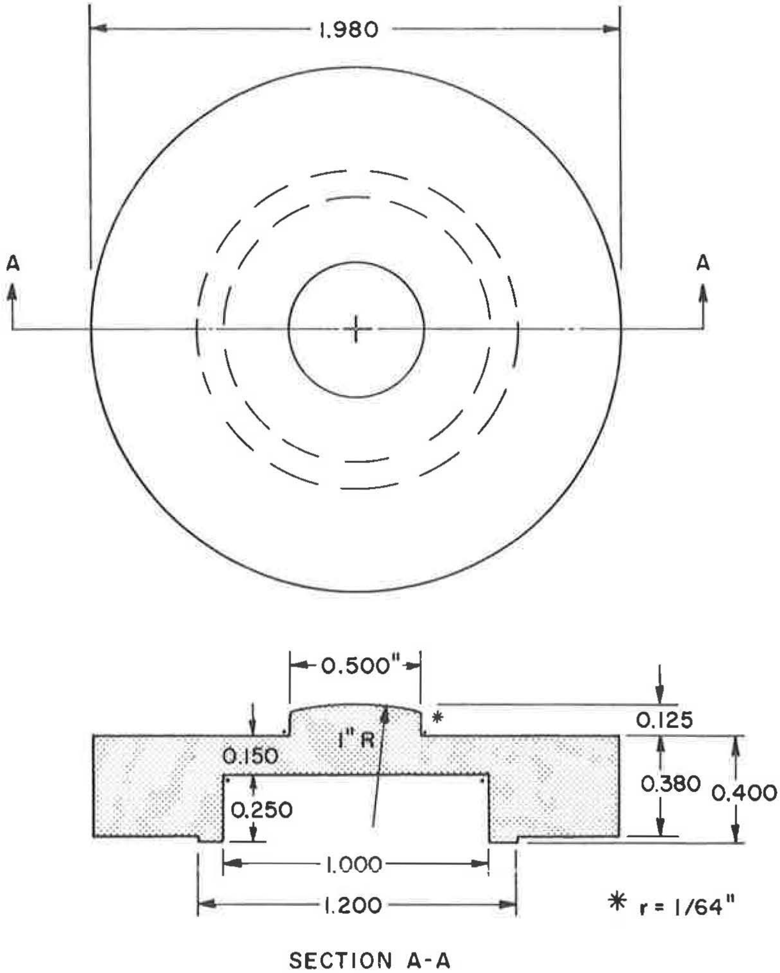


Figure 4. Top view and section showing dimensions of load cells.

the opposite side of the diaphragm. Strain thus detected is evidenced by a change in the electrical resistance of the gage, and is related linearly to the applied load.

All load cells used in the transducer are connected in series (Fig. 2). Since eight cells having identical change in electrical resistance with load are selected by individual calibration, and since the change is linear with load, the total change in resistance in the series-connected set of cells is the same for a given load whether the load is carried by one cell or distributed among several. This arrangement of load cells and plates makes the electrical output signal independent of either load contact area or placement of the load on the transducer.

The spiral strain gages used on the load cells are of the so-called temperature-compensating type, but compensation is not complete over the full range of temperatures to which the transducer will be subjected. Eight gages, identical to those on the load cells, are therefore bonded to steel discs which are exposed to the same temperature environment as the load cells, but which are not loaded in any way. These gages sense temperature-induced strains of precisely the same magnitude as those set up in the load cells. They are connected in an electrical network so as to cancel exactly the effects of temperature on the output signal from the transducer.

The bottom steel plate is $\frac{1}{4}$ in. thick and serves to transfer load from the load cells to the pavement into which the transducer is installed. It is bolted around its periphery to the rectangular steel frame, with a thin neoprene gasket to effect a waterproof seal. Recesses which accommodate the middle four load cells are provided in the plate and result in small protrusions from the bottom surface, but these are only about $\frac{1}{2}$ in. high and 3 in. in diameter. Hardened steel inserts are placed to provide a bearing surface for the spherical boss on each load cell.

Strain gage circuits are notoriously sensitive to moisture. Each strain gage in the transducer is waterproofed by being coated with Di-Jell wax and a layer of room-temperature vulcanizing rubber. All lead wire junctions are similarly treated, and external access to these lead wire terminals is provided through gold-plated contacts of a miniature connector which is sealed inside a standard $\frac{1}{4}$-in. pipe nipple threaded into the rectangular steel frame. Even the small amount of moisture contained in the air which is trapped inside the transducer can adversely affect the performance of the strain gages if it condenses. Air is therefore purged from the sealed transducer by introducing dry nitrogen through small ports in the frame. These ports are subsequently sealed with special plugs. It is entirely feasible to maintain a small positive pressure in the void space of the transducer and thereby prevent moisture from entering. Lead wires between the transducer and a roadside terminal point are cased in $\frac{5}{16}$-in. copper tubing. Nitrogen under pressure can be introduced conveniently into this conduit if moisture in the transducer becomes a problem.

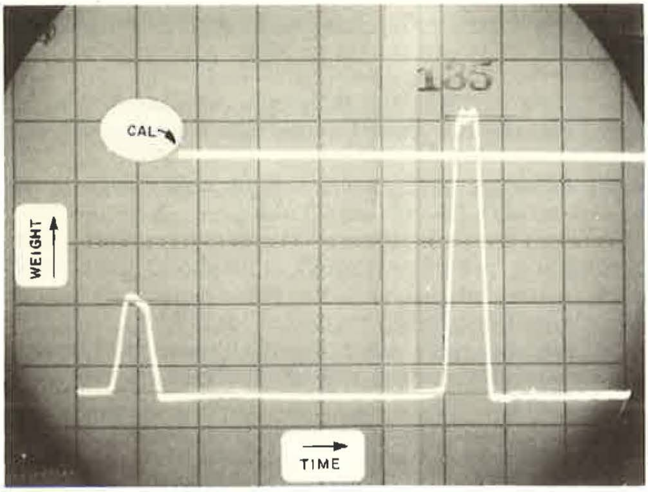
This description indicates that the design of the transducer incorporates many desirable features such as portability, insensitivity to load contact area or load position, ruggedness, and good dynamic response characteristics. It is difficult at this time to estimate the cost of manufacturing the transducers in quantity, but since no elaborate production techniques are involved, costs should be quite reasonable.

INSTRUMENTATION

Load applied to the surface of the transducer causes a small, but proportional, change in the electrical resistance of the strain gages on the load cells. Under dynamic loading conditions, the magnitude of this change can be measured most conveniently by determining precisely the amount of unbalance in a Wheatstone bridge circuit. For the experimental work, use was made of a half-bridge arrangement in which one arm of the bridge consisted of eight load cells connected in series, with the adjacent arm consisting of eight temperature-compensating gages connected in series. Precision resistors for completing and balancing the bridge were provided outside the transducer. A full bridge can be formed inside the transducer by connecting four load cells and four temperature-compensating gages alternately in a closed network. This arrangement has certain advantages and will be used in subsequent research.

Conventional SR-4 strain gage indicators were used to determine the calibration factor for each load cell under static load and to study the behavior of the transducer under static load. Certain advantages in instrument simplicity and in precision are inherent in a balanced bridge system, but it is not feasible to balance the bridge for measuring rapidly changing loads.

To display the electrical signals of a few milliseconds duration, which were produced by a wheel passing over the transducer, an oscilloscope with a high-gain dc amplifier was used. The light beam of the oscilloscope was made to sweep horizontally at a precisely controlled speed to form a time reference, and the beam was deflected vertically by the voltage across the unbalanced bridge circuit of the transducer. The horizontal sweep of the beam was initiated when the front wheels of a vehicle actuated a pneumatic tube detector placed at a given distance in advance of the transducer. Figure 5 shows the face of the oscilloscope, with a typical trace produced by the wheels of a 2-axle vehicle moving at a speed of approximately 35 mph. The front axle of this vehicle weighed 2,500 lb and a rear axle weighed 7,700 lb. A calibration trace representing 6,600 lb was superimposed on the photograph for reference purposes. The horizontal sweep speed of 50 msec/cm was selected so that the electrical signals produced by all the wheels of the vehicle would be displayed in parade fashion as shown. From this



Horizontal sweep speed, 50 ms/cm

Vertical sensitivity, 0.1-1.0 mv/cm

Calibration trace	=	6,600 lb
Front wheel wt	=	2,500 lb
Rear wheel wt	=	7,700 lb
Axle spacing	=	14.1 ft
Vehicle speed	=	35 mph

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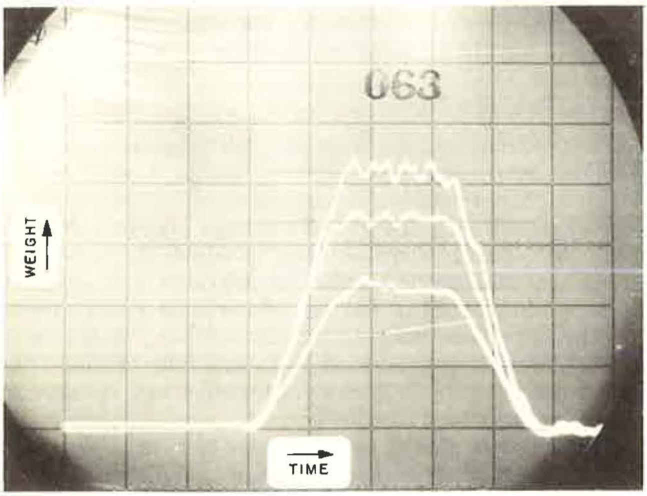
Figure 5. Typical trace on oscilloscope for 2-axle vehicle.



Horizontal sweep speed, 10 ms/cm

Vertical sensitivity, 0.50-1.0 mv/cm

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Figure 6. Oscilloscope trace showing superimposed pattern for 3-axle vehicle.

display, vehicle speed, axle spacing, and wheel loads can be determined. Speed is determined by dividing the known distance between the pneumatic detector and the wheel load transducer by the time required for the front wheel of the vehicle to travel this distance. The time can be measured directly from the oscilloscope trace. Axle spacing is calculated by multiplying speed by the time between successive wheel actuations on the transducer. Wheel load is, of course, represented by the height of the trace on the oscilloscope display.

By increasing the horizontal sweep speed, wheel load traces can be superimposed in the manner shown for a 3-axle vehicle in Figure 6. This form of display yields more information about the high frequency variation in load, but axle spacing cannot be determined. Inertial effects of the transducer are negligible, and there is a rapid, but small, variation in the magnitude of the wheel load during the time it is on the transducer. The speed of the vehicle was constant.

The oscilloscope provided a convenient means for displaying the transducer signals, and Polaroid photographs of the traces produced a permanent record of the data. For some of the development work, an oscilloscope with a memory feature which permitted retention of the display for several minutes was used. The pattern could be evaluated visually and then recorded on film if desirable.

Some 500 photographs of oscilloscope traces were studied to determine the frequency response characteristics required in a recording instrument for the scale. Specifications have been written for a special digital recording system, and the instrument is now under contract. Digital information concerning date, time of day, number of axles per vehicle, vehicle speed, axle spacing, and wheel load will be recorded on magnetic tape in a form ready for computer processing. One pair of portable wheel load transducers and three vehicle detectors provide all necessary electrical signals for the recorder.

EXPERIMENTAL EVALUATION

A single wheel load transducer was used in a series of laboratory and field experiments designed to evaluate its response to static and dynamic loads. In the laboratory, the transducer was supported on the lower platen of a hydraulic testing machine in a box of sand, and load was applied at different positions on the surface through wooden blocks with approximately the same contact area as typical vehicle tires. The output signal was affected by neither the contact area nor the position of the load. A relationship between applied load and electrical response under static loading conditions was developed from these tests.

The transducer was then installed successively at three different field sites. Each installation involved removing about 1½-in. flexible pavement, setting the transducer in a thin layer of fresh cement-sand grout, and pressing it flush with the pavement surface. Conventional hand tools were used for removing the pavement material, and the installation took between 2 and 3 hr at each site. Power equipment would, of course, facilitate this work and reduce the time required for initial installation.

The site selected for the first series of field studies was on a 4-lane farm-to-market road near Austin and was conveniently located adjacent to a Texas Highway Department maintenance warehouse. The pavement on this road was a double-surface treatment with good riding qualities. Precise elevations of the pavement surface were determined at 1-ft grid intersections with a Wild level for 200 ft in advance of the detector; the elevations varied no more than about 0.02 ft between adjacent points. The pavement was considered reasonably smooth. Although truck traffic was rather heavy, the significant experimentation was confined to studying the static and dynamic loads produced by a series of test vehicles. These vehicles were loaded to represent typical operating conditions, weighted on a loadometer, and driven at various speeds across the transducer. Some tests involved stopping the vehicle on the transducer, and speeds ranged up to 70 mph.

During the eight months following the first field installation, test vehicles, which ranged from passenger cars and two-axle trucks to multi-axle vehicles and front-end loaders, made several hundred trips across the transducer. A systematic study was made of the effects of vehicle speed, load placement on the transducer, tire-inflation pressure, vehicle acceleration, braking, and other factors. The transducer responded satisfactorily under all conditions. The magnitude of the output signal was not affected by speed, load placement on the transducer, or tire inflation pressure. Acceleration and braking caused a transfer of load among the wheels of the test vehicles, which was expected and indicated by the studies. The transducer withstood the traffic and the winter environment without adverse effects.

The second series of tests conducted during the summer of 1964, subjected the scale to heavy traffic on Interstate 35 near Temple, Texas. The transducer was placed in the outer lane and was positioned to weigh the wheels on the right side of all vehicles (Fig. 7). The site was about a mile downstream from the loadometer station, which is operated periodically by the planning survey division of the Texas Highway Department. The normal operating schedule called for occupancy of the loadometer station for 4 hr

Figure 7. Portable scale installation on Interstate 35 at Temple-Belton, Texas.

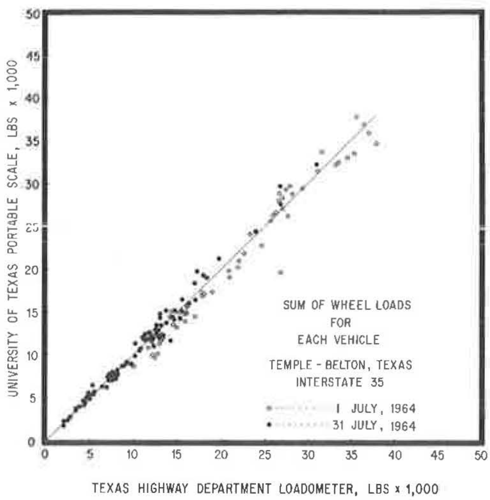

Figure 8. Loadometer weights vs portable weights.

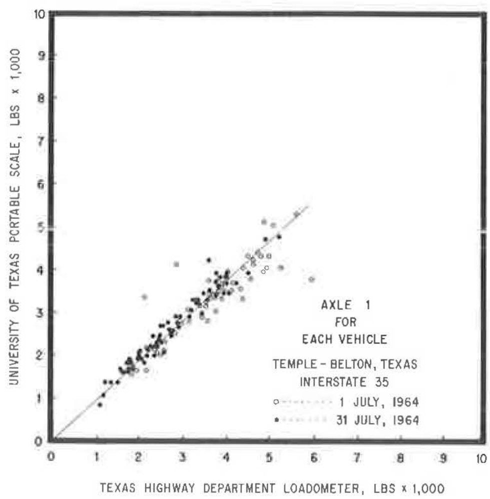

Figure 9. Loadometer weights vs portable weights.

on the first and last day of July. The portable scale was operated during these periods to obtain comparable data on the static weight and the dynamic weight of a large variety of commercial vehicles. Walkie-talkie radios were used to coordinate weighing operations at the two sites, and wheel weights for over 200 vehicles were recorded. The vehicles which were weighed while moving were traveling at speeds ranging from about 35 to 60 mph. Polaroid photographs made permanent records of the oscilloscope traces.

Wheel load data were scaled from these photographs and transferred to punched cards for machine processing. Wheel load data procured by loadometer weighing were also punched on cards. A computer was used to plot these data in the form shown in Figures 8 through 13. The regression lines through the points are the straight lines of best fit

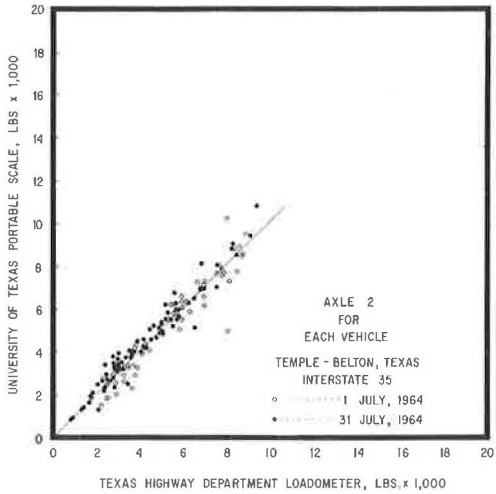

Figure 10. Loadometer weights vs portable weights.

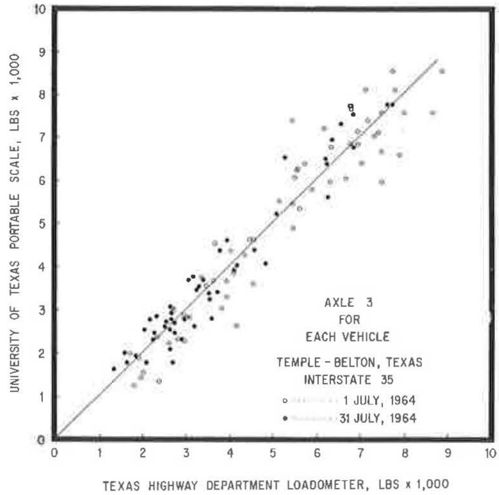

Figure 11. Loadometer weights vs portable weights.

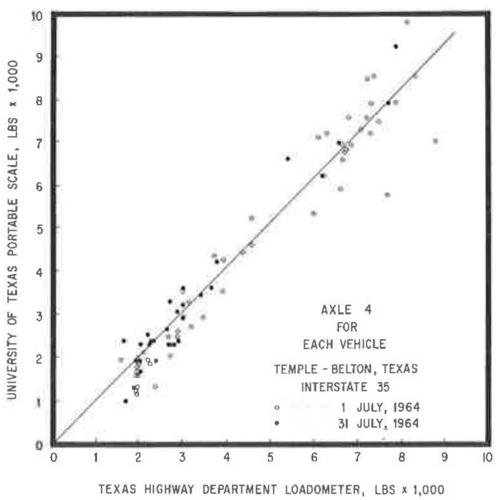

Figure 12. Loadometer weights vs portable weights.

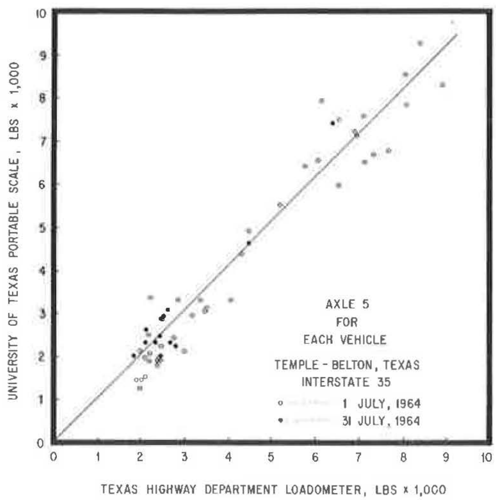

Figure 13. Loadometer weights vs portable weights.

as determined by a least squares technique. If there were perfect agreement between the loadometer weights and the portable scale weight, all data points would lie along a straight line inclined at 45 deg. Figure 8 shows that the line of best fit is inclined at approximately 45 deg, but that the data points are somewhat scattered about this line. In some cases the portable scale weights for the sum of the wheel loads on each vehicle are higher than the loadometer weights; in other cases they are lower. In virtually all cases the portable scale weights are within 10 percent of the loadometer weights and the scatter is approximately equally distributed on the high side and on the low side.

Figure 9 shows the relationship between the loadometer weights and the portable scale weights for the right front wheel of each vehicle. The portable scale weights are, on the average, lighter than the loadometer weights, and the variation of the dynamic weight from the static weight is as much as 40 percent in a few cases. Most of the data points agree within about 15 percent, however.

Since many of the vehicles were accelerating when they passed over the portable scale, it is logical that a part of the normal front axle load might have been transferred to other axles. For certain axles (Figs. 10 through 13) the wheel weights determined by the portable scale are higher than those measured statically, whereas for other axles they are lower. The scatter in the data is somewhat larger when considering individual wheel loads than when considering the sum of the wheel loads for each vehicle. The scatter is, however, approximately equally distributed on the high and low side for every case.

The third site at which the portable scale was installed was also adjacent to a loadometer station operated by the Highway Department near Luling. Truck traffic during the 4-hr weighing period was very light, and this installation served more to demonstrate the portability of the scale than to provide data. As a matter of fact, only 13 commercial vehicles were weighed during the 4-hr period. This installation took only 2 hr to complete.

At each site, premix asphalt laid on a sheet of paper was used to fill the grout-lined depression remaining after the wheel load transducer had been removed. The paper prevented the asphalt mix from adhering to the grout, and it was a simple matter to remove the temporary patch material at a later time. The transducer could be replaced at a previously occupied site in about 20 min. No difficulty with keeping the transducer or the patch material seated in its recess has been experienced.

SUMMARY

The portable electronic scale consists of a pair of wheel load transducers and associated electronic recording instruments. The transducers, each of which is 50 by 20 in. in plan dimensions and only slightly over 1 in. thick, are simple in design, rugged, and portable. Inertial effects in the transducer are negligible, and the electrical output signals depend only on the magnitude of the load applied normal to the surface. Since only 1½ in. of pavement must be removed, the transducers can be installed in any smooth roadway surface including rigid pavements and bridge decks. Initial installation requires approximately 3 hr, but subsequent installation at a previously occupied site requires only about 30 min.

Basic electronic equipment has been used in the experimental stage of the scale development. Signals are displayed on an oscilloscope, and Polaroid photographs made for permanent records. An instrument system will record in digital form on magnetic tape information regarding date, time of day, vehicle speed, number of axles per vehicle, axle spacing, and wheel weight. This system will be operative early in 1966.

Analysis of data on nearly 300 different vehicles, each of which was weighed both statically by a conventional loadometer and while moving at normal road speed by the portable electronic scale, indicates that static vehicle weight can be estimated from the weights obtained by the portable electronic scale with sufficient precision for planning and design purposes. The precision of the estimate can undoubtedly be improved by using more than one pair of transducers for sensing the moving wheel loads.

There are many potential uses for the portable electronic scale in highway planning, design, and operation. Routine statistical data procurement without stopping or delaying traffic has been described. Vehicles can be classified automatically into groups according to the number of axles per vehicle and wheel weight. Land use by various classes of vehicles can be studied. Traffic control devices can be operated. Unnecessary delay to vehicles which are within the legal weight limits can be eliminated by using the electronic scale as a sorting device at static weight enforcement stations. Research leading to a better understanding of the behavior of highway structures and pavements subjected to repeated dynamic loads can be initiated. Engineers with imagination will find many applications for the portable dynamic weighing device.

A patent application on the portable electronic scale described herein was filed in April 1965 with the U. S. Patent Office.

ACKNOWLEDGMENTS

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George L. Carver, contact representative for the Texas Highway Department, contributed generously of his resources to the project. Henry Bremer represented the U. S. Bureau of Public Roads. Personnel of The University and the Texas Highway Department too numerous to mention aided immeasurably in this research.

REFERENCES

1. Normann, O. K., and Hopkins, R. C. Weighing Vehicles in Motion. Highway Research Board Bull. 50, 1952.
2. Normann, O. K., and Hopkins, R. C. Weighing Vehicles in Motion. Public Roads, Vol. 27, No. 1, pp. 1-17, April 1952.
3. Bovitz, Vince. No Waiting for Weighing with New Electronic Scales. Better Roads, Vol. 25, pp. 31-46, Dec. 1955.
4. Stiffler, W. W., and Blensly, R. C. Weighing Trucks in Motion and the Use of Electronic Scales for Research. Traffic Eng., Vol. 26, No. 5, pp. 195-199, 206, Feb. 1956.
5. Dearinger, John A. Dynamic Weighing of Vehicles. Public Roads, Vol. 31, No. 10, pp. 200-204, Oct. 1961.
6. Blythe, D. K., Dearinger, J. A., and Puckett, R. E. A Research Report on Electronic Highway Scales for Weighing Trucks in Motion. Prepared in coop. with Kentucky Dept. of Highways and U. S. Bur. of Public Roads, Aug. 1964.
7. Puckett, Russell E. Comparison of Two Methods for Preloading Electronic Scales. Public Roads, Vol. 32, No. 8, pp. 181-185, June 1963.
8. Puckett, Russell E. Selecting the Best Scale for In-Motion Weighing. Public Roads, Vol. 33, No. 3, pp. 45-47, Aug. 1964.
9. Keep 'Em Rolling. Engineering News Record, p. 28, Aug. 25, 1955.
10. Cronk, Duane L. Machine with a Memory. The Highway Magazine, Vol. 47, pp. 254-257, Nov. 1955.
11. Weigh Axles in Motion. New York, Taller and Cooper, Inc. (Commercial ad.).
12. Bachmann, Ing. Wolfgang. Weighing Moving Vehicles. German Construction Eng., pp. 870-871, June 1959.
13. Edholm, Stig. Methods of Traffic Measurement—Determination of Number and Weight of Vehicles. Highway Research Board Bull. 338, pp. 81-99, Sept. 1962.
14. Lee, Clyde Edward. A Portable Electronic Scale for Weighing Vehicles in Motion. Thesis, Mississippi State College, May 1956.
15. Hutchison, Paul T., and Fitzgerald, D. F. Electronic Device for Weighing Moving Trucks. Res. project sponsored by Bd. of Trustees of Institutions of Higher Learning, State of Miss., 1952-1954.
16. Trott, J. J., and Williamson, P. J. Measuring, Classifying and Counting Wheel Loads of Moving Vehicles. The Engineer, pp. 859-862, Dec. 1959.