# ECONOMIC RESULTS OF DIESEL ELECTRIC MOTIVE POWER ON THE RAILWAYS OF THE UNITED STATES OF AMERICA*

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## Part I: Economic Conditions and General Statistical Data

### INTRODUCTION

THIS STUDY OF THE ECONOMICS of diesel motive power is based mainly on data contained in the 'Statistics of Railways of the United States' published annually by the Interstate Commerce Commission, hereinafter referred to as I.C.C.

The decisions by the various railways to make the change from steam to diesel power were based largely on the operating economies made by the relatively few units placed in yard and in road service during the period 1935–46. These economies appeared so large in comparison with the costs of existing steam operation at that time, that the question of steam *versus* diesel has been regarded as a closed issue, and of but academic interest in the United States of America since 1950.

However, by 1955 it was becoming evident that a number of factors pertaining to the economics of diesel operation had not been fully known as early as 1945–50. Today, with nearly twenty years of diesel operation, these factors can be more clearly defined. During these years, and for at least two decades prior to these years, other important factors have been shaping railway economics in the United States.

The problem, in this study, has been not only to isolate the motive power statistics, which are quite complete for both steam and diesel motive power, but also to show enough of the general operating and traffic data to enable the identification and evaluation of these other important economic factors, the results of which have been often attributed to diesel operation.

In the final analysis made in this study, the costs of the actual diesel operations for the year 1957—the latest available at the time this study was made—are compared with the similar costs of hypothetical operations with equivalent steam power, of modern design and of the same average age, sufficient in numbers and capacity to handle the same amount of traffic. Such steam power, of necessity, would have been installed, had the diesel not been available. By such a comparison, many of the other contemporaneous factors which have confused the true picture of diesel operating economies are eliminated.

This study is not to be construed as advocating a return to steam operation. Its sole purpose is to determine the economic position of diesel motive power with respect to other types whose economics are known, or yet to be determined.

### TRAFFIC

The railways of the United States of America grew steadily and contributed largely to the development of the country, up to about 1920. Then the increasing growth of automotive highway traffic began to divert the short-haul passenger traffic to the highways. As highways were rapidly improved, more of the passenger traffic, and then the short-haul freight traffic was diverted.

With the loss of most of the short-haul traffic, the railways began to abandon service on branch lines and to reduce the 'local' train service on the main lines by eliminating stops at the smaller communities. This eliminated many of the short, slower trains, both passenger and freight, leaving the remaining long-haul traffic on fewer, heavier trains.

These trends started as far back as 1920, but have been increasing more rapidly since 1945.

Between 1930 and 1940 the country went through a serious business depression which affected not only the railways, but all business and employment generally. All traffic on the railways, both passenger and freight, dropped to levels lower than those attained in 1910.

The depression was immediately followed by the 1939–45 war. During 1941–46, traffic returned to the railways, and rose to volumes never achieved before, or since. Much of this traffic was due to the restricted use of automotive fuel for highway traffic, as a war emergency measure.

*The MS. of this paper was received at the Institution on 15th December 1959. For a report of the meeting, in London, at which this paper was presented,* *see p. 318.*

* *This paper is a necessary datum for a forthcoming paper dealing with the economic results of the electrification of parts of certain class I railways in the United States of America.*

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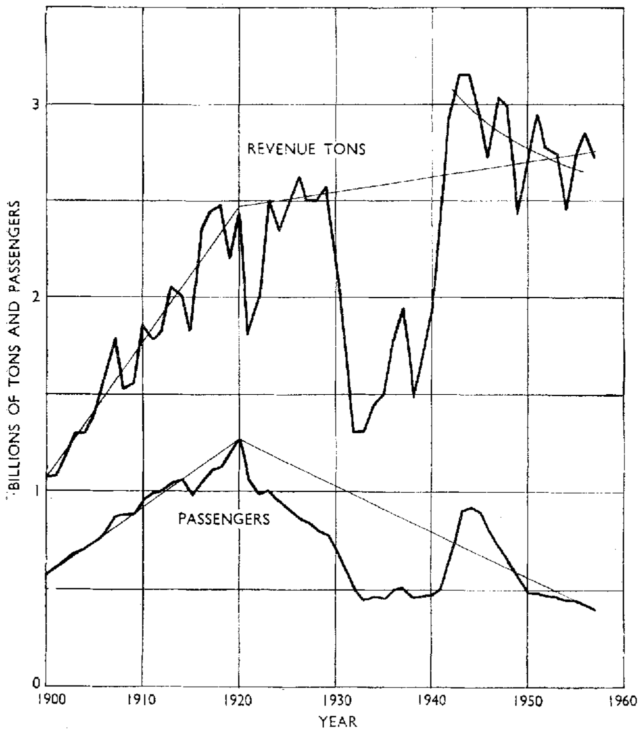
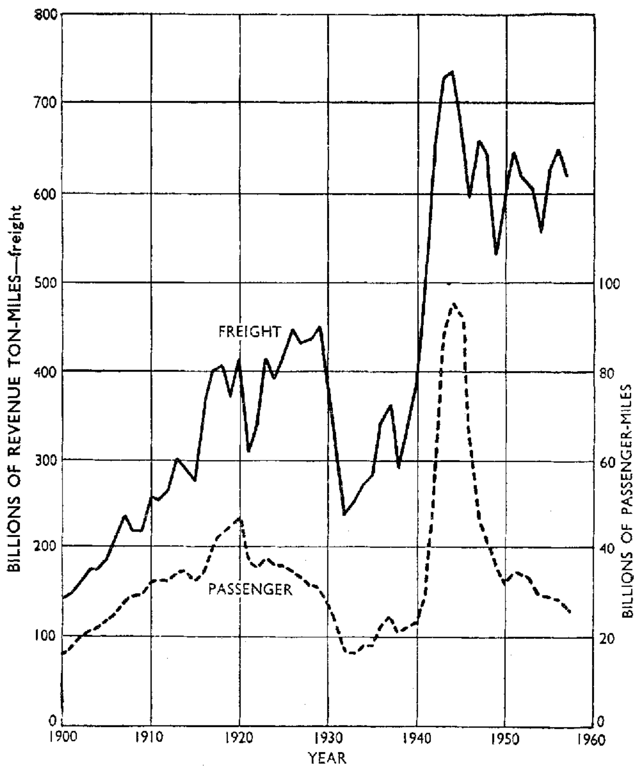



*a* Revenue tons and passengers carried.




*b* Revenue ton-miles and passenger miles.

*Fig. 1. Traffic. All classes I and II railways*

Since the war, railway passenger traffic declined further owing to increasing diversion of the short-haul traffic to the highways, and of the long-haul traffic to the airways. Railway freight revenue-tons are still declining (Fig. 1*a*), but revenue ton-miles remain at a high level owing to the increasing length of haul (Fig. 1*b*).

Since 1920, the miles of road operated by the class I railways has declined more than 10 per cent. The number of passenger cars has declined more than 40 per cent, and the number of passenger trains has declined approximately 60 per cent.

The traffic pattern is shown graphically in Fig. 1. Traffic has been the most influential factor in motive power requirements and operation, as well as in railway operating expenses and earnings.

## MOTIVE POWER REDUCTION

The number of locomotives on the United States railways increased steadily until 1924, in which year there were 69 486 locomotives in service on all the classes I, II, and III railways. Their average tractive capacity has steadily increased up to the present time (Fig. 2). Except for the war years, the number has steadily declined since 1924, and is still declining.

The necessity for longer and fewer trains to reduce operating expenses created the demand for motive power of greater horsepower. Motive power, by itself, did not create the longer trains.

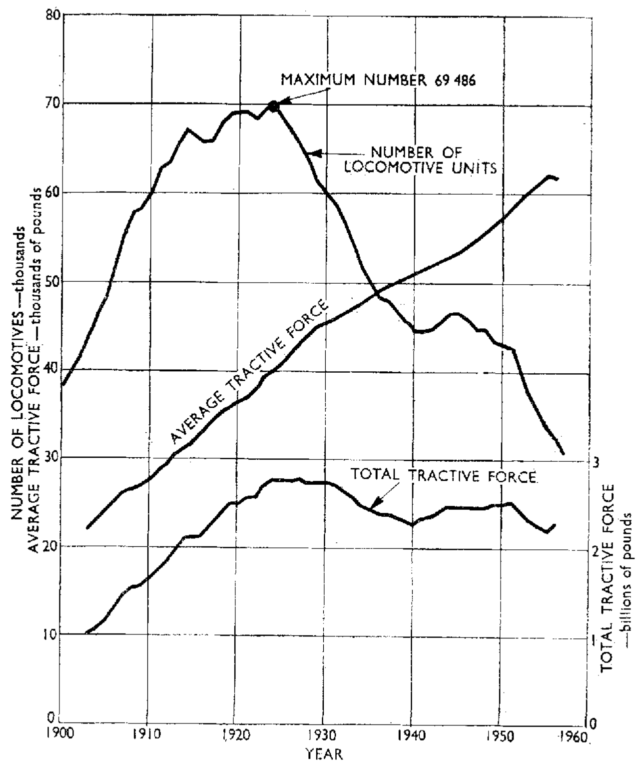



*Fig. 2. Motive power in service on all railways in the United States of America*

Classes I, II, and III.

The advances in engineering, technology, and manufacturing between 1915 and 1935 were able to increase the maximum horsepower capacity of steam locomotives from 1500 h.p. to single units of 5000 h.p. Since 1935, maximum steam locomotive capacity has been further increased to nearly 7000 h.p. for special operations (Fig. 3).

The acquisitions and retirements of locomotives on the class I railways over the past 50 years are shown in Fig. 4. Ever since 1922, long before the advent of diesel power, retirements have exceeded acquisitions each year by a ratio greater than two to one, except during the war years. New

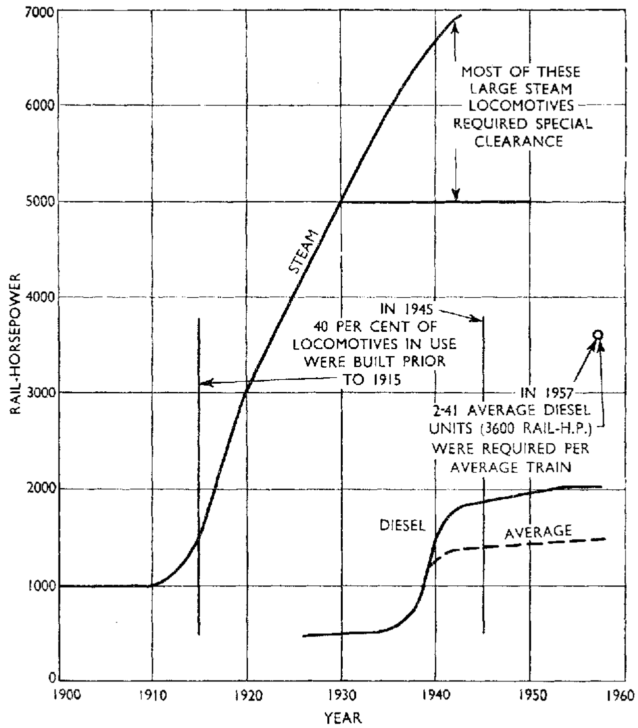



*Fig. 3. Development of maximum locomotive rail horsepower*

Available at rim of driving wheels.

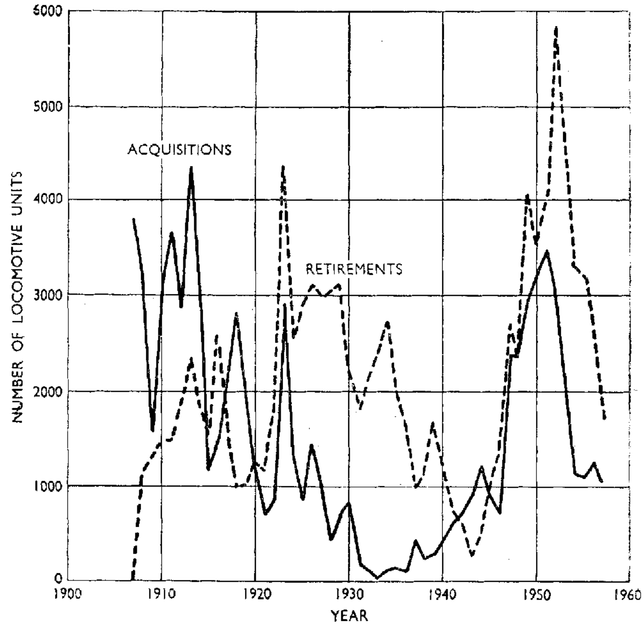



*Fig. 4. Locomotive acquisitions and retirements on all class I railways from 1907 to 1957*

All types, steam, electric, diesel and other.

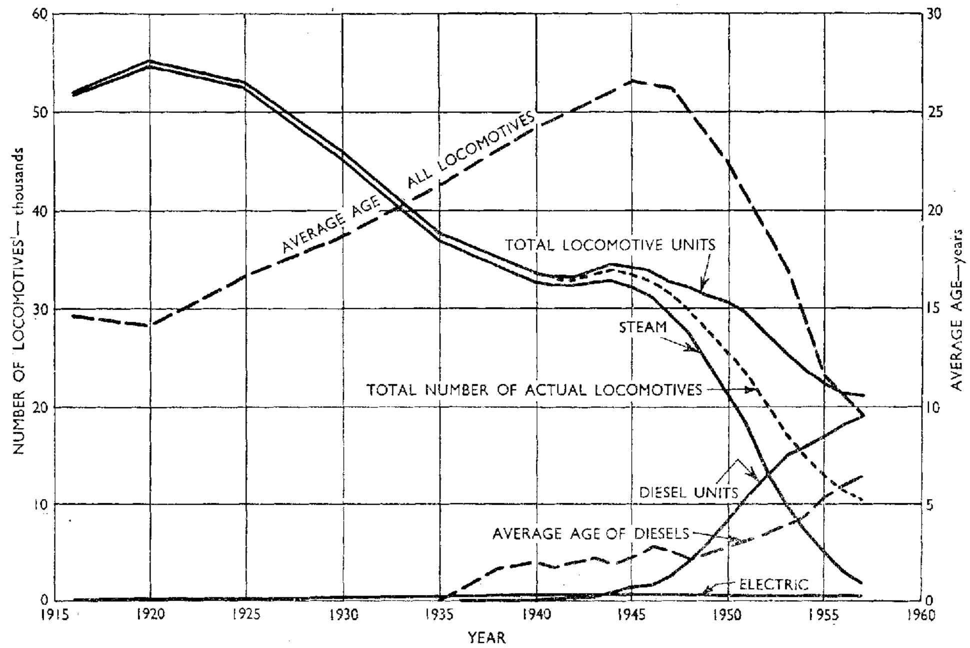



*Fig. 5. Road locomotives on all class I railways*

locomotive capacity doubled during the life of the old units retired, and fewer locomotives were required for the declining traffic. This trend has continued unaffected by, and certainly not initiated by, the change in type of motive power.

Nearly 50 per cent of the motive power was either unserviceable or stored during the depression. Very little new power, therefore, was acquired during those years, and little new power could be acquired during the war years.

At the end of the 1939–45 war, *more than 40 per cent* of all the motive power still in service consisted of locomotives built prior to 1915, and well over 31 years old. This equipment was small in capacity, completely worn out, and long overdue for replacement. Never before in the history of American railroading had the motive power been permitted to become so old and so inadequate in such large numbers.

## ROAD, OR LINE-HAUL MOTIVE POWER

The decrease in total number of locomotives in road, or line-haul service on the class I railways since 1920 is shown in Fig. 5. The change in numbers of the three principal types, steam, electric, and diesel, and the change in average age for the diesels and for the whole group are also shown. The relatively small amount of electric motive power is quite apparent.

The change in total number reflects the changes in traffic patterns and in operating methods, together with the gradual change to motive power of greater capacity.

Particular attention is called to the change in the average age.

## YARD AND SWITCHING (SHUNTING) MOTIVE POWER

Similar data are shown for yard and switching locomotives in Fig. 6.

A large reduction in number is shown between 1925 and 1940 due to the same causes that influenced road power.

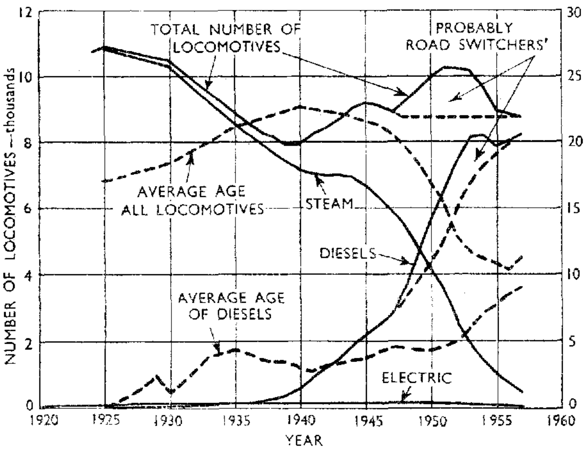



*Fig. 6. Yard and switching (shunting) locomotives on all class I railways*

There were not sufficient electric or diesel locomotives in yard service prior to 1940 to cause this reduction in number. The reduction made during the depression was restored during the war, mainly with diesel units.

A substantial increase in number is indicated from 1947 to 1953, due to the inclusion with yard power of a large number of diesel units known originally as 'road switchers'. By 1956 most of these had been properly reclassified as road locomotives.

The change from steam to diesel power has not reduced the number of yard locomotives required, which remained in 1957 at about 8800 units, approximately the same as in 1935, 1943, and 1948.

## OPERATION

Motive power performance during the period under review is indicated by the train-miles, shown in Fig. 7.

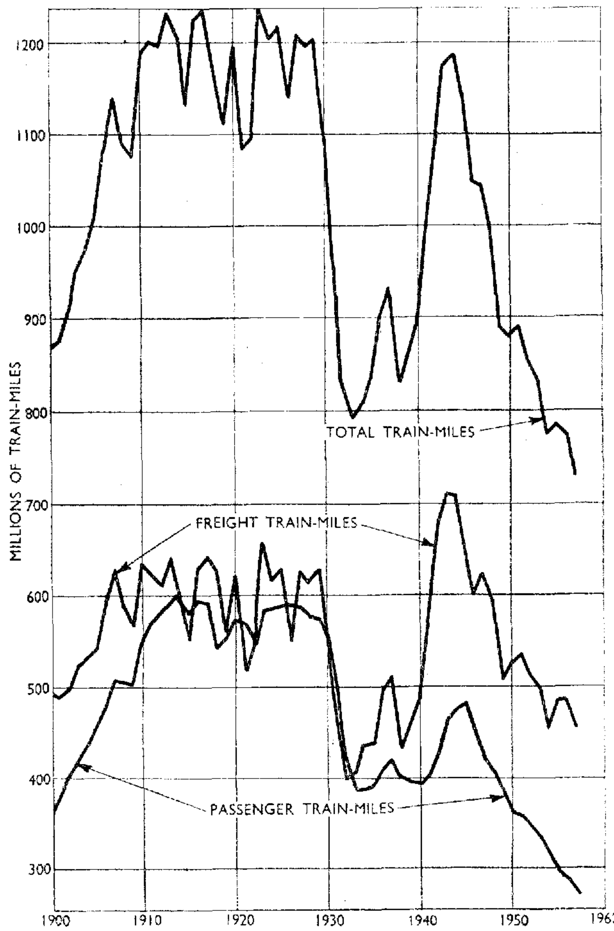



*Fig. 7. Train-miles*

All classes I and II railways.

Locomotive-miles per train-mile (average locomotives per train), car-miles per train-mile (average cars per train), and ton-miles per train-mile (average tons per train) are shown in Fig. 8.

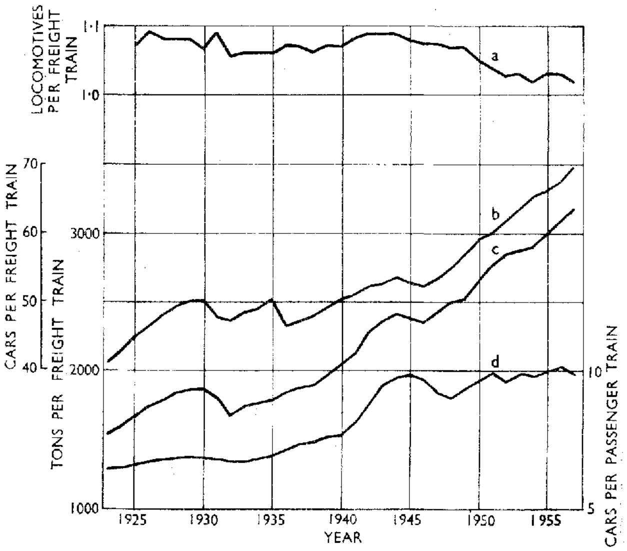



*Fig. 8. Locomotive-miles, car-miles, and ton-miles per train mile*

a Locomotive-miles per freight train-mile (average locomotives per freight train).
b Car-miles per freight train-mile (average cars per freight train).
c Gross ton-miles trailing per freight train-mile (average tons per freight train).
d Car-miles per passenger train-mile (average cars per passenger train).

## TOTAL RAILWAY OPERATING EXPENSE

Total railway operating expenses and revenues have in general followed the traffic pattern. Nothing indicates that the change in type of motive power since 1940 has had a bearing on either of these items, unless unfavourably. Operating expenses have increased at a greater ratio than operating revenues.

This fact is indicated by the operating ratio, which is the ratio of total railway operating expense to total railway operating revenue, shown for all classes I and II railways in Fig. 9. The average operating ratio since 1945 is higher than for any similar previous period except 1918–22, when

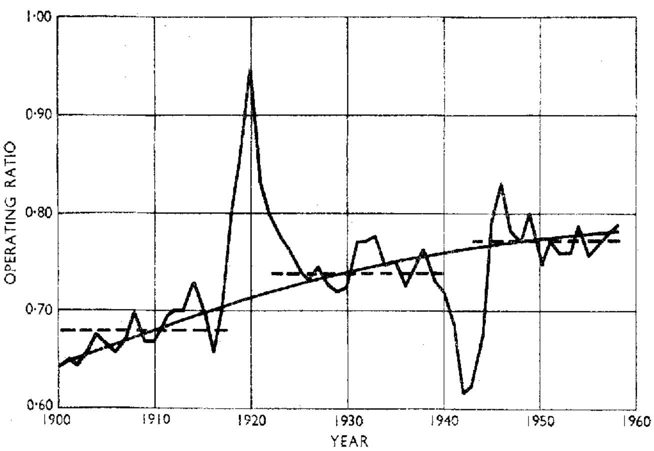



*Fig. 9. Operating ratio, all classes I and II railways*

all railways were under Federal Administration as a war measure.

All items of railway operating expense are classified in six major groups by the I.C.C. These are:

I Maintenance of way and structures
II Maintenance of equipment
III Traffic
IV Transportation
V Miscellaneous
VI General

The sum of all these group expenses is the total railway operating expense.

Maintenance of way and structures, maintenance of equipment and transportation comprise more than 90 per cent of the total operating expense.

The total railway operating expenses for all class I railways as a group from 1916 to 1957 are shown graphically in Fig. 10 in billions of dollars.

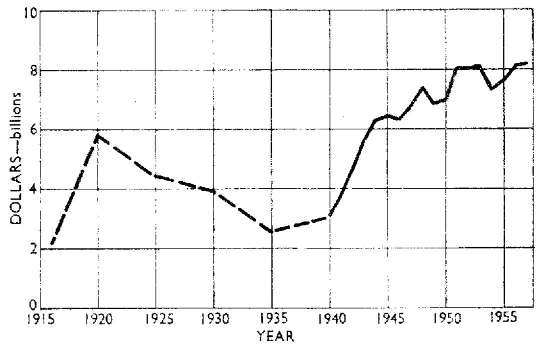



*Fig. 10. Total railway operating expense, all class I railways*

## MOTIVE POWER OPERATING AND MAINTENANCE COSTS

The I.C.C. statistics show separately for road locomotives and yard locomotives the following items of expense involved with motive power on the class I railways:

(1) Locomotive repairs
(2) Fuel, including electric power where used
(3) Wages of enginemen
(4) Engine house expenses
(5) Water
(6) Lubricants
(7) Other locomotive supplies
(8) Depreciation

Repairs and depreciation are items of maintenance of equipment expense. All others are items of transportation expense.

All of the above itemized costs for road locomotives, with the exception of depreciation, are shown in Table 1*a* in millions of dollars, for the years 1916, 1920, 1925, 1930, 1935, 1940, and for each year thereafter to 1957. Each item is also shown as a 'ratio cost', or as a proportionate part of

*Table 1a. Cost of operating and maintaining road locomotives (excluding depreciation)*

All class I railways

Costs as incurred in millions of dollars

| Year | Total railway operating expense | Operating ratio | Repairs | | | | Fuel and power | | | Engine men | Engine house ex-pense | Water | Lubri-cants | Other supplies | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Steam | Diesel | Other | Total | Fuel | Power | Total | | | | | | |
| 1916 | 2211 | 65·38 | 150·7 | | 0·7 | 151·4 | 192·6 | 2·9 | 195·5 | 129·0 | 36·3 | 12·6 | 3·6 | 3·5 | 531·9 |
| 1920 | 5831 | 94·38 | 512·0 | | 4·1 | 516·1 | 566·0 | 8·5 | 574·5 | 268·0 | 124·9 | 26·1 | 8·7 | 10·4 | 1528·7 |
| 1925 | 4540 | 74·10 | 388·5 | | 2·7 | 391·2 | 340·5 | 8·2 | 348·7 | 229·4 | 83·1 | 21·7 | 7·5 | 6·4 | 1088·0 |
| 1930 | 3931 | 74·43 | 293·5 | | 3·8 | 297·3 | 237·8 | 9·9 | 247·7 | 204·6 | 69·1 | 20·0 | 7·2 | 4·7 | 850·6 |
| 1935 | 2593 | 75·11 | 191·6 | | 4·0 | 195·6 | 173·1 | 11·3 | 184·4 | 149·8 | 41·0 | 14·3 | 5·7 | 2·8 | 587·6 |
| 1940 | 3089 | 71·90 | 230·1 | | 8·0 | 238·1 | 210·8 | 15·2 | 225·0 | 171·0 | 46·1 | 16·2 | 7·5 | 3·2 | 707·1 |
| 1941 | 3664 | 68·53 | 284·4 | | 10·5 | 294·9 | 259·5 | 16·2 | 275·7 | 204·3 | 52·5 | 17·8 | 9·3 | 3·9 | 858·6 |
| 1942 | 4601 | 61·63 | 342·5 | | 14·0 | 356·5 | 335·8 | 18·3 | 354·1 | 262·6 | 69·8 | 21·3 | 12·0 | 5·1 | 1082·0 |
| 1943 | 5657 | 62·48 | 411·7 | | 19·0 | 430·7 | 432·4 | 19·6 | 452·0 | 295·1 | 88·9 | 24·7 | 14·6 | 6·1 | 1312·1 |
| 1944 | 6282 | 66·57 | 474·2 | | 28·3 | 502·5 | 473·8 | 21·3 | 495·1 | 321·9 | 111·2 | 27·3 | 16·2 | 7·2 | 1481·4 |
| 1945 | 6418 | 72·10 | 461·8 | | 34·4 | 496·2 | 462·8 | 21·3 | 494·1 | 317·2 | 110·7 | 26·8 | 16·8 | 7·5 | 1469·3 |
| 1946 | 6357 | 83·35 | 451·7 | | 40·9 | 492·6 | 452·5 | 21·4 | 473·9 | 328·5 | 115·8 | 26·1 | 16·0 | 7·2 | 1460·1 |
| 1947 | 6797 | 78·27 | 453·5 | | 59·9 | 513·4 | 545·7 | 23·2 | 568·9 | 334·3 | 120·7 | 27·6 | 18·7 | 8·3 | 1591·9 |
| 1948 | 7472 | 77·26 | 441·4 | | 89·7 | 531·1 | 643·8 | 25·0 | 668·8 | 365·7 | 129·7 | 28·1 | 21·3 | 8·9 | 1753·6 |
| 1949 | 6892 | 80·32 | 334·9 | | 126·0 | 460·9 | 479·5 | 23·4 | 502·9 | 329·7 | 119·4 | 24·0 | 19·7 | 7·9 | 1464·5 |
| 1950 | 7059 | 74·52 | 316·4 | | 162·7 | 479·1 | 472·4 | 22·6 | 495·0 | 338·9 | 119·6 | 22·1 | 19·2 | 8·1 | 1482·0 |
| 1951 | 8041 | 77·39 | 326·9 | | 215·6 | 542·5 | 494·7 | 22·4 | 507·1 | 378·8 | 136·3 | 22·2 | 21·5 | 9·7 | 1618·1 |
| 1952 | 8053 | 76·11 | 243·9 | | 265·5 | 509·4 | 436·3 | 22·5 | 458·8 | 374·3 | 129·8 | 18·3 | 21·5 | 9·2 | 1521·3 |
| 1953 | 8135 | 76·29 | 173·5 | | 303·5 | 477·0 | 409·6 | 22·4 | 432·0 | 365·8 | 119·8 | 14·7 | 21·3 | 8·8 | 1439·4 |
| 1954 | 7384 | 78·80 | 86·4 | 299·6 | 16·6 | 402·6 | 356·4 | 22·8 | 379·2 | 346·2 | 106·4 | 9·5 | 20·9 | 8·1 | 1272·9 |
| 1955 | 7646 | 75·66 | 65·3 | 323·3 | 18·2 | 406·8 | 364·5 | 23·1 | 387·6 | 365·8 | 101·6 | 3·1 | 22·3 | 8·2 | 1295·4 |
| 1956 | 8108 | 76·85 | 55·0 | 365·0 | 19·8 | 439·8 | 374·5 | 23·3 | 397·8 | 385·9 | 105·5 | 2·0 | 24·9 | 8·7 | 1364·6 |
| 1957 | 8228 | 78·42 | 30·9 | 377·4 | 20·7 | 429·0 | 366·7 | 23·2 | 389·9 | 388·3 | 104·2 | 5·3 | 27·2 | 8·8 | 1352·7 |

*Table 1b. Cost of operating and maintaining road locomotives (excluding depreciation)*

All class I railways

Dollar costs converted into 'ratio costs'

(Proportion of total railway operating expense)

| Year | Total railway operating expense | Repairs | Fuel | Engine men | Engine house expense | Water | Lubricants | Other supplies | Total |
|---|---|---|---|---|---|---|---|---|---|
| 1916 | 2211 | 0·0686 | 0·0885 | 0·0584 | 0·0164 | 0·0057 | 0·0016 | 0·0016 | 0·2408 |
| 1920 | 5831 | 0·0886 | 0·0986 | 0·0460 | 0·0214 | 0·0045 | 0·0015 | 0·0018 | 0·2624 |
| 1925 | 4540 | 0·0864 | 0·0770 | 0·0505 | 0·0183 | 0·0048 | 0·0016 | 0·0014 | 0·2400 |
| 1930 | 3931 | 0·0757 | 0·0630 | 0·0521 | 0·0176 | 0·0051 | 0·0018 | 0·0012 | 0·2165 |
| 1935 | 2593 | 0·0755 | 0·0713 | 0·0555 | 0·0158 | 0·0055 | 0·0022 | 0·0011 | 0·2269 |
| 1940 | 3089 | 0·0770 | 0·0724 | 0·0554 | 0·0149 | 0·0052 | 0·0024 | 0·0010 | 0·2283 |
| 1941 | 3664 | 0·0805 | 0·0752 | 0·0557 | 0·0143 | 0·0049 | 0·0025 | 0·0011 | 0·2342 |
| 1942 | 4601 | 0·0775 | 0·0770 | 0·0570 | 0·0152 | 0·0046 | 0·0026 | 0·0011 | 0·2350 |
| 1943 | 5657 | 0·0762 | 0·0800 | 0·0521 | 0·0157 | 0·0044 | 0·0026 | 0·0011 | 0·2321 |
| 1944 | 6282 | 0·0801 | 0·0790 | 0·0513 | 0·0177 | 0·0044 | 0·0026 | 0·0011 | 0·2362 |
| 1945 | 6418 | 0·0774 | 0·0770 | 0·0494 | 0·0173 | 0·0042 | 0·0026 | 0·0012 | 0·2291 |
| 1946 | 6357 | 0·0775 | 0·0745 | 0·0517 | 0·0182 | 0·0039 | 0·0025 | 0·0011 | 0·2294 |
| 1947 | 6797 | 0·0755 | 0·0836 | 0·0492 | 0·0178 | 0·0041 | 0·0028 | 0·0012 | 0·2342 |
| 1948 | 7472 | 0·0710 | 0·0895 | 0·0489 | 0·0174 | 0·0038 | 0·0029 | 0·0012 | 0·2347 |
| 1949 | 6892 | 0·0669 | 0·0730 | 0·0480 | 0·0179 | 0·0035 | 0·0029 | 0·0012 | 0·2134 |
| 1950 | 7059 | 0·0680 | 0·0701 | 0·0480 | 0·0170 | 0·0031 | 0·0027 | 0·0012 | 0·2101 |
| 1951 | 8041 | 0·0676 | 0·0631 | 0·0472 | 0·0170 | 0·0028 | 0·0027 | 0·0012 | 0·2016 |
| 1952 | 8053 | 0·0633 | 0·0570 | 0·0465 | 0·0161 | 0·0023 | 0·0027 | 0·0011 | 0·1890 |
| 1953 | 8135 | 0·0587 | 0·0532 | 0·0450 | 0·0148 | 0·0018 | 0·0026 | 0·0011 | 0·1772 |
| 1954 | 7384 | 0·0546 | 0·0514 | 0·0470 | 0·0145 | 0·0013 | 0·0028 | 0·0011 | 0·1726 |
| 1955 | 7646 | 0·0532 | 0·0507 | 0·0479 | 0·0133 | 0·0004 | 0·0029 | 0·0011 | 0·1695 |
| 1956 | 8108 | 0·0542 | 0·0491 | 0·0476 | 0·0130 | 0·0002 | 0·0031 | 0·0011 | 0·1683 |
| 1957 | 8228 | 0·0522 | 0·0475 | 0·0472 | 0·0127 | 0·0006 | 0·0033 | 0·0011 | 0·1646 |

*Table 2a. Cost of operating and maintaining yard locomotives (excluding depreciation)*

All class I railways

Costs as incurred in millions of dollars

| Year | Total railway operating expense | Repairs | Fuel | Engine men | Engine house expense | Water | Lubricants | Other supplies | Total |
|---|---|---|---|---|---|---|---|---|---|
| 1916 | 2211 | e26·55 | 34·42 | 37·82 | 11·18 | 2·35 | 0·62 | 0·72 | 113·66 |
| 1920 | 5831 | e89·1 | 109·32 | 96·70 | 45·55 | 4·74 | 1·69 | 2·05 | 349·16 |
| 1925 | 4540 | e68·0 | 67·23 | 88·93 | 30·53 | 4·40 | 1·35 | 1·46 | 261·9 |
| 1930 | 3931 | e51·9 | 45·66 | 83·55 | 25·18 | 3·97 | 1·18 | 1·16 | 212·6 |
| 1935 | 2593 | 34·35 | 30·61 | 57·2 | 15·15 | 2·97 | 0·88 | 0·73 | 141·89 |
| 1940 | 3089 | 41·44 | 36·08 | 75·4 | 17·5 | 3·3 | 1·31 | 0·9 | 175·9 |
| 1941 | 3664 | 53·63 | 43·94 | 91·86 | 19·96 | 3·63 | 1·67 | 1·11 | 215·8 |
| 1942 | 4601 | 60·22 | 52·03 | 113·4 | 25·3 | 4·0 | 2·15 | 1·35 | 258·45 |
| 1943 | 5657 | 73·5 | 62·56 | 124·4 | 31·2 | 4·36 | 2·57 | 1·56 | 300·15 |
| 1944 | 6282 | 82·45 | 66·32 | 136·7 | 37·5 | 4·6 | 2·8 | 1·8 | 332·17 |
| 1945 | 6418 | 80·9 | 65·85 | 135·4 | 37·0 | 4·6 | 2·9 | 1·9 | 328·6 |
| 1946 | 6357 | 84·1 | 66·77 | 147·7 | 38·6 | 4·4 | 2·9 | 1·9 | 346·3 |
| 1947 | 6797 | 91·0 | 82·37 | 157·8 | 40·8 | 4·75 | 3·5 | 2·25 | 382·5 |
| 1948 | 7472 | 100·1 | 97·57 | 180·0 | 45·6 | 5·0 | 3·9 | 2·5 | 434·7 |
| 1949 | 6892 | 81·9 | 69·86 | 164·7 | 39·7 | 4·2 | 3·4 | 2·2 | 366·0 |
| 1950 | 7059 | 84·4 | 66·95 | 179·9 | 39·1 | 3·9 | 3·3 | 2·1 | 379·65 |
| 1951 | 8041 | 93·2 | 67·05 | 216·4 | 42·9 | 4·0 | 3·7 | 2·4 | 429·65 |
| 1952 | 8053 | 90·5 | 55·88 | 209·7 | 39·1 | 3·3 | 3·7 | 2·3 | 429·40 |
| 1953 | 8135 | 86·2 | 50·35 | 214·0 | 36·3 | 2·7 | 3·6 | 2·2 | 421·25 |
| 1954 | 7384 | 73·8 | 43·07 | 208·9 | 31·0 | 2·0 | 3·4 | 1·9 | 364·1 |
| 1955 | 7646 | 74·5 | 42·76 | 219·5 | 29·3 | 1·6 | 3·7 | 1·95 | 373·3 |
| 1956 | 8108 | 82·8 | 45·31 | 237·2 | 30·3 | 1·44 | 4·0 | 2·16 | 403·2 |
| 1957 | 8228 | 84·1 | 43·42 | 242·7 | 29·9 | 1·14 | 4·44 | 2·18 | 407·9 |

e Estimated. Costs were included with road locomotives.

*Table 2b. Cost of operating and maintaining yard locomotives (excluding depreciation)*

All class I railways

Dollar costs converted into 'ratio costs'
(Proportion of total railway operating expense)

| Year | Total railway operating expense | Repairs | Fuel | Engine men | Engine house expense | Water | Lubricants | Other supplies | Total |
|---|---|---|---|---|---|---|---|---|---|
| 1916 | 2211 | 0·0120 | 0·0156 | 0·0171 | 0·0051 | 0·00107 | 0·00028 | 0·00033 | 0·0514 |
| 1920 | 5831 | 0·0153 | 0·01875 | 0·0166 | 0·00781 | 0·00081 | 0·00029 | 0·00035 | 0·0599 |
| 1925 | 4540 | 0·0150 | 0·0148 | 0·0196 | 0·00673 | 0·00097 | 0·00030 | 0·00033 | 0·0577 |
| 1930 | 3931 | 0·0132 | 0·0116 | 0·02125 | 0·00641 | 0·00101 | 0·00030 | 0·00029 | 0·0541 |
| 1935 | 2593 | 0·01325 | 0·0118 | 0·0221 | 0·00584 | 0·00115 | 0·00034 | 0·00028 | 0·0548 |
| 1940 | 3089 | 0·0134 | 0·01169 | 0·0244 | 0·00567 | 0·00107 | 0·00043 | 0·00029 | 0·0572 |
| 1941 | 3664 | 0·01463 | 0·0120 | 0·0251 | 0·00545 | 0·00099 | 0·00046 | 0·00030 | 0·0589 |
| 1942 | 4601 | 0·0131 | 0·0113 | 0·0247 | 0·0055 | 0·00087 | 0·00047 | 0·00029 | 0·0563 |
| 1943 | 5657 | 0·0130 | 0·01106 | 0·0220 | 0·00552 | 0·00068 | 0·00045 | 0·00028 | 0·0530 |
| 1944 | 6282 | 0·01313 | 0·01055 | 0·0216 | 0·00598 | 0·00073 | 0·00045 | 0·00029 | 0·0530 |
| 1945 | 6418 | 0·0126 | 0·01025 | 0·0211 | 0·00576 | 0·00072 | 0·00045 | 0·00030 | 0·0513 |
| 1946 | 6357 | 0·0132 | 0·0105 | 0·0232 | 0·00608 | 0·00069 | 0·00046 | 0·00030 | 0·0545 |
| 1947 | 6797 | 0·0134 | 0·0121 | 0·0232 | 0·00600 | 0·00070 | 0·00052 | 0·00033 | 0·0563 |
| 1948 | 7472 | 0·01335 | 0·01306 | 0·0241 | 0·00608 | 0·00067 | 0·00052 | 0·00033 | 0·0581 |
| 1949 | 6892 | 0·0119 | 0·01013 | 0·0239 | 0·00576 | 0·00061 | 0·00049 | 0·00032 | 0·0532 |
| 1950 | 7059 | 0·01195 | 0·0095 | 0·0255 | 0·00555 | 0·00055 | 0·00047 | 0·00030 | 0·0538 |
| 1951 | 8041 | 0·0116 | 0·00835 | 0·0269 | 0·00534 | 0·00050 | 0·00046 | 0·00030 | 0·0535 |
| 1952 | 8053 | 0·01122 | 0·00694 | 0·0261 | 0·00485 | 0·00041 | 0·00046 | 0·00029 | 0·0534 |
| 1953 | 8135 | 0·0106 | 0·0062 | 0·0264 | 0·00447 | 0·00033 | 0·00044 | 0·00027 | 0·0518 |
| 1954 | 7384 | 0·0100 | 0·00583 | 0·0284 | 0·00421 | 0·00027 | 0·00046 | 0·00026 | 0·0494 |
| 1955 | 7646 | 0·00975 | 0·0056 | 0·0288 | 0·00383 | 0·00022 | 0·00048 | 0·00026 | 0·0489 |
| 1956 | 8108 | 0·0102 | 0·00559 | 0·0292 | 0·00374 | 0·00018 | 0·00049 | 0·00027 | 0·0497 |
| 1957 | 8228 | 0·01022 | 0·00528 | 0·0295 | 0·00363 | 0·00014 | 0·00054 | 0·00027 | 0·0496 |

the total railway operating expense for the year in which it is incurred, in Table 1*b*.

The itemized costs for yard locomotives are shown similarly in Tables 2*a* and 2*b*.

## TREATMENT OF COST FIGURES

An economic factor affecting all expenses and revenues has been the decline in the purchasing value of the dollar over the period studied. This 'inflation factor' distorts the direct comparison of costs incurred over a term of years.

By converting all dollar costs into 'ratio costs', that is, as proportionate parts of the total railway operating expense, the 'inflation factor' appears nearly equally in the numerator and denominator of the ratio, and is approximately cancelled out, leaving the basic factors which are comparable.

Ratio costs of any item may be compared year after year to determine whether they are rising, falling or stationary, thereby enabling their change to be more readily related to the economic factors causing the change.

The totals of the items of road locomotive operating expense for each year, presented as 'ratio costs' in Table 1*b*, are shown in Fig. 11. The graph of the total number of road locomotives in service is also shown for comparison. It is evident, and logical, that the operating costs have decreased, in general, as the number of locomotives has decreased.

The three largest items of road locomotive operating expense shown in Table 1 are repairs, fuel, and engine men. Their ratio costs are shown in Fig. 12*a*, and comprise about 90 per cent of the total shown in Fig. 11. The remaining four items of engine house expense, water, lubricants, and other supplies, are shown to a larger scale in Fig. 12*b*.

The totals of the items of yard locomotive operating expense for each year, presented as ratio costs in Table 2*b*,

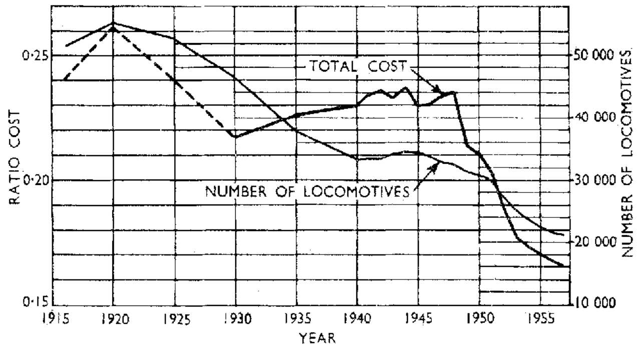
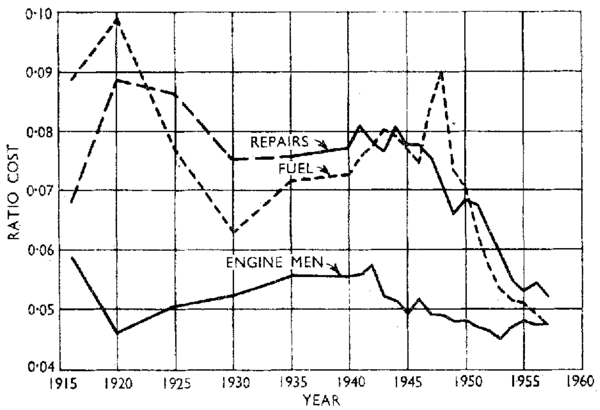
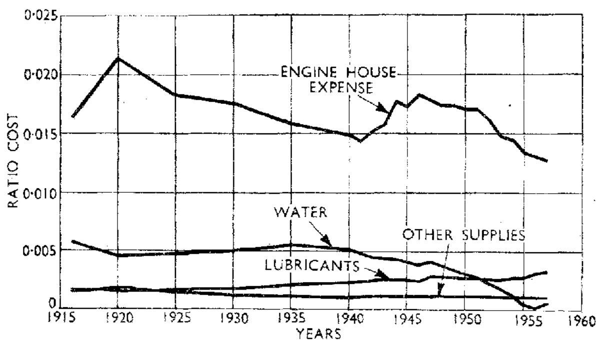



*Fig. 11. Total cost of operating and maintaining road locomotives on all class I railways*

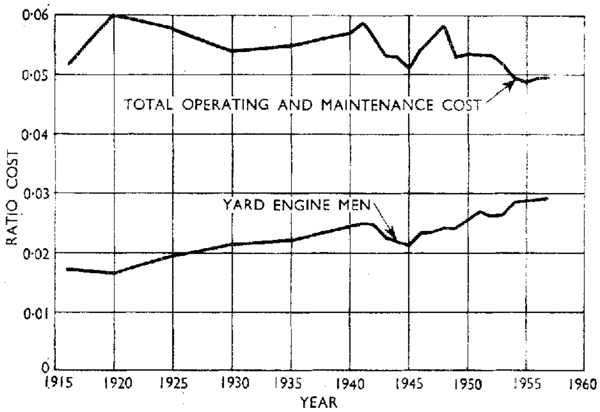



*a* Repairs, fuel, and engine men for road locomotives.

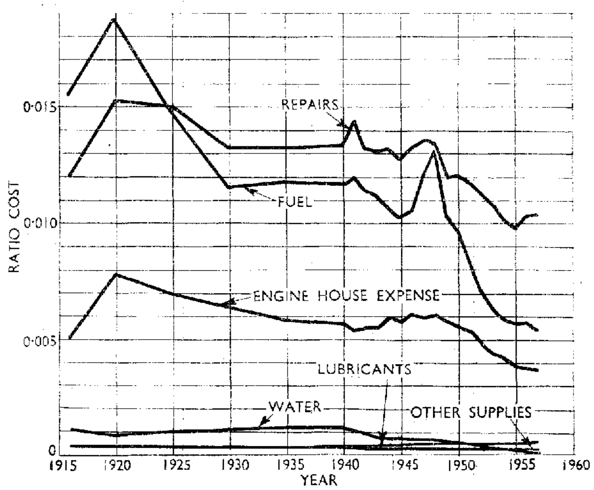



*b* Other itemized costs of operating road locomotives.

*Fig. 12. Costs on all class I railways*




*a* Total cost of operating and maintaining yard locomotives, also cost of yard engine men.




*b* Other itemized costs of operating yard locomotives.

*Fig. 13. Costs on all class I railways*

are shown in Fig. 13*a*. Also shown are the costs of yard engine men, the largest single item of yard locomotive operating expense. The ratio costs of the other six items are shown to a larger scale in Fig. 13*b*.

## FACTORS INVOLVED IN TRENDS OF LOCOMOTIVE EXPENSE ITEMS

The trends in the graph of each item of locomotive expense are due to some factors common to all, combined with special factors in some items.

All items vary with the number of locomotives in service. All items may vary with the type of motive power used. Special factors of importance in specific items are:

Repair costs will also vary with the age of the equipment and at a different rate for each type.

Fuel costs will also vary with trends in the fuel market.

Cost of engine men will vary with the number of locomotives (not units) used per train, separately manned; with the total weight on drivers, and with change in wage rates.

Engine house expense will also vary with traffic, as short runs and branch line operations have been eliminated with their engine terminals; also if steam and diesel power are being operated simultaneously.

Where several factors are acting simultaneously to shape the trends, careful analysis must be made to ensure that each factor involved is quantitatively identified. Many of the claims of economies attributed to the diesel locomotive have been made erroneously because this analysis has been overlooked or ignored.

## DEPRECIATION

Depreciation is an accounting charge for the cost of the equipment spread over its service life. It should equal, during the life, the original cost less the ultimate scrap value.

Although by I.C.C. ruling an item of operating expense under maintenance of equipment, depreciation cannot be properly converted to a ratio cost since it is not a function of operation but of investment.

A correct depreciation rate is essential to prevent depletion of assets when renewals become necessary. A rate based on a 30-year life has been generally used for steam and electric locomotives, although many of these have been retained in service longer.

When diesel locomotives were introduced, it was assumed they would have service life characteristics similar to electric locomotives, reduced somewhat by the known shorter life of the internal combustion-type prime mover. A depreciation rate based on a 20-year life for road power, and a 25-year life for yard power of this type was approved by the I.C.C. The I.C.C. does not establish depreciation rates. It approves such rates established by the railways based on proper supporting data.

More recently, studies based on accumulated experience relative to obsolescence and to rise in repair costs with age of diesel power indicate an economic life of but 12–14 years for road power and about 18 years for yard power. The road locomotives of this type rebuilt or remanufactured within the past few years have been between 11 and 16 years old. Such rebuilt equipment must appear on the books as new units, for by a ruling of the I.C.C., when more than 50 per cent of the original cost is spent in any one year for repairs, that equipment must be retired and charged to the depreciation reserve.

It is becoming apparent that the depreciation charges included with the present operating expenses are not adequate to properly maintain the equipment depreciation reserve, and that in some cases the diesel retirements may have to be charged to the profit and loss account.

The evidence is now rather well established that the diesel locomotive has about one-half the service life of a steam or electric locomotive in the same service.

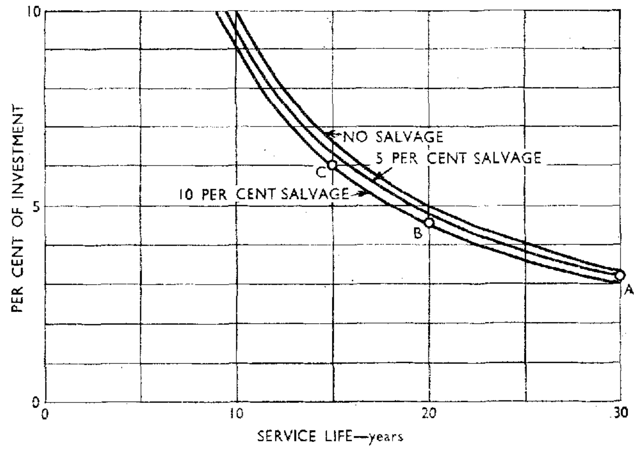



*Fig. 14. Annual depreciation charge in per cent of investment*

A Steam and electric locomotives.
B Yard diesel locomotives.
C Road diesel locomotives.

The annual depreciation charge, on a 'straight line' basis becomes larger as the service life decreases, as shown in Fig. 14. Depreciation rates used in this study are 3·16 per cent for all steam and electric locomotives; 6 per cent for all road diesels, and 4·5 per cent for yard diesels.

The advantage of equipment having a long economic life is apparent.

## INTEREST CHARGES

Interest on the unamortized cost of equipment, while not an item of operating expense, is a proper item to be considered in an economic study of motive power. A conservative rate of 2 per cent of the investment, per year, over the service life is used in this study.

Taxes and insurance are additional fixed charges to be considered. These charges are relatively small, and are not uniform on all the railways, nor isolated in the statistics. They have been omitted in this study.

## INVESTMENT IN MOTIVE POWER

The changes in investment in locomotives on the class I railways from 1941 to 1957 are shown in Fig. 15. This information is unavailable in the I.C.C. statistics prior to 1941. Although the total number of *locomotives*, as distinguished from *units*, in 1957 was less than one-third the number in 1941, the total investment has increased 2·4 times. In 1957, the investment in road diesel motive power was $2760 million, and for yard diesel power, $1120 million.

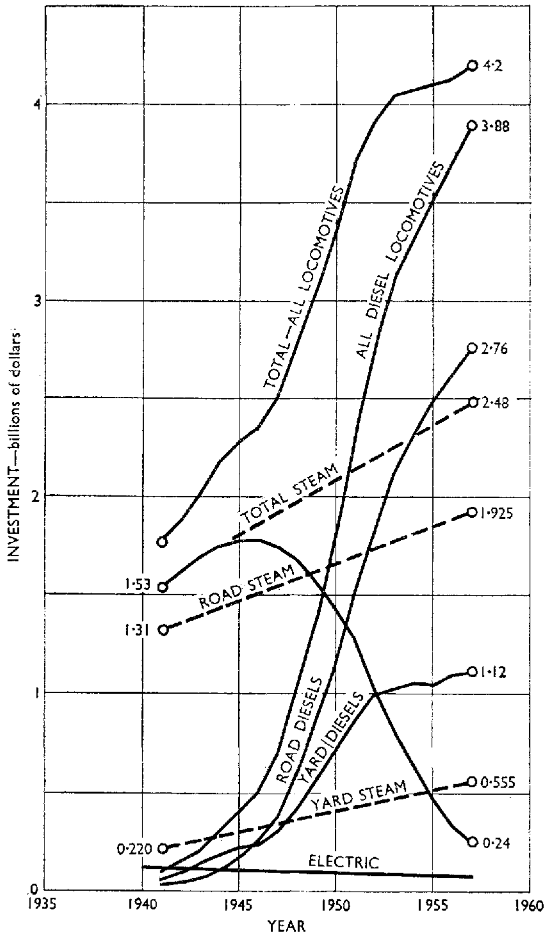



*Fig. 15. Investment in locomotives, all class I railways*

A large increase in investment for motive power servicing facilities, shops, engine houses (sheds), water and fuel stations, has also been made since 1941, shown in Fig. 16, amounting to more than $400 million.

The calculated hypothetical investment for the equivalent number of modern steam locomotives required to perform the service of diesel locomotives in 1957 is shown by the light broken lines in Fig. 15 as $1925 million for road locomotives, and $555 million for yard locomotives*.

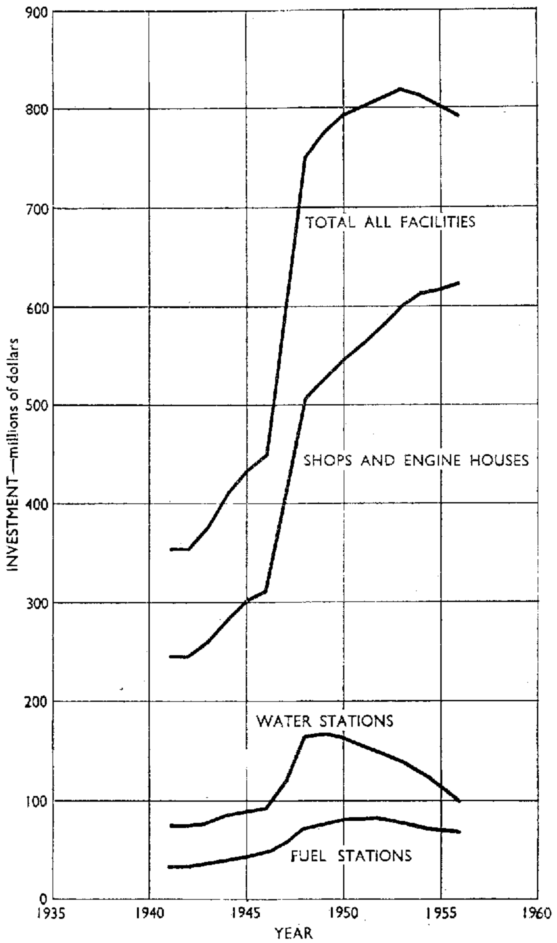



*Fig. 16. Investment in motive power facilities*

All investment costs have been influenced by the 'inflation factor' previously mentioned.

The value of long-life investments is enhanced during periods when the currency is being devaluated.

* *See the Appendix for method of calculation.*

# Part II: Economic Results of Diesel Electric Locomotive Operation

### THE CHANGE FROM STEAM TO DIESEL MOTIVE POWER

The diesel electric locomotive made its initial appearance on the United States railways in yard service in 1925, but fewer than 100 such units were acquired during the next ten years. By the end of 1939, there were about 435 diesels in yard service and about 90 in road service—too few to have any noticeable effect on the general railway economy.

After the 1939–45 war, the automotive industry started an active campaign to sell the diesel locomotive to the American railways. The time was most opportune because of the age and general worn-out condition of the steam motive power.

The first road diesels were used in preferred passenger service on long runs, and on lines having stiff gradients. It was quickly found that in such service this new motive power could be used to the limit of its availability, which was quite high.

High annual milages per unit were being made. Grades could be negotiated without the former 'helper' service required. Fuel costs were low, with diesel oil then at 4 cents per gallon. Thermal efficiencies were about four times better than steam in road service, and up to ten times better in yard service. Maintenance costs of this new power compared with the old steam power were quite low.

The steam locomotive almost immediately became outmoded by the testimony of its former manufacturers, then all competitively engaged with the automotive industry in the manufacture of diesel power. About 8000 diesel locomotives had been acquired prior to 1949. During the years 1949–52, more than 12 500 units were acquired; and since 1952, about 7000 more have been acquired up to the end of 1957. No steam locomotives have been built in the United States since 1953. One of the largest manufacturers stopped building steam locomotives in 1948.

The class I railways are all operating today with most of their motive power relatively new, compared with that in service prior to 1945.

### BASIC DIFFERENCES: STEAM AND DIESEL ELECTRIC MOTIVE POWER

Diesel locomotives have operating characteristics fundamentally different from those of steam locomotives. These must be understood before the operating economies can be appraised. Diesels are more nearly like electric locomotives, limited, however, by the capacity of their own power plant.

The steam locomotive develops its maximum horsepower at near its full speed. At starting, the boiler can generate steam faster than the cylinders can use it. The cylinder pressure and wheel diameter determine the maximum starting tractive force, within the limits of adhesion. At high speed, the boiler horsepower determines the tractive force.

The diesel engine is a constant-horsepower machine. With its electric drive, which is simply a 'torque converter', the engine can be operated at full speed at starting, and nearly its full horsepower can be converted into tractive force, also within the limits of adhesion.

Tractive force and horsepower are related to each other through the speed, by the well-known equation

$$T = \frac{\text{h.p.} \times 375}{V}$$

(where $T$ is the tractive force, lb., and $V$ is the speed, mile/h).

The tractive force therefore falls off rapidly as the speed increases.

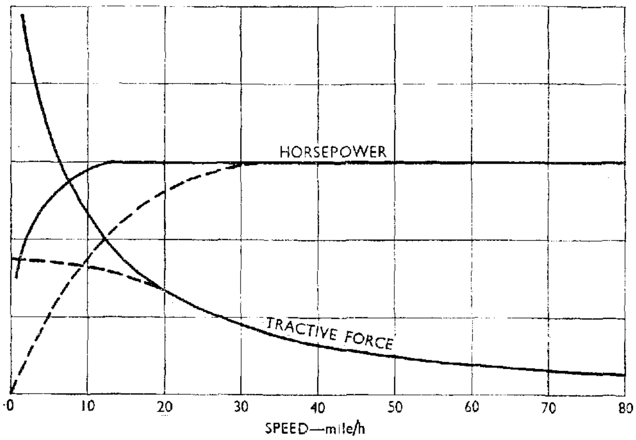



*Fig. 17. Comparative horsepower and tractive force, steam and diesel locomotives of same maximum horsepower*

— — — — Steam.
———— Diesel.

The relative horsepower and tractive force curves of a diesel, and of a steam locomotive having the same maximum horsepower are shown in Fig. 17. The diesel has greater tractive force up to about 25 mile/h. Above this speed both locomotives have equal tractive force. This would be, however, a relatively small steam locomotive.

The comparative horsepower and tractive force curves for a diesel and a steam locomotive having equal weight on drivers are shown in Fig. 18. In this case more horsepower can be built into the steam locomotive than into the diesel. The diesel still has a higher starting tractive force up to about 6 mile/h, but above 20 mile/h the steam locomotive has double the tractive force of the diesel.

American manufacturers have not been able to build a single diesel unit having much more than 2000 h.p., delivered to the rim of the driving wheels. The average diesel locomotive will produce about 14 h.p. per ton of its weight.

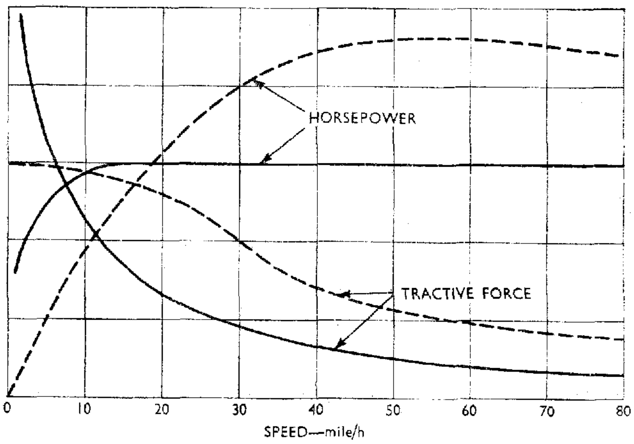



*Fig. 18. Comparative horsepower and tractive force, steam and diesel locomotives of same weight on drivers*

— — — — Steam.
———— Diesel.

The superior performance of the diesel at slow speeds is one reason why it was adopted so rapidly in switching and yard service, where speeds average but 6 mile/h. The diesel became popular also on the railways having heavy mountain grades, because by slowing down, the diesel can increase its tractive force to a greater extent than can a steam locomotive.

Starting tractive force, however important, is but a short part of the time of the total road performance. Horsepower is required for speed, and single diesel units cannot produce the horsepower that modern steam or electric locomotives can supply in single units.

The tractive force rating usually given for any locomotive is that for starting. This can be quite misleading in the comparison of types, for it overrates the ability of the single diesel unit. The important tractive force required in road service is that for accelerating and moving the train load at the schedule speed. This requirement is independent of type of motive power. Any locomotive can usually keep moving any train it can start. The criterion is, 'Can it bring that train up to the desired speed, and in the desired time?'

## THE TRUE NUMBER OF LOCOMOTIVES

The I.C.C. statistics for 1957 show that it required 2·08 diesel units per average passenger train, and 2·59 diesel units per average freight train. The average for all trains in road service was 2·41 units. The tractive force of any of these combinations *at the running speed* is well within the capacity of most of the modern steam power remaining in either passenger or freight service in 1957.

This leads to the interesting conclusion that it has required more motive power units of the diesel type to perform the present transportation service on the class I railways than would have been required had modern steam locomotives been purchased in their stead. The actual number of diesel *locomotives* in road service in 1957 was not the 18 959 diesel *units* given in the statistics, but was this number divided by 2·41, which is 7870 locomotives.

The true reduction in number of locomotives caused by the traffic losses, and the changes in operating patterns and methods made to meet these losses is shown in Fig. 5 by the dotted graph, which departs from the solid graph for numbers in 1941 and drops to 10 330. This is the theoretical total number of all road locomotives in service in 1957.

## AVAILABILITY: DIESEL AND STEAM LOCOMOTIVES

New diesel locomotives have an availability as high as 90 per cent. Modern steam power has an availability of at least 60 per cent when new. The availability of all motive power is reduced as it becomes older.

Availability is of no great value beyond the utilization that can be made of the motive power. The high utilization made of the diesel power in selected service during its earlier years has been reduced, as diesels increased in numbers.

This is indicated in Table 3 by the approximate annual milage shown for diesel locomotives, which dropped from 101 000 in 1953 to 86 500 in 1957.

To establish a basis for comparison of operating costs and investment, it may be assumed that the number of modern steam locomotives equivalent to the road diesel *locomotives* is inversely proportional to their availabilities. This assumption is favourable to the diesel.

Then 7870 times 1·5 or 11 800 steam locomotives would be the hypothetical equivalent of the 18 959 diesel units in road service in 1957.

## EFFECT OF DIESEL OPERATION ON NUMBER OF TRAINS AND TRAIN-MILES

It is claimed that the large reduction in the number of trains as indicated by the reduction in train-miles since 1946 in Fig. 7 has been due to the multiple-unit operation of diesel units, which has enabled the operation of longer and faster trains in both freight and passenger service. This in turn has allowed a large reduction in the number of trains, thereby making large savings in operating labour. This claim is given great emphasis by the diesel manufacturers, and considerable credence by the general public.

It does seem plausible to relate the large drop in train-miles after 1946 to the known substitution of diesels for steam, as shown in Fig. 5, during this same period. Nevertheless, a little analysis will show that these two facts are not at all related to each other.

Consideration of Fig. 3 shows that at least two diesel units are required to perform the service of the largest steam power installed between 1920 and 1930, and up to 5 units to equal the largest steam locomotives built after 1930. Ever since the introduction of diesel motive power in road service, the multiple-unit operation of two or more units has been a necessity to equal the horsepower of the steam

*Table 3. Diesel operating statistics 1953–57*

All locomotive- and train-miles in millions

| | 1953 | 1954 | 1955 | 1956 | 1957 | 1953 against 1957 | |
|---|---|---|---|---|---|---|---|
| | | | | | | Increase, per cent | Decrease, per cent |
| *Freight* | | | | | | | |
| Diesel locomotive-miles | 375 | 391 | 428 | 446 | 438 | 17 | |
| Diesel unit-miles | 921 | 964 | 1054 | 1113 | 1134 | 23 | |
| Units per locomotive | 2·46 | 2·46 | 2·46 | 2·50 | 2·59 | 5·3 | |
| Diesel train-miles | 358 | 374 | 409 | 424 | 417 | 16 | |
| Total freight train-miles | 492 | 447 | 476 | 475 | 447 | | 10 |
| Cars per train | 64·0 | 65·6 | 66·2 | 67·6 | 70·0 | 9·3 | |
| Gross tons per train | 2870 | 2900 | 3000 | 3100 | 3220 | 12·3 | |
| Train-miles per train-hours | 18·2 | 18·7 | 18·6 | 18·6 | 18·8 | 3·5 | |
| *Passenger* | | | | | | | |
| Diesel locomotive-miles | 244 | 251 | 244 | 243 | 233 | | 5 |
| Diesel unit-miles | 493 | 506 | 497 | 502 | 483 | | 2 |
| Units per locomotive | 2·02 | 2·02 | 2·04 | 2·07 | 2·08 | 3 | |
| Diesel train-miles | 239 | 246 | 239 | 239 | 229 | | 4 |
| Total train-miles, locomotive propelled | 302 | 288 | 271 | 261 | 245 | | 23 |
| Total passenger train-miles | 333 | 317 | 299 | 290 | 275 | | 21 |
| Cars per train | 10·0 | 9·7 | 10·1 | 10·3 | 9·8 | | 2 |
| Train-miles per train-hours | 39·1 | 39·5 | 39·8 | 40·0 | 40·2 | 3·5 | |
| *Total* | | | | | | | |
| Diesel locomotive-miles | 619 | 642 | 671 | 689 | 671 | 9 | |
| Diesel unit-miles | 1413 | 1470 | 1551 | 1615 | 1617 | 14·5 | |
| Units per locomotive | 2·29 | 2·29 | 2·31 | 2·35 | 2·41 | 5 | |
| Train-miles, all | 826 | 764 | 776 | 766 | 722 | | 15 |
| *Diesel* | | | | | | | |
| Average miles per locomotive, thousands | 101 | 95·0 | 93·5 | 91·5 | 86·5 | | 17 |

locomotive replaced. Multiple-unit operation is not a virtue, except where 'double-heading' or 'helper service' can be eliminated, or reduced. It does provide also for some flexibility for maintenance.

There are two possible explanations for the large drop in train-miles since 1946:

(1) The increase in cars-per-train and in tons-per-train shown in Fig. 8 could be caused by the consolidation of two or more trains into one much longer train, with a reduction in the number of train-miles. This would call for an increase in the number of diesel units per locomotive nearly proportional to the reduction in the number of train-miles, in order to justify the above claim.

(2) The same increase in cars-per-train and in tons-per-train, with the same reduction in train-miles could be due to the withdrawal of the many short trains on branch lines and to loss of the short-haul traffic on the remaining trackage. The remaining traffic would be handled by trains of no greater maximum length than before, yet the total cars-per-train and tons-per-train would show a rise in Fig. 8 due to the elimination of the shorter trains which made up the average. In this hypothesis, the number of diesel units per locomotive would show only a slight increase.

Data on diesel unit-miles are not available prior to 1953. In Table 3 are shown the diesel operated train-miles, locomotive-miles, and diesel unit-miles in freight and in passenger service for the years 1953–57 inclusive. Freight train-miles decreased 10 per cent during this period, gross tons per train increased 12·3 per cent, and cars per train 9·3 per cent. Units per locomotive, however, increased only 5·3 per cent. These statistics indicate improved operating skill in the loading of cars and trains, but this is independent of the type of motive power.

In passenger service, train-miles (locomotive-propelled) decreased 23 per cent, cars per train decreased 2 per cent, but units per locomotive decreased only 3 per cent.

It is quite obvious from Table 3 that the data fits explanation (2) rather than explanation (1), and that this entire claim for the diesel is invalid.

The average of 10 cars per train in passenger service, and 70 cars or 3200 gross tons per train in freight service are no greater than could have been handled by any average steam or electric locomotive remaining in service in 1957.

Table 3 also indicates that the diesel, *per se*, has not been responsible for the slight increase in average speed shown. It is probable that this increase is due to the elimination of slower trains and intermediate stops, together with improved dispatching and signal systems. Also, the elimination of passenger trains allows faster average freight train speeds.

## ANALYSIS OF LOCOMOTIVE OPERATING EXPENSE ITEMS

### Repairs

*Road locomotives*

The graph of repair costs shown in Fig. 12*a* is a function of numbers, age, and type of motive power.

The ordinates of the 'number' curve and the corresponding ordinates of the 'age' curve in Fig. 5 were multiplied together to make a composite curve of both these factors. This composite curve and the repair cost graph are compared in Fig. 19, which leave little doubt that these two factors dominate in repair costs.

The rise in repair costs with age for steam locomotives has been recognized for many years. In Fig. 20 is shown the result of a study of steam locomotive repair costs which appeared in a statement of the Federal Co-ordinator of Transportation in 1934. This graph is based on a repair cost survey covering about 66 per cent of all the steam locomotives of all sizes and types in use on the class I railways during 1927–29.

The rise in repair costs with age for diesel locomotives is often debated and denied on the basis that after 'heavy repairs' the running repair costs drop to former low levels. When the costs of these 'heavy repairs' are spread *pro rata* over the intervening period between such heavy overhauls, the total costs of repairs will be found to rise continuously with age.

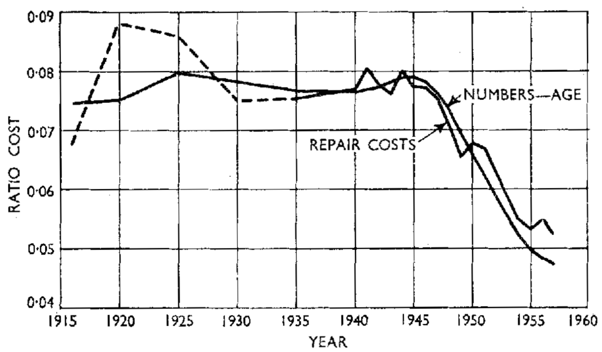



*Fig. 19. Road locomotive repair costs, all class I railways compared with the numbers–age graph*

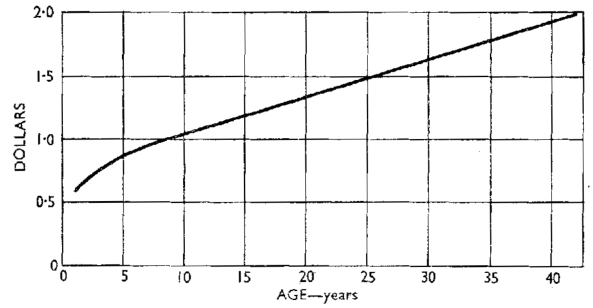



*Fig. 20. Cost of steam locomotive repairs in dollars per 10 000 h.p.-mile unit*

From report of Federal Co-ordinator of Transportation, June 1934. Costs are approximately 1929 level.

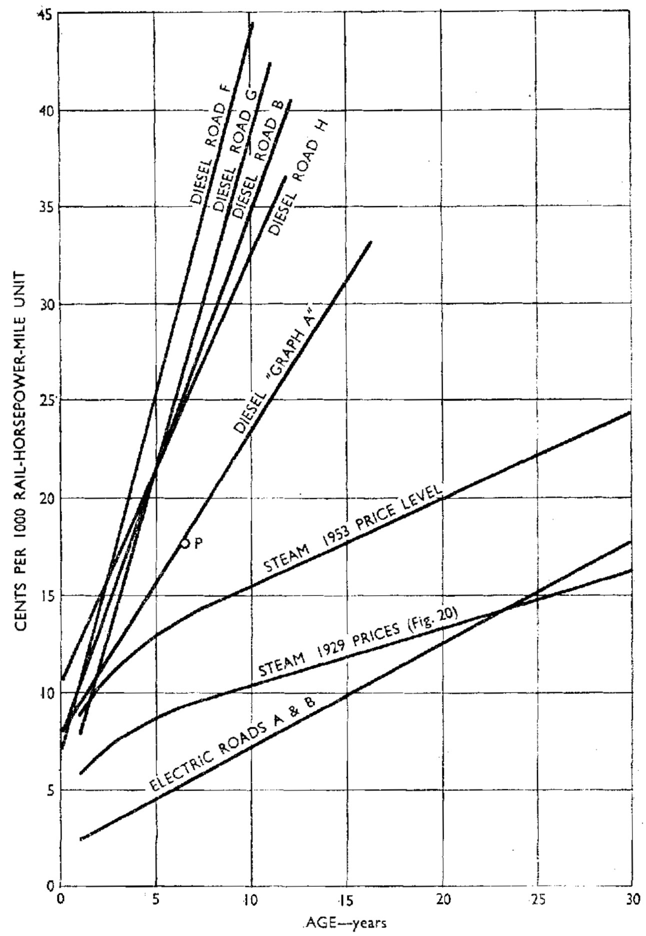



*Fig. 21. Comparison of steam, diesel, and electric locomotive repair costs on basis of 1953 price level*

In Fig. 21 are shown comparative repair costs in cents per 1000 rail-h.p.-miles, related to age, for steam, diesel, and electric locomotives. The steam curve is the 'Co-ordinator's Curve' from Fig. 20, adjusted from 1929 to 1953 price levels. The electric graph is from costs on two class I railways operating similar electric motive power designed around 1938. The diesel graphs are from studies made in 1955 of repair costs related to age of more than 3000 diesel units of all ages up to 12 years (on seven class I railways). All costs are shown in 1953 price levels.

The graph marked A is based on calculated diesel repair costs for an economic life of 15 years. Point P is the calculated repair cost in cents per 1000 rail-h.p.-mile incurred by all the road diesel power on the class I railways in 1957, adjusted to the 1953 price level. The average age of this diesel power was 6·6 years in 1957. The point P falls almost exactly on the graph A, at 17·8 cents.

Steam repair costs at age 6·6 years are 78 per cent of diesel repair costs shown in graph A. Road diesel repair costs in 1957 were $377·4 million. Equivalent steam power of the same age, to perform the same number of horsepower-miles, would cost $377·4×0·78 or $293 million.

## Yard locomotive repair costs

It can be shown that the graph of repair costs in Fig. 13*b* also follows a composite 'number-age' curve made from data in Fig. 6. In 1957, diesels in yard service had an average age of 9 years. The ratio of steam to diesel costs (graph A) in Fig. 21, in the 9th year is 0·695. Yard diesel repair costs in 1957 were $76 million. Steam locomotives of same number and age would cost $76×0·695 or $52·8 million.

## Fuel costs

The graph for fuel costs in Fig. 12*a* is a function of numbers, type of motive power, and trends in the fuel market. It shows a greater drop in the final 5 years than shown in the repair cost graph. Without question this is due to the change in type of motive power.

Diesels in road service have an average thermal efficiency of about 26 per cent, compared with 6 per cent for steam. In Fig. 22 are shown comparative costs, on a B.t.u. basis, of fuel used by the class I railways between 1939 and 1957. Although diesel oil is a high-cost fuel, the higher thermal efficiency of the diesel engine makes it lower in cost than coal for the same work performed. The cost of diesel fuel used in road service, adjusted for ratio of efficiencies has averaged 79·2 per cent of coal costs on a B.t.u. basis during the past 10 years.

The cost of fuel for all road locomotives was $366·7 million in 1957, exclusive of $23·2 million for electric power. Diesels were 88 per cent of total road power, using this proportion of the fuel cost, which is $323 million. This is 79·2 per cent of the cost of coal for equivalent service, which would have been $408 million, making the total fuel bill $451·7 for equivalent steam operation.

In yard service, with lower load factors and higher stand-by losses, the ratio of efficiencies is approximately 15 per cent for diesel and 1·5 per cent for steam, or ten to one. Diesel fuel costs, adjusted for ratio of efficiencies in yard service, have averaged 34·3 per cent of the cost of equivalent coal on a B.t.u. basis during the past 10 years.

Diesel fuel cost $40·5 million for yard operation in 1957. This is 34·3 per cent of the cost of $118 million for coal for the same service with steam locomotives. Diesel operation was 95 per cent of the total yard operation. The total fuel and power bill was $43·4 million in 1957. With equivalent steam operation, this would have been $121·4 million.

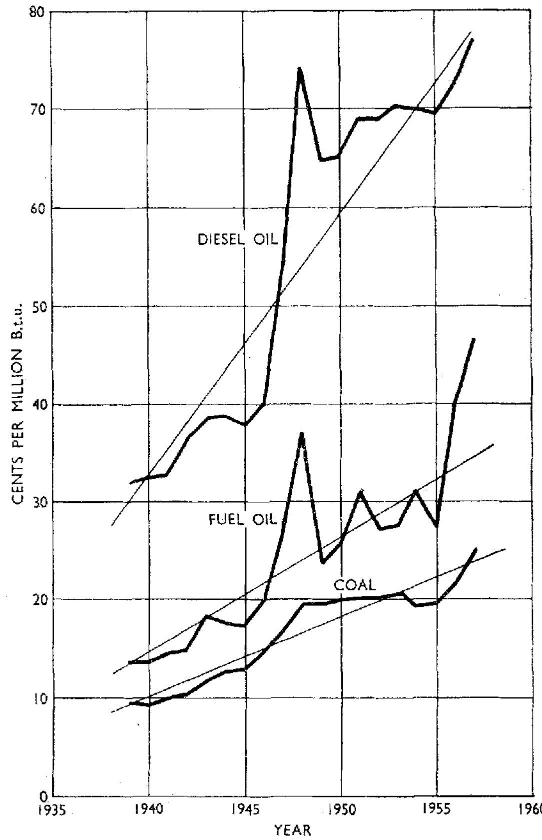



*Fig. 22. Comparative cost of fuels used on class I railways, on B.t.u. basis*

Assumed B.t.u. content: coal 12 500 per lb; fuel oil 149 000 per gal; diesel oil 138 000 per gal.

## Engine men

The graph for engine men in Fig. 12*a* is a function of the reduction in number of locomotives, the weight on drivers, and increase in wage rates.

In Fig. 8, locomotive-miles per train-mile shows a reduction from 1·07 in 1940 to 1·02 in 1957. This 5 per cent reduction is probably in 'double-heading' and 'helper service', and can be credited to diesel operation. This can also mean a 5 per cent reduction in engine men.

Engine men in road service cost $388·3 million in 1957. On the above basis, they would have cost 5 per cent more with steam operation, or $407·7 million. No statistical data are available for the additional cost of engine men with diesel operation due to increased weight on drivers.

No savings in the cost of engine men ($242·7 million) is indicated in yard service. This is one example where savings which might be made with diesel or electric motive power cannot be made because of working agreements. The second engine man (fireman) performs no essential function on switching locomotives of these types. Nearly $100 million could be saved annually by their elimination.

### Engine house expenses

The graph for engine house expenses in Fig. 12*b* reflects largely the reduction in number of locomotives, branch line terminals, and traffic and, to a lesser extent, the change in type of motive power. The rise between 1941 and 1954 reflects war traffic and operation of dual types of power.

In the graph for this item in yard service, shown in Fig. 13*b*, the downward trend since 1950 must be assigned to the change in type of motive power. Costs in 1950 are the same as in 1941, at 0·0055 as a ratio cost. In 1957 this ratio cost was 0·0036, a reduction of 0·0019, which amounts to $15·6 million.

The ratio of road diesel units to yard units in 1957 was 2·3 and the ratio of hypothetical steam road locomotives to road diesel units is 0·623. It may be assumed that the savings in engine house expenses in road service for diesels over steam would be $\$15{\cdot}6\times2{\cdot}3\times0{\cdot}623$, or $22·3 million. This is about $4 million greater than would be estimated by taking the drop shown in Fig. 12*b* for the period 1940–57.

### Water

There can be no question that the diesel is saving almost the entire cost of water. Assuming the cost of $5·3 million in 1957 was for the 1942 steam locomotives still in road service, the cost of water for 11 800 steam locomotives would be $5·3 times the ratio of 11 800 to 1942 or $32·2 million.

In yard service, there were 455 steam locomotives still in service in 1957 and the water cost was $1·1 million. Had all the 8227 yard diesels been replaced with steam, the water cost would have been $1·1 times the ratio of 8227 to 455, or $19·8 million.

### Lubricants

In the diesel locomotive, some of the lubricants are consumed with fuel. The costs of lubricants are higher than for other types of motive power.

Most lubricants are products of petroleum, which has increased in cost 2·4 times since 1940 (see Fig. 22). Lubricants cost $7·5 million for 33 700 steam and electric road locomotives in 1940. The equivalent steam and electric locomotives in 1957 would be 14 300, or 42·5 per cent of the 1940 number. The costs of lubricants in 1957 on the basis of above assumptions would be $\$7{\cdot}5\times2{\cdot}4\times0{\cdot}425$ or $7·7 million, a very slight increase compared with the actual cost in 1957 of $27·2 million.

Lubricants for yard service locomotives cost $1·3 million in 1940. Multiplied by the assumed rise in cost, this would be $3·1 in 1957, compared with the actual cost of $4·4 million.

### Other locomotive supplies

The cost of other supplies has not been materially affected by the change in type of motive power. These costs were $8·8 million in 1957, for road locomotives, and $2·2 million for yard power.

### Summary of savings with diesel electric motive power

The summary of savings for all the items of locomotive operating expense is given in Table 4, together with the comparative total investment and the fixed charges. This shows that the diesel locomotives, *in toto*, made operating savings of $137·0 million compared with the assumed equivalent steam operation, on the basis of 1957 costs. For each year in retrograde prior to 1957, the savings would be correspondingly less.

The total investment is $1·8 billion greater for the diesels, and the fixed charges are $165·5 million greater than for the equivalent steam locomotive investment, exceeding the operating savings by $28·5 million.

In road service alone, the investment in diesels and prorated facilities is $1135 million more than for the equivalent modern steam power. Diesel operation is $49·7 million cheaper than steam operation, but fixed charges amount to $71·6 million more than the operating savings.

In yard service alone, the investment in diesels and prorated facilities is $665 million more than with equivalent steam power. Diesel operation is $87·3 million cheaper than with steam operation, and fixed charges are only $44·2 million greater than for steam, making a net overall saving of $43·1 million. This is 6·6 per cent return on the $665 million increase in investment.

Quite obviously, the savings realized by diesel operation in yard service have not been realized in road operation. It is clear in the development of the analysis just why this has not been possible. Nothing can be found in this analysis to justify the claim so often made that the diesels are producing a 30 per cent return on their investment. If this were true, such large savings would become apparent in lower operating ratios, and in increased earnings.

## EARNINGS

Each one of the class I railways is a private enterprise operated primarily for a profit. In Fig. 23 are shown the total capital stock outstanding, common and preference, together with the amount of stock paying dividends, and the total amount of dividends paid, for all the classes I and II railways. It is clear by comparing with Fig. 1 that earnings are closely related to traffic.

The increase in dividends since 1940 does coincide with the change in type of motive power; but to relate these two facts is wholly unwarranted. Earnings for this period are lower, with a greater traffic volume, than in the period 1925–30, when all the motive power was steam and electric.

## OTHER CONSIDERATIONS

Although the diesel is a cleaner type of motive power than the steam locomotive, it still requires expensive ventilating equipment in long tunnels and is excluded from operating in large enclosed or built-over urban terminals. Any savings resulting from the through diesel operation of former short electrified sections in tunnels are included in the general statistical data studied.

Diesel locomotive design has proved, as electric locomotive design has proved in Europe, that high speeds can be safely made with locomotives having small-diameter driving wheels without the necessity of idle leading axles. Thus all of the locomotive weight may be used for adhesion. Small-diameter driving wheels, and lower centre of gravity do produce greater track and rail stresses. Rail 'burns' from slipping driving wheels are more prevalent with diesel operation than with former steam. It is often claimed that the change from steam to diesel has reduced

*Table 4. Comparative costs diesel operation* versus *operation with equivalent modern steam on basis of 1957 costs*

All figures in millions of dollars

| | Diesel | | Steam | |
|---|---|---|---|---|
| | Cost | Saving | Cost | Saving |
| *Road power* | | | | |
| Repairs: | | | | |
| Diesel and equivalent steam | 377·4 | | 293 | 84·4 |
| Other | 51·6 | | 51·6 | |
| Fuel: | | | | |
| Diesel and equivalent steam | 366·7 | 85 | 451·7 | |
| Other | 23·2 | | 23·2 | |
| Engine men | 388·3 | 19·4 | 407·7 | |
| Engine house expense | 104·2 | 22·3 | 126·5 | |
| Water | 5·3 | 26·9 | 32·2 | |
| Lubricants | 27·2 | | 7·7 | 19·5 |
| Other locomotive supplies | 8·8 | | 8·8 | |
| Total road locomotive expense | 1352·7 | 153·6 | 1402·4 | 103·9 |
| Net operating savings | | 49·7 | | |
| *Yard power* | | | | |
| Repairs: | | | | |
| Diesel and equivalent steam | 76 | | 52·8 | 23·2 |
| Other | 8·1 | | 8·1 | |
| Fuel: | | | | |
| Diesel and equivalent steam | 40·5 | 77·5 | 118 | |
| Other | 3·4 | | 3·4 | |
| Engine men | 242·7 | | 242·7 | |
| Engine house expense | 29·9 | 15·6 | 45·5 | |
| Water | 1·1 | 18·7 | 19·8 | |
| Lubricants | 4·4 | | 3·1 | 1·3 |
| Other locomotive supplies | 2·2 | | 2·2 | |
| Total yard locomotive expense | 408·3 | 111·8 | 495·6 | 24·5 |
| Net operating savings | | 87·3 | | |
| Total expense, road and yard | 1761·0 | | 1898·0 | |
| Total net operating savings | | 137·0 | | |
| *Investment* | | | | |
| Road locomotives | 2760 | | 1925 | 835 |
| Yard locomotives | 1120 | | 555 | 565 |
| Total locomotives | 3880 | | 2480 | 1400 |
| Facilities (pro-rated 300 road, 100 yard) | 400 | | | 400 |
| Total investment | 4280 | | 2480 | |
| Net saving in investment | | | | 1800 |
| *Fixed charges* | | | | |
| Depreciation of equipment: | | | | |
| Road | 165·6 | | 61·0 | 104·6 |
| Yard | 50·4 | | 17·5 | 32·9 |
| Interest on undepreciated equipment: | | | | |
| Road | 55·2 | | 38·5 | 16·7 |
| Yard | 22·4 | | 11·1 | 11·3 |
| Total fixed charges, equipment | 293·6 | | 128·1 | 165·5 |
| Total, all charges road | 1573·5 | | 1501·9 | 71·6 |
| Total, all charges yard | 481·1 | 43·1 | 524·2 | |
| Total, all charges road and yard | 2054·6 | | 2026·1 | 28·5 |

Return on differential in investment for yard operation, 6·6 per cent.

the cost of track maintenance. Maintenance of way costs have been carefully examined over the period studied to verify this claim. No indication can be found that the change in type of motive power has produced any savings in this field. Such costs have increased slightly.

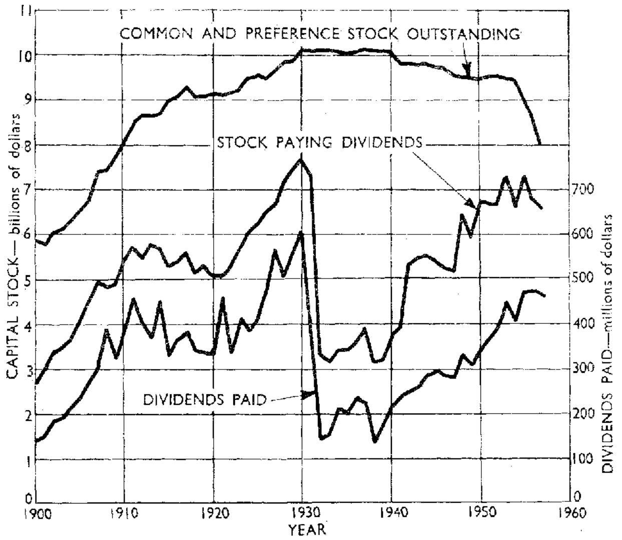



*Fig. 23. Capital stock and dividends paid, all classes I and II railways*

During the period since 1940, railway management has been beset with many serious problems, including increased competition with subsidized carriers, loss of traffic, rising costs, and higher operating ratios. To solve these problems management has changed operating methods, made large investments in new motive power, cars, and facilities, in improved freight terminals and yards, in new signals and dispatching systems, and in general improvements in way, and in maintenance methods.

In this period the total investment in the classes I and II railways has been increased $9 billion, or more than one-third. Of this increase, motive power and facilities have accounted for $2·5 billion; new cars, $4 billion; with all other improvements accounting for the balance of $2·5 billion. The investment in diesel motive power has been the most spectacular, and has had the greatest amount of publicity.

To claim, however, that the diesel is responsible for all the operating economies made since 1935, or even 1945, is to belittle the skill of management, and to expropriate the credits due to these other investments.

Such claims cannot be made equitably for any one factor. All have made their contribution.

This study simply states that the all-embracing economies claimed for diesel motive power on the class I railways of the United States, as a whole, do not appear in the statistical record.

The diesel locomotive has not 'revolutionized' American railway economics. In road service, diesel motive power has added to the financial burden of the railways.


## ACKNOWLEDGEMENTS

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Tables 1*a*, 2*a*, 3, and diesel costs in Table 4 are compiled directly from the I.C.C. statistics. Tables 1*b* and 2*b* are calculated from Tables 1*a* and 2*a* respectively.

Figs. 1, 2, 4–10, 15, 16, and 23 are plotted from I.C.C. statistical data.

The average age in Figs. 5 and 6, the ratio costs in Figs. 11, 12*a* and *b*, 13*a* and *b*, and 19, and fuel costs in Fig. 22, are calculated from I.C.C. statistics.

Fig. 3 is compiled from locomotive encyclopaedias and other published data relative to steam and diesel locomotive characteristics.

Diesel and electric locomotive maintenance costs shown in Fig. 21 are from studies made in 1953 and 1955 in which the author collaborated.

Depreciation costs given in the I.C.C. statistics were not always itemized for the different types of motive power, and are not used for reasons stated in the text.

Figs. 17 and 18 are from *The Steam Locomotive*, by Ralph P. Johnson, published by Simmons-Boardman in 1945.

## APPENDIX

### HYPOTHETICAL INVESTMENT IN STEAM POWER EQUIVALENT TO EXISTING DIESEL POWER

*Road locomotives*

Existing number of diesels (1957), 18 959 units.
At 1500 h.p. average, 28 500 000 h.p.
These units make 18 959/2·41 or 7870 locomotives.
Assume the number of equivalent steam locomotives is inversely proportional to their availabilities.
Then 7870 × 90/60, or 11 800 steam locomotives will be required.

28 500 000 h.p. × 90/60 is 43 000 000 h.p.

Assume 1953 as average year of purchase.
In 1929, steam locomotives cost approximately $30/h.p.
1929 prices times 1·49 equal 1953 prices.
Steam locomotives would cost $45/h.p.* in 1953, assuming manufacturing would have been continued.

43 000 000 h.p. × $45/h.p. is $1925 million.

*Yard locomotives*

Existing number of diesels in 1957, 8227 units.
At 1500 h.p. average, 12 250 000 h.p.
At $45/h.p., $555 million.

| | | |
|---|---|---|
| Total investment . . . . . | road | $1925 |
| | yard | 555 |
| | total | $2480 million |

* *Actually, the last few steam locomotives made in the United States in 1952 and 1953 did cost approximately this amount.*

# Discussion

**Mr Julian S. Tritton** (*Member*), opening the discussion, said that his first reading of the paper had produced two main impressions: first, how clever statisticians could be in their selection and interpretation of figures; secondly, how dangerous it could be to generalize from specific instances.

Locomotive engineers prided themselves on being able to design a machine to meet very accurately the specific requirements of the operating department. How closely they did that had been demonstrated some years earlier, when comparative trials on British Railways had shown that each locomotive tested was just a shade more efficient when working on its own Region than when pulling the equivalent loads on a foreign section. That was a compliment to the locomotive designer!

Some of those present might remember the comparison which he had given in his Presidential Address to the Institution of Locomotive Engineers*. At that time the ratio of diesel to steam cost per locomotive mile was of the order of 60 per cent. Surely it was that figure (taken from the same source as that given by the author) which had induced American railroad administrations to make their subsequent huge investments in diesels. Yet the author had said that 'No indication can be found that the change in the type of motive power has produced any savings in this field'. It was necessary to be careful there, because if any attempt was made to apply that statement to the entirely different conditions on British Railways it must not go unchallenged by the railway accountants, just as the fruits of the carefully planned diesel programme in the modernization scheme were begining to become apparent. He was thinking of references to it in the lay Press by someone who might take the statement out of its context and use it to the disadvantage of the railway administration.

He saw also that the author agreed with the relative thermal efficiencies of steam and diesel types which he had given in the Seymour Tritton Lecture when he had stated 'Diesel thermal efficiencies were about four times better than steam in road service and up to ten times better in yard service'. That being so, he wondered why that advantage had not shown up in the figures for savings in locomotive operating costs. Without belittling the skill of management, surely locomotive engineers deserved some of the credit? He hoped that in the discussion some locomotive statistician would show who had slipped up in his calculations and where.

* TRITTON, J. S. 1947 *Trans. Instn Loco. Engrs*, vol. 37, p. 200, 'The Challenge to Steam'.

The paper was based on railway statistics, and that gave him an opportunity to renew his plea for greater account to be taken of the cost of *speed* in those statistics. Railways existed to sell transport. Speed was a vital factor in transport. The consigner and the passenger were interested in the *door-to-door speed* of transport. Railway administrations must know the cost of speed when meeting competition from air, road, and sea. Costs per 1000 ton-miles which omitted the speed factor could be very misleading. He suggested that it was time that railway statistics were given a new look and costs were worked out *per 1000 miles per hour*.

The paper came at a very appropriate time, when railway policy and accountancy in Britain were being bandied about by politicians and other imaginary experts. Next time members spoke to their own Member of Parliament they should ask him to look at Fig. 9, which gave the rise and fall of the operating ratio over the past 60 years in the United States of America. It had reached a peak of 0·95 in 1920, when significantly, as the author had pointed out, all the railways were under Federal administration! Politicians should note that.

**Mr C. M. Cock** (*Member*) said that the author's study was based on statistics issued by the Interstate Commerce Commission in the United States of America up to the year 1957, and at the outset he would like to say that he fully agreed with Mr. Tritton on the way in which statistics should be looked at; they should not become masters, but they could be very helpful. When in 1950 a study had been made of more than 50 American railroads, diesel traction was already firmly established, and it had been said then that the cost of diesel fuel for the operation of main-line services was roughly half that of coal, and for shunting rather under one-third. Maintenance and repair costs of main-line diesels were stated to average only one-third to one-half of those for steam locomotives. The American railroads were then so satisfied with diesel locomotives that their acquisitions of them were reaching a peak. There were then, according to Fig. 2, 43 000 locomotives of all types in service, of which he believed some 14 000 were diesels, and those diesels were responsible for nearly half of all the traction required from the total locomotives.

If the result of diesel operation before that time had not been successful with that type of motive power, expansion would or should have been stopped. It must be a fair supposition, however, that American railroad administrations of the time did indeed expand the use of diesels on the economics of the case. They had accumulated vast experience and were fully aware that they were pitting young diesels against elderly steam locomotives. Another very important factor was that the diesels were working under the most favourable traffic conditions for utilization. They had the best of the traffic, but surely as hard-headed business men the railroad administrations made due allowance for all that.

But the author's conclusions, from statistics ending in the year 1957, had led him to deprecate the diesels, mainly on the basis of repair costs. He had stated that those costs were increasing with age and implied that the introduction of diesels had been justified by comparing new diesels with old steam locomotives and that in general in the long term the American railroads had not improved their operating ratio by the use of diesels. His conclusions on current repair costs appeared to be founded on what could not be other than hypothetical figures applied to modern steam locomotives. He claimed a high performance for huge new steam locomotives of up to 7000 h.p. Those assumptions surely could not be nearly so realistic as the more actual operating experience available to American railroads in the years when from time to time they must have reviewed their operating conditions with the object of deciding their future policy on the renewal of their motive power. It was very difficult to understand how new steam techniques could change the case adversely for diesels so drastically in so short a space of time.

Possibly British people were unable correctly to assess American values. He believed, however, that the hypothetical but fundamental assumptions in the Appendix were so wrong as to tip the scales quite unfairly in favour of the steam locomotive as concluded in Table 4. Having British values in mind, it would not be right to accept the assumption that steam locomotives could be built in quantity currently at about only $1\frac{1}{2}$ times what they would have cost 30 years ago and that their depreciation could be at such a far lesser rate than diesels. He thought that Board of Trade statistics would show that the cost would be about three times more. Also, there was no proof that their depreciation was much less than would be allowed for diesels. Moreover the author had chosen a very favourable and perhaps hypothetical top limit of power for a steam locomotive. For a true comparison it should be brought to notice as a fact that since 1957 the horsepower of the largest single-unit American road locomotive of the diesel-electric type had been raised by some 30 per cent to 2600. It seemed to him that some fresh arithmetic on those bases was very desirable and would make quite a difference.

On points of practical operation, he agreed that single-unit steam locomotives of 5000–7000 h.p. could in high-speed service compete successfully with multiple-unit diesels, but, as their total weight was usually not available for adhesion, he would like to be assured that they would have sufficient tractive effort even to start the enormous trailing loads, some up to 10 000 tons, which originated in some of the great American terminals. He would like to have further information about their ability successfully to work with heavy loads on long steep gradients, because, unlike diesels, they were unable to maintain constant horsepower in those conditions. It was also important to take into account the extent to which the modern steam locomotive envisaged by the author could be utilized, like the diesel, as a universal mixed traffic locomotive, equally well for both freight and passenger services.

He had often said that were it not for the diesel, American railroads would have gone bankrupt. That might be an over-statement; full credit must be given to the economies made in other operational departments in an effort to retain solvency in a changing and fiercely competitive era of transportation, but the diesel was entitled to some acknowledgement for a substantial contribution to the general economy. In spite of the author's rather gloomy analysis, the diesel locomotive still seemed to remain the more efficient and economic motive power unit and there was ample evidence that it was becoming permanently established on the railways of the world. He believed that it would survive on merit.

**Mr S. B. Warder** (*Member*) said that as he understood it, the conclusion from the paper was that for the conditions applying in the United States of America and on their main lines dieselization was no cheaper than steam, and the optimum period for retiring locomotives 12–14 years; after 15 years the cost of dieselization increased. That was very contrary to anything Britain had experienced and he could not believe that Britain could justify diesel traction on a similar basis.

He had visited America in 1946 and in 1954. He had studied traction and covered approximately the same ground on both occasions. On the first occasion the dieselization programme was in full spate and locomotives were being turned out rapidly, but the troubles in service were similar to those experienced in Britain in the past two years. A great future was, however, promised, though there were still a few doubters; he had been told once or twice 'Wait a bit! We have something new round the corner; look at our gas turbines.' On his return eight years later they had still been optimistic, but only four locomotives a day were being turned out and various ideas were being propounded for keeping the plants employed. He had then observed the rising costs of repair and operation, and the views which he had expressed at that time were corroborated in the paper to a far greater extent than he had ever imagined they would be. Previous speakers had questioned them, but the trend was there. He had seen the trend in 1954, but it was now, according to the author's statistics, far in excess of anything that he imagined could ever happen. He would like to ask whether the author had any information on the average numbers of unserviceable locomotives, not available for traffic, on any of the important American railroads.

For many years he had been advocating the merits of electrical operation, and it was therefore very encouraging to him to observe that since it became evident that steam motive power was no longer popular in Britain a growing body of technical opinion preferred the alternative of electric rather than diesel for the main trunk routes. The modernization plan looked to electrification as the ultimate objective, with dieselization as a half-way stage. The facts disclosed in the paper were therefore of the greatest importance in Britain. There was accurate knowledge of the operating costs of steam traction and also of electric, and the ratio of the two could be of the order of 2/1, which corresponded to the experience of many other countries. Very many countries—France, Italy, Germany, Belgium, Holland, Sweden, Spain, Portugal, Russia, Japan, China, South Africa, and others were more interested in electrification than in diesel traction and they had decided that for themselves on national grounds. North America seemed to be different in that respect.

The American railroads were offered a 30 per cent saving. That was the figure which was recognized in Britain and there were certain schemes estimated on a similar basis. It had come as a shock to learn that that figure might not be correct. There were, however, circumstances which made dieselization more favourable. Britain had a very high proportion of diesel railcar sets, and planning could be done in such a way that there was more certainty of a return than the statistics in the paper would suggest.

The paper presented one of the most powerful cases he had ever seen for electrification, and a justification for all that was being planned for Britain, and in fact of what other people were doing throughout the world in finding a solution for their problems. Perhaps the author could say whether the realization was growing in the United States that a more effective use of the natural resources of the country might have to be directed on a national basis. If so, what were the prospects of its implementation?

He suggested that when the paper was printed in the PROCEEDINGS the author might include in Figs. 17 and 18 the corresponding characteristic curves for electric locomotives. Fig. 24, taken from Fig. 18, showed what he suggested. The author had not given a scale, but he had taken two locomotives of equal weight, 78 tons, one diesel hydraulic

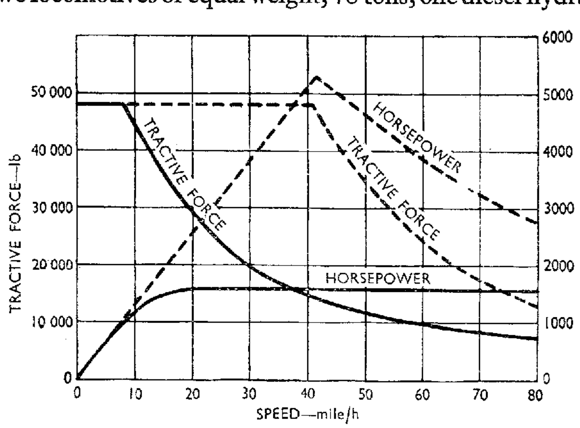



*Fig. 24. Comparative horsepower and tractive force of electric and diesel locomotives of 78 tons adhesive weight*

———— Diesel.
— — — — Electric.

and the other electric. It would be seen that there was the same factor of adhesion and it would be noticed that the tractive effort fell off very rapidly on the diesel after a certain speed, whereas it could be maintained until over 50 mile/h with the electric locomotive, and still further if desired, so that there was all that available horsepower for traction. That was why electrification could provide a punctual and reliable service with locomotives of different characteristics. He was strongly in favour, therefore, of electric traction.

**Colonel Sir Ralf Emerson** (Hastings) said that he approached the paper from the point of view of the general manager of a railway and not from that of a locomotive engineer. On p. 265 the author had stated that 'The evidence is now rather well established that the diesel locomotive has about one-half the service life of a steam or electric locomotive in the same service'. He had stated that the I.C.C. allowed a depreciation rate based on a 20-year life for road power, as against 30 years for the steam locomotive, and had further stated that 'when more than 50 per cent of the original cost'—presumably the original cost of the whole locomotive—'is spent in any one year for repairs, that equipment must be retired and charged to the depreciation reserve'. He had mentioned that road locomotives rebuilt or remanufactured within the past few years had been between 11 and 16 years old. From those statements he himself could only draw the conclusion that the diesel locomotive manufacturers of the United States must be the most super-salesmen of the locomotive world, for he had always understood that the life of a diesel locomotive was the life of the hull, and that the electrical part was long-lasting, so that the only replacement required was that of the prime mover, which could be replaced as a unit by either a new unit or a reconditioned one. It was hard to believe that such a replacement would cost more than 50 per cent of the original cost of the whole locomotive, or that the hull was so weakly designed that it would not stand up to more than 11–16 years of wear and tear. He therefore questioned that statement on p. 265.

On p. 268 the author had stated: 'To establish a basis for comparison of operating costs and investment, it may be assumed that the number of modern steam locomotives equivalent to the road diesel locomotives is inversely proportional to their availabilities'. He had then taken the actual number of diesel locomotives (as opposed to units) in 1957 as 7870. Whilst accepting that basis of comparison for investment purposes only, it seemed to him that the author had omitted consideration of the manning requirements for a steam locomotive, and therefore his statement of operating costs would not be correct, since on his own figure it would require 2·41 crews for steam locomotives as against 1 for a diesel. Each steam locomotive on a train had to be manned, while diesels worked in multiples with one engine crew.

He also suggested that while the comparison of investment costs might be correct for the United States it was certainly not correct for Britain, where the currency had deteriorated much more than had the dollar in the United States. The author's calculation of the hypothetical investment for the equivalent number of steam locomotives in 1957 depended, apart from the assumption to which he had just referred, on the statement in the Appendix that '1929 prices times 1·49 equal 1953 prices'. Reference to the *Economist* gave the value of the dollar in 1929 as 152·4 compared with 100 in 1953. The same source gave the purchasing value of the £ as 94 in 1929 and 42 in 1953 referred to a basis of 100 in 1938. If his arithmetic was correct the equivalent statement for Britain would be '1929 prices times 2·23 equal 1953 prices'.

He appreciated that the paper related to results in the United States, and so, he suggested, it might be more correct to say on p. 274 that 'the all-embracing economies claimed for diesel motive power *in America* did not appear in the statistical record'. Nevertheless he would be very surprised indeed if it had been possible to purchase modern steam locomotives in the United States in 1953 for \$45/h.p., and it was known that, in general, prices in England had risen by considerably more than the factor of 2·23 to which he had referred. That figure of 2·23 was an average and it did not necessarily follow that it was related to the increase in costs for locomotives.

Again reminding locomotive engineers present that he spoke as a former general manager, he would respectfully say to the author that were he still the general manager of a railway he would, even after studying the paper, remain in favour of the replacement of steam by diesel power on general grounds, and not simply on availability and economics.

**Mr T. T. Lambe,** B.Sc. (Eng.) (*Member*), M.I.C.E., said that Fig. 21, comparing repair costs of steam, diesel, and electric locomotives, certainly gave what he would call fantastic results for the maintenance costs of diesel locomotives. It was not clear from the text how diesel graph A was obtained and why it was so much better than B, F, G, and H, relating to various railroads in the United States. He would like to know whether the steam curve in Fig. 21 was the life of 30 years' normal American practice. He understood that on some railroads it was more usual to base the life of the engine on the life of the boiler and that a life of 24 years was normal for main-line engines. That was different from the practice in other parts of the world. In India, for example, it used to be the intention to reboiler after about 17 years, giving an overall life of 35 years, and in the 1920's the opportunity was taken when reboilering to convert from saturated to superheated steam and make changes in the cylinders and motion. Fig. 25 showed what could be done to make allowance for reboilering, assuming cost totals were otherwise accepted. He had taken the author's steam curve for 1953 and extended it for 35 years. Then assuming an availability for the diesel in the ratio of 3/2, the time basis for steam costs had been brought back in the ratio of 2/3, while he had assumed reboilering at half life. Reboilering brought the cost of maintenance back to what it was in the beginning so far as the boiler was concerned. It

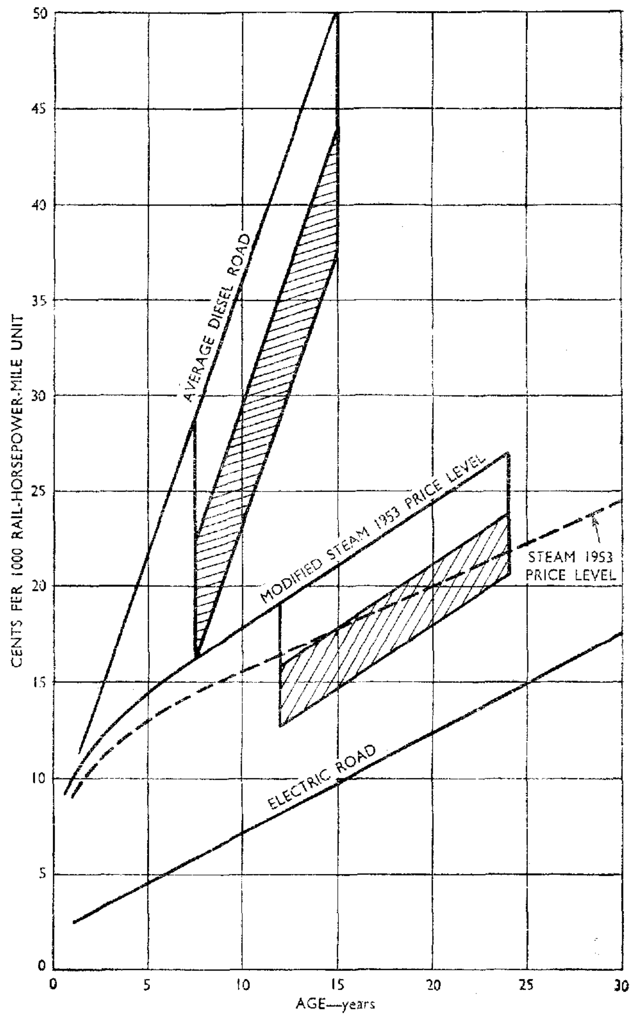



*Fig. 25. Modified comparison of steam, diesel and electric locomotive repair costs on basis of 1953 price level*

seemed that if a life of 15 years was correct for diesel engines it could be assumed that re-engining would be necessary after a half life. In addition to that, if steam locomotives were reboilered it meant an extra capital cost, and so he had included shaded areas to show a rough estimate of the amount to be added in extra depreciation due to having to provide a new engine or a new boiler.

The figures for repair and maintenance on electric locomotives were most interesting. In Fig. 21 the repair and maintenance costs of overhead equipment were, he assumed, omitted. If that were so the complete picture was not represented. Those costs depended so much on the density of traffic that it might not be possible to put a line on Fig. 21 to represent that factor, but it would be useful if a comparative table was given, on the lines of Table 4, where all the other factors, including density of traffic, had been taken into account. Meanwhile, he wondered whether figures were available to show how electric locomotive maintenance compared with the maintenance of the electric portion of diesel-electric locomotives. Although the diesel-electric locomotive had to carry a generator, the electric locomotive on high-tension operation had to carry additional transformers and other electrical equipment, so that the cost of maintenance might not be so very different so far as the electrical portion of the diesel-electric locomotive was concerned, provided that it was designed with robust control equipment, equivalent to that used for electric traction. It would in any case be interesting to know the extent to which the maintenance of electrical equipment on a diesel-electric locomotive compared with that on low-tension electric locomotives.

With regard to capital cost, Mr Cock and Sir Ralf Emerson had already challenged the increase for steam, given in the Appendix, of about 50 per cent, at any rate as applied to a locomotive of average size, and he agreed that over the period in question the price would have increased about three times. Based on that figure, the figures in Table 4, which gave overall costs, would show a saving of $99 million for diesel engines, apart from any reconsideration of comparative operating costs.

**Mr. K. Cantlie** (*Member*) said that he had a number of questions to put to the author, but before doing so, he wished to point out that the steam curve in Fig. 21 was, or was based on, the well-known Baldwin graph published about 1930. That was, he had found from experience, more or less correct for American practice, in which locomotive boilers and chassis were regarded as one, but was not correct for those countries which followed the British method of taking boilers, chassis, and tenders as separate entities with different economic lives.

He would also like to have more information about Fig. 14. He noted that the author had taken a 10 per cent salvage value as the maximum, but after only fifteen years' service, surely a locomotive was worth more than that? He was aware that General Motors and other makers were offering 40 per cent trade-in values for ten-year-old diesel locomotives, but that was rather specially high to make the offer attractive to the railways. It did nevertheless show that the railways realized that diesel locomotives had exceptionally short economic lives when it was remembered that steam locomotives over thirty years old had comprised 40 per cent of American locomotive stock in 1945.

The author was undoubtedly right when he said that the economic life of a locomotive was not necessarily its actual life. The cause was that few, if any, railways had sufficiently accurate accounting methods to decide when it paid them to scrap each locomotive. Furthermore, the matter was confused by the existence of workshops, full employment of the staff, and, frequently, the sheer inability of a railway to afford to replace its locomotives at the right time. A few years earlier he had carried out a world survey and found that over 30 per cent of the world's locomotives should be scrapped as uneconomic as soon as possible, but he had no expectation that that would be done. It was possible for a railway to keep a locomotive going for ever, by replacing all parts as they became worn-out—like the sailor's knife which had had three new blades and two new handles—but it did *not* pay to do it, and the fact that it had been done on such a wide scale might well be the reason why railways throughout the world were in such a parlous financial state.

It had been said that it was a pity the author had not presented the paper ten years earlier. The fact was that it could not have been written before because it was only now that large numbers of main-line diesels had been at work long enough to provide accurate information on operating costs and economic life.

He questioned whether the author was correct when he stated that the American railways had changed motive power without any close investigation of relative costs over a term of years. He had said that there were over 100 diesel locomotives in the United States of America in 1940. He would like to know whether they were scattered all over the country, or concentrated on a few large roads where their performance could be studied.

Referring to the operating ratio in Fig. 9. He himself thought that that was an excellent yardstick of efficiency, and certainly showed little trace of the 30 per cent economies that diesel proponents claimed. But he would ask for the author's assurance that the rising ratios were not caused by any other factor. The fact that traffic was falling throughout the period would certainly cause the ratio to rise to some extent.

The author had compared diesel costs and investments with a hypothetical figure for steam power. He himself had checked that figure from I.C.C. statistics and found it to be more or less right, but he would remind the author that some outstanding steam designs had been built after 1945, and asked whether it would not have been possible to work on their figures rather than a hypothetical figure. For example, the N.Y.C. 'Niagara' Class 4–8–4's, which developed 6600 h.p. at 85 m.p.h. Six of that class had been on intensive trial for a period of three months and had averaged 26 168 mile/month each, or 314 000 mile/year exclusive of shop repair times. Even when shop time was included, that still left an annual average of over 280 000 miles per locomotive per year. That was far more than any operating department could utilize in general service, to judge by the annual I.C.C. figures which were only 86 500 miles per locomotive (diesel, electric and steam) in 1957, and largely nullified any plea that diesels' higher availability could be utilized in practice.

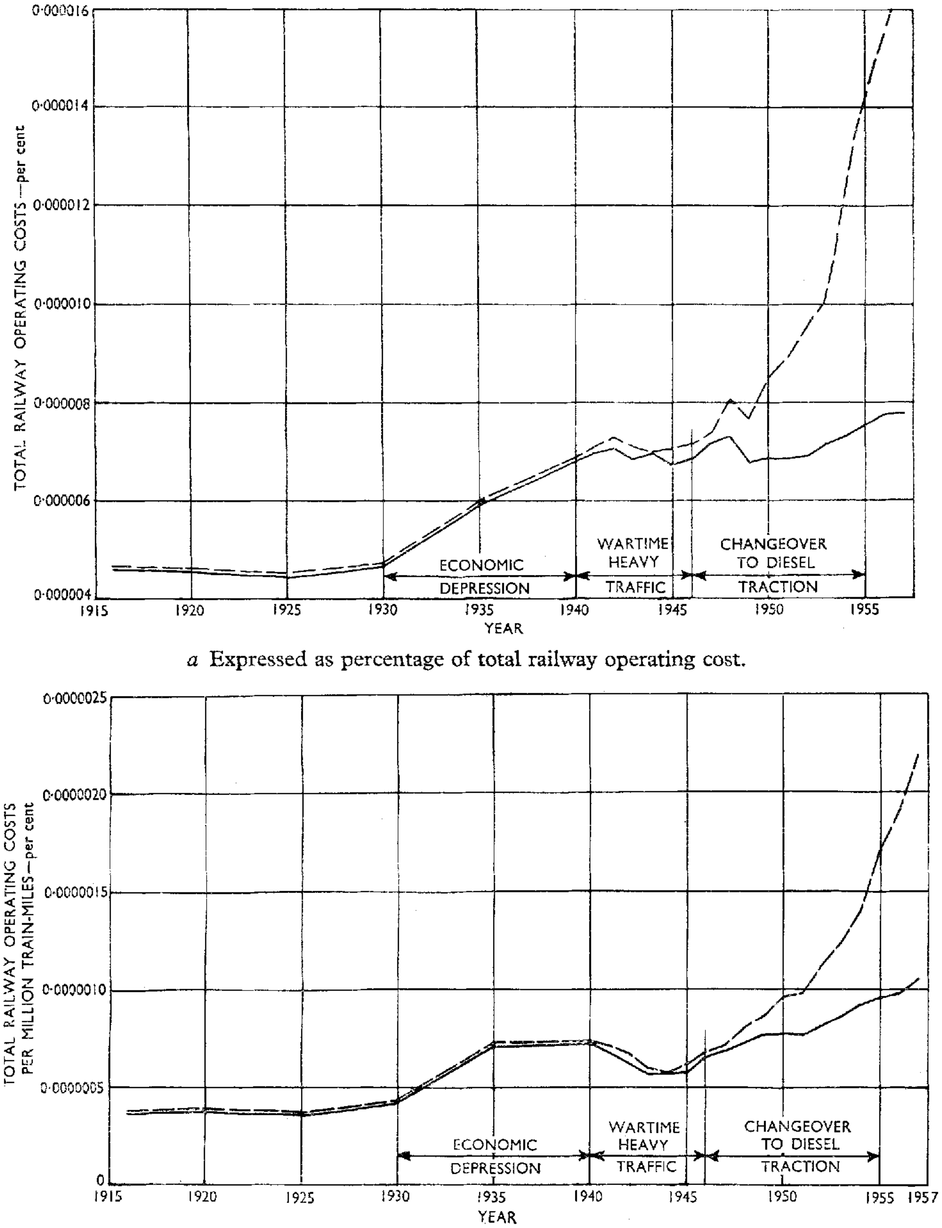
In Table 1b the cost of operating and maintaining locomotives showed a steady decline over the years to 0·1646 in 1957 but two graphs which he had made, Fig. 26, showed that per locomotive per million train-miles there was a large increase. In dollars the figures were still worse. He would like to have the author's comments on that.

On p. 268, para. 4, the author had pointed out the higher horsepower at high speed obtainable from a steam locomotive of equal weight to a diesel, but that would be ineffective if large stretches of road had speed limits.

He thought that an availability of only 60 per cent for a steam locomotive in service was unduly pessimistic. Modern steam power should have an availability of over 75 per cent in favourable circumstances, and with water-treatment and the latest forms of boiler washout, coaling, ash-removal, mechanized lubrication etc., more still.

On p. 270, para. 3, the author had stated that the repair costs of diesel locomotives in Fig. 12*a* were a function of numbers, age, and type of motive power. He himself thought that there was more in it than that. He wanted more information to account for the short economic life of a diesel electric locomotive as compared with a straight electric locomotive. He wondered whether it was high-frequency vibration that caused the body and bogies to deteriorate. He had seen the effects of vibration in other countries. He also wondered whether a shortage of competent diesel fitters was another cause of deterioration, and whether diesel repair costs were invariably higher than those of equivalent steam.

There were a minimum of five men on an American freight train, two of which were on each locomotive. He wondered whether the Brotherhoods would be likely to agree to a reduction in that number. If they did not it appeared doubtful whether the present union consent, in the United Kingdom, to one man would continue, and even if it did, that, which appeared to be the only concrete economy of diesel traction, might be wiped out by a wage increase to compensate for solo operation.




*a* Expressed as percentage of total railway operating cost.



*b* Expressed as percentage of total railway operating cost per million train-miles.

*Fig. 26. Operating and maintenance cost of average main-line locomotives on class 1 railway*

From I.C.C. statistics.

— — — — Cost per actual locomotive, including multiple-heading. ———— Cost per locomotive unit.

He noted from the paper that diesel locomotives were forbidden to operate into enclosed terminal stations. Most London termini were of that type, and he had himself seen several cases of serious smoke and fume trouble. He would like to know whether there was a Federal law about that in the United States.

He had been at King's Cross on one occasion when the train for which he had been waiting was over half an hour late, and during that time five locomotives, three steam and two diesel had also been waiting. The two diesels had kept their engines running, and one of them had let out a tremendous cloud of black smoke. An inspector had spoken to the driver, who had got out and had a look and had said 'We can't have that'. He had then got back into his cab. What he had done he did not know, but the black smoke had suddenly turned to a big cloud of white smoke. The inspector had said 'What do you think you are doing? Electing a new Pope?'

The author had stated that diesel locomotives had caused no reduction in track maintenance costs. He thought that diesel electric locomotives with nose-suspended motors, heavy unsprung weight, low centre of gravity and small wheels might easily prove more costly.

He congratulated the author on a paper which would cause people all over the world to think. He himself, ten years earlier, had firmly believed that diesel traction was in nearly all respects superior to steam, but as an engineer he tried to have no prejudices and to be led by facts. The facts that he had observed in many parts of the world during the past decade had made him realize that though diesel shunters and rail-cars were economically sound investments, the same did not apply to main-line locomotives, except in locations where feed water was scarce or bad, or fuel exceptionally costly. Oil at present was cheap and plentiful, but he wondered how long that would continue.

**Dr F. T. Barwell,** B.Sc. (Eng.) (*Member*), said that the subject-matter of the paper being essentially economic, it might appear strange that a research man should intervene in the discussion. Nevertheless, unless the scientist took an intelligent interest in the economic aspects surrounding his activities he might well find himself dissipating his energies on topics which might yield no social benefit. The study, therefore, of such papers helped in the rational selection of suitable topics for research.

The paper was naturally based on certain accounting conventions, as for example methods of calculating depreciation, which might not be considered appropriate in all administrations; indeed, referring to what was said in the penultimate paragraph on p. 265, what a wonderful railway system would be possible if it was only necessary to serve capital at the rate of 2 per cent! Possibly the application of different interest rates and different accounting methods might result in the computation of a different economic life for the equipment. Nevertheless, the comparison of the relative lives of different forms of equipment should remain valid.

Because no one, not even the author himself, would suggest a return to steam operation, it was obvious that he was really concerning himself with the relative merits of electrification and dieselization. It might therefore be helpful to look at what had happened in certain European countries which were among the pioneers of electrification and which therefore had equipment which had been in service for many years. In one such administration a class of locomotive had been in operation for 40 years, although the estimated life for accountancy purposes was 25 years. As indicated by the author, maintenance costs were high, partly due to the effects of obsolete design, and were running at an annual value which was twice the estimated maintenance cost for a new, modern machine; nevertheless the capital cost of the new machine was so high that those savings would represent only 2·3 per cent of the investment, so that it was more economic to continue to run the older locomotives. In that particular case the locomotives were subject to a speed restriction and it was likely that their life would be determined by the extent to which operating practices rendered those locomotives embarrassing from the standpoint of performance. Thus obsolescence became the limiting factor and in that case, at any rate, would set the limit of life.

In considering the reasons why certain managements in the United States selected a particular form of motive power, it was important to make a distinction between the financial and the economic aspects. For example, throughout the period since 1945 and, indeed, from the time of the great depression, American railways had been very short of capital and had found it difficult to raise money in the open market, and so in the provision of rolling stock they had tended to borrow on the chattel mortgage system. A plate could be seen on the side of the locomotive stating who owned it, and it was not the railway company. Even the new Pennsylvania electric locomotives bore a plate indicating that they were owned by the General Electric Company. Because a locomotive or a vehicle might be distrained quite easily if the company failed to keep up its payments, the risk embodied in the loan was comparatively small and therefore the rate of interest was comparatively low. On the other hand, the fixed equipment required in an electrification scheme could not be so easily recovered by a creditor and therefore more conventional and expensive methods of finance must be adopted.

Another limitation of purely financial calculation arose from the difficulty of predicting the relative changes of cost during the life of equipment. In 20 or 30 years' time, who could say what would be the relative price levels? It was possible, however, to extrapolate the general economic trend of advanced and advancing countries which, irrespective of inflation or deflation, would see an increasing productivity of manufacturing industry which would be reflected in the relative wage rates between employees in that industry and employees in the service industries, for whom the problem of raising productivity was more difficult. Thus, labour shortages would continue to occur in the service industries, owing to men seeking more highly paid employment in manufacturing industry, or, alternatively, the service industries would be faced with higher wages bills without corresponding increase in productivity. Therefore, it must be expected that maintenance costs would become an increasing burden which, if the author's thesis was followed, would lead to progressive shortening of the economic life of the equipment. He thought that the practical lesson to be drawn from that, however, was that when financial studies showed that the total annual cost of the two forms of motive power were approximately in balance, but that the relative proportion of those costs applied to service of capital and cost of maintenance differed, the system having lower maintenance but higher capital charges should be selected, namely electrification.

**Mr W. J. A. Sykes** (*Associate Member*) said that his interest was mainly electrification, but he was also concerned with diesel maintenance.

On p. 268 the author had drawn attention to the fact that availability was of no great importance if it could not be fully utilized. That, of course, was a truism, but he wondered whether there was more behind it; whether the author was implying that American traffic operators were not making the fullest possible use of diesel locomotive availability. Diesel power should have been in use for a sufficient length of time for the traffic people to know precisely what they could do with it. He wondered whether the author had any ulterior motive in making the statement to which he had referred.

On p. 265 the author had stated that diesel locomotives had been discovered to have an economic life of 12–14 years. That had been dealt with by previous speakers, but he must echo their amazement. It was a most remarkable statement. He would have thought that the difference between a diesel-electric locomotive and an electric locomotive of similar performance lay in the presence of the diesel engine itself. He wondered how it was that that should make such an outstanding difference to its life, in view of the fact that the inherent overload capacity of the electric locomotive must produce greater wear and tear on the mechanical parts. He was concerned with the maintenance of three 1500-h.p. Co–Co mixed-traffic electric locomotives built between the years 1941 and 1948, so that the oldest had almost 20 years' service. They ran on an average 67 000 miles/year per locomotive, mainly on freight services. The cost of running repairs at maintenance depots during the past eight years had increased from 5½*d.* to 6½*d.*/mile, mainly accounted for by the normal rise in costs during that period. In other words, there had been practically no increase whatever in the cost of depot maintenance. During the same period the amount of heavy overhauls in main workshops had been about 7*d.* per locomotive mile, so that it would be seen that there had been no upward trend whatever in the maintenance costs of the mechanical parts. It seemed to him that the statement in the paper about the upward trend of costs in the repair of diesel locomotives was very hard to understand.

It was assumed, of course, that the reference to the extremely short life of the American diesel locomotives related to the whole locomotive and not only to the diesel engine. Fig. 21 showed a comparison of steam, diesel, and electric locomotive repair costs on the basis of the 1953 price level, and there was the astonishing conclusion that repair costs for diesel locomotives had gone up in the ratio of 4/1 over a period of 10–12 years. In view of the relatively less steep rises in the repair costs of electric and steam locomotives it was assumed that that was due to heavy repairs and renewals required on diesel locomotives, but that seemed to him to be quite unaccountable. It might be, of course, that the American diesel locomotive tended to run at a much higher speed than those in Britain. He noted from Table 3 that the train-miles per train-hours for both freight and passenger service were considerably higher than were normally achieved in Britain even with electric haulage. He assumed that the 'train-hours' were total train-hours and not merely those hours during which the train was in motion. Perhaps the author would comment on that.

**Mr H. H. C. Barton** (*Member*) said that he wished to query the author's figure of 1·49 as the multiplying factor for the increase in steam costs between 1929 and 1953. He could not dispute the figure; but it did not agree with other American statistics. In a publication called 'Historical Statistics of the United States from Colonial Times to 1957' it was stated that the cost of heavy materials (steel and the like) had gone up 1·89 times in the period of 20 years and that the cost of transportation wages had gone up 2·67 times. If it was assumed (and he thought it was probably a fair assumption) that wages and materials were 50/50 in maintenance costs—if there was any error it was probably that the wages side should be higher, because so much of the work in a running shed was examination rather than the changing of components—it would be found that the cost of steam maintenance over that period had risen roughly 2¼ times, and not 1½ times as the author had stated. Perhaps he would like to qualify his figure.

# Communications

**Mr E. S. Beavor,** B.Sc. (Eng.) (*Associate Member*), wrote that during the discussion numerous speakers had expressed incredulity at the steep rise of diesel maintenance costs with age, resulting in an economic life of only 15 years for main-line locomotives.

He would venture to suggest that the principal reason for that alarming prospect might well be the American habit of replacing component parts by new ones, instead of reconditioning them. It had been stated during the discussion that vast numbers of American locomotives were held by the railroad companies on mortgage and that they were owned by locomotive manufacturers or by finance corporations. It was feasible that the terms of mortgage might stipulate maintenance standards which obliged the railroad companies to buy new components at overhauls. If that system of unit replacement were applied to large items such as diesel engines, generators, and traction motors, then costs would indeed soar in the manner described in the paper.

In Great Britain, although modernizing was being done on deficit loans, it was not in the hands of vested interests who could oblige clients to buy new components at overhauls. In Britain engines, traction motors, control equipment etc., were usually repaired long after the Americans would have scrapped them, and he considered that that method was generally less expensive.

He would be glad if the author would state whether those assumptions were correct or not. If they were correct it would seem that the railroad companies had paid in two ways for their enormous borrowings.

**Mr L. W. Birch** (Mansfield, Ohio) wrote that the author's analysis of locomotive operating expense items as illustrated in Fig. 21, where he compared the cost per 1000 rail-horsepower-mile unit of steam, diesel, and electric locomotive repair costs, suggested the similarity of those several costs to that of bus operation, namely, diesel, propane, and electric.

Comparing the maintenance expense as affected by age of the buses it was readily apparent from Fig. 27 that the maintenance cost of all coaches increased with age but more rapidly with the coach powered by the internal combustion engine. Admittedly, a comparison of various coaches must be made on an equivalent milage basis and an equivalent age basis, therefore that information had been carefully selected from the operation of well-known fleets of buses on six American properties.

The keeping of data was started with the first year of life of each fleet; whether diesel, propane, or electric, and yearly recordings were made thereafter. It would be noted that the 45-passenger and the 51-passenger diesel curves were approximately together while the curve for the 51-passenger propane bus rose a little more rapidly than that for the diesels. It would also be noted that the trolley-coach curve fell considerably below the diesel and propane curves and had a tendency to flatten out after the first five or six years of operation.

It was recognized that those curves would not necessarily continue in the direction noted for an indefinite period since it was usually customary to rebuild the internal-combustion-engine-driven buses after a certain milage or a certain age. Nevertheless the rebuilding cost, properly allocated against years of life, would provide approximately the same curves.

In the author's Fig. 21, the locomotive repair costs for the electric locomotive fell considerably below that for the diesel locomotive somewhat in the same manner as shown in Fig. 27 for buses, and having worked with the author on many reports and analyses of railroad operating expenses he was sure that his comparison was on the same basis as that of the author for locomotives. Age must be considered

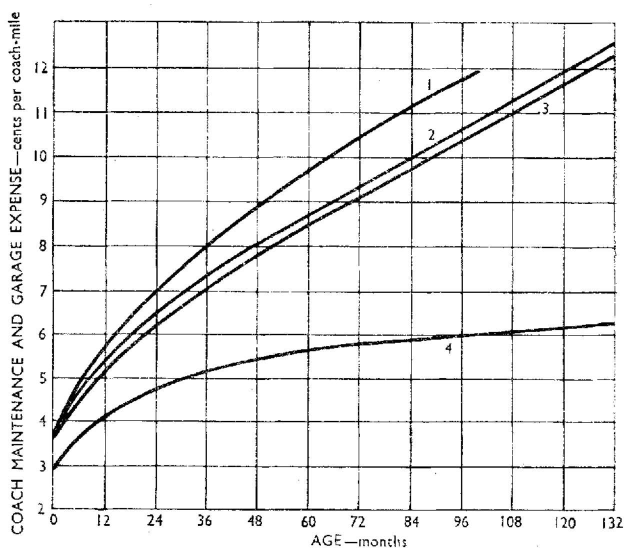



*Fig. 27. Comparison of repair costs for coaches*

1. 51-passenger, propane.
2. 51-passenger diesel.
3. 45-passenger diesel.
4. 48-passenger trolley.

when selecting the coach and age must be considered when selecting a satisfactory locomotive for railroad operation, main-line or commuter service.

**Dr C. de Inza** (Madrid) wrote that the major interest of the piece of research work could be summarized in the following two points: (1) In considering what happened in the United States, based on the analysis of the detailed statistics published there, the large economies ordinarily attributed to diesel operation were not apparent. (2) Improvement of installations, equipment and methods had resulted in economies which should not be attributed solely to diesel power.

Those ideas were quantitatively materialized in Table 4, where the operating costs, under the conditions prevailing in 1957, were carefully compared for diesel and steam power.

That, however, was subject to the objection which could generally be made to all comparisons of that kind, namely that the diesel operation costs corresponded to an actual situation whereas steam operation costs corresponded to a hypothetical situation and were therefore subject to errors inherent to estimated figures.

In view of that, the final result which showed a lower cost of $28·5 million for steam could not be accepted without reserves about the accuracy of the figures.

The exactness of the results was further weakened by the rate of depreciation for diesel power which had been established as a percentage almost double that for steam power. That percentage should be assayed and checked very carefully. Likewise, the economic loss involved in retiring a certain number of locomotives still not amortized, as happened when dieselizing, should be considered and evaluated. The author had evidently tried to balance the conditions by assuming, in computing the investments corresponding to the unreal situation of steam operation, that all the steam locomotives required to perform the traffic hauled by the diesels had to be purchased within the period considered; that surely would not have been the case had steam operation been retained.

From all the above it could be concluded that the author's documented and concise paper provided grounds for support of the two statements:

(1) In the case of the United States, economic advantages of dieselization were much smaller than had commonly been assumed. It was impressive that the estimated cost for steam operation, without fixed charges, was only 3·67 per cent higher than diesel operation cost.

(2) Even if those results were valid only for the United States and could not be applied to any other situation since it was most improbable, for instance, to find again that one steam locomotive had to be replaced by 2·41 diesel units, still it was advisable to make the pertinent economic studies before dieselizing, with special regard to the rate of substitution and possible utilization of electric traction, as the author had accurately pointed out. Economies made at the start of diesel operation considerably declined with the generalization of that mode of traction.

Although nobody should think that steam power was to be retained for ever, and much less that steam operation should return, it would be worth while to clarify and assay the figures which actually corresponded to depreciation of diesel equipment, because they certainly influenced to a great extent the cost of diesel operation, so that the author's idea on that point could be confirmed or perfected.

**Mr A. E. Durrant** (London) wrote that he congratulated the author on his most interesting, carefully prepared, and valuable contribution to locomotive engineering knowledge, and indeed his courage in presenting the paper at a time when the word 'Diesel' was regarded by many with almost religious fervour.

Whilst of course, the subject was of but academic interest in the United States, where a return to steam would be almost as expensive and uneconomic as the original conversion to diesel traction, the matter was of vital significance to those countries who were actually implementing, or considering a change to diesel power. The closest of those to Great Britain at present was British Railways' system with its ill-conceived 'modernization scheme'.

The complete failure of that scheme to produce the economic results first claimed for it were sufficiently well known to need little general comment, but of course, the large-scale introduction of diesel power and its equal failure to produce results in keeping with the capital expended upon it were most pertinent. Although possibly co-incidental, he found a disturbing parallel between the proportion of diesel power used and the rise in passenger fares. All that was completely contrary to British Railways' claims that diesel traction was substantially reducing costs that he would like to know by what financial conjuring trick the equation:

deficit + substantial saving = bigger deficit

was valid. The only answer could be that British Railways were spending pounds to save pennies when common sense showed that the opposite was not only possible, but greatly superior in effect.

To consider the matter in detail, there seemed firstly to be no argument against the diesel shunting locomotive which was, of course, competing against steam in its most inefficient form and only in a few special cases could steam break even in cost. A special exception was winter-time empty-stock working where the standard diesel electric shunter carried no steam-heating boiler, and was also too slow for the longer hauls, whilst the larger Bo-Bo diesels were far too expensive to use on that kind of work.

At one time it would have seemed obvious that the diesel mechanical railcar, using cheap, mass-produced, automotive power equipment could not but be a paying proposition and there was every reason for British Railways to invest in them. No matter what the prime mover, a railcar was a most convenient unit to operate and that in itself should point to considerable economies. However, the reluctance of British Railways to publish any *complete* financial figures for railcar operation (that is, including all capital charges), plus the continual rise in fares, would seem to indicate that the results were not so rosy as the propagandists would like to be believed.

Usually, upon the introduction of a diesel railcar service, a very considerably augmented service had been provided compared with the previous steam service. That in itself was enough to attract passengers and when the increased number of passengers claimed for 'Diesels' (i.e. railcars) was compared with the increased number of trains run (not usually published for comparison) the increased patronage was found to be smaller in proportion than the increased service. In other words, the steam trains were carrying more per train than the diesels. An interesting case seems to be in the Cardiff Valleys, where increased patronage was obtained by providing a regular interval service with steam power, and at the same time reducing the number of locomotives, carriages, and men, yet giving an improvement in service. Briefly, all the virtues usually claimed in order to justify much capital expenditure on diesel locomotives was here obtained with no capital expense, and with a reduced amount of equipment! It was significant that the usual diesel 'big talk' had not been made about those services.

However, despite those misgivings, it could generally be conceded that diesel railcars were a paying proposition, and it was in the field of main-line locomotion that the most controversial issues were to be found. In that sphere steam was at its most efficient thermally and was thus able to compete far more strongly with other forms of traction. The capital cost of steam power was lower than any other form, whilst it also had a long life and moderate maintenance costs. Electric traction, including fixed installations was high in first cost, but shared the long life of steam traction. Both steam and electric locomotives could be overloaded to quite considerable degrees.

Against those, the diesel put up a poor showing. High in first cost, short in life, and expensive to maintain, it was only in the most favourable conditions that it could be made really competitive. Those conditions had existed in the United States at the end of the war, long hauls with heavy loads gave the good utilization that was necessary to amortize capital, whilst the competing steam power was mostly overage and in many cases relegated to the lesser duties. Even under those conditions the diesel had not, apparently paid.

It had been mentioned on a number of occasions that the author's figures need not apply to other countries as 'the conditions are different'. That was indeed the case, as in most other railways, conditions were far less favourable to diesel traction than in the United States. On British Railways, turns were generally short with relatively long turnround times and even when well planned, as on the Great Eastern lines, only low milages were obtainable from the diesels. Those milages were no more than were possible with steam, given equal thought in scheduling, and thus would give less return on capital than would new steam power.

British Railways were guilty of setting in motion an extensive programme of main-line diesel locomotives, with virtually no experience to go on. With only the distorted and inapplicable American figures to go on, an incredibly optimistic view seems to have been accepted all round without any more sober views being taken into consideration. Foolish figures had been bandied, such as 'one diesel can replace $2\frac{1}{2}$ steam locomotives' due to its greater availability. Well, the steam locomotive had been proved capable of averaging upward of 25 000 mile/month and he was still waiting for the diesel which could average 62 500 mile/month.

Maximum performances for steam locomotives, in the United States were, on passenger work, the ability to haul a 1000-ton train at 100 mile/h, and in freight duties to haul 15 000 tons over an undulating route at average speeds of 25–30 mile/h. In both cases, those were with single steam units, and took 3 or 4 diesels to equal. Thus it could be seen that modern steam power, in addition to being more economic, could also greatly out-perform a diesel, and the 'success' of the diesel had largely been due to methods which could only be described as brainwashing. Such terms as 'New Diesel Services' (i.e. Railcar Services) and even 'Steam Radio' had all been used to condition the general public, and even those who should have known better, to think that the 40-year-old oil-engined locomotive was the latest thing on rails.

The author had obviously cut across many people's ideas. That was most obvious in the ensuing discussion wherein although many people had risen to defend the diesel, some even doubting the author's well attested figures, *not one of them could produce any set of figures to prove the diesel's alleged superiority*! That in itself seemed most significant, as was a statement by one gentleman to the effect that if he were a Railway General Manager today, he would buy diesels irrespective of what the statistics proved. Such were the results of heavy indoctrination, and he was glad that he held no shares in that railway.

He agreed largely with the author, and apparently most European engineers, that the right solution for main-line traffic was ultimate electrification. Experience in three continents with the three main forms of traction, steam, electric, and diesel, plus a careful consideration of all available figures, had also convinced him that until the money and equipment for electrification was forthcoming, steam was a far better proposition, and that any large-scale introduction of diesel main-line locomotives such that utilization did not equal availability, was so much electrification capital down the drain. If he could be proved wrong, then he was willing to change his views, but until then he eagerly awaited a diesel report from British Railways, based on actual facts rather than optimistic forecast, and *complete*, i.e. without leaving out all those embarrassing figures which did not support the facts given.

**Lt-Col. L. F. R. Fell**, D.S.O., O.B.E. (*Member*), wrote that the conclusion reached by the author that the substitution of diesel motive power for steam had added to the financial burden of the American Railways appeared to be due to three facts: (1) The capital cost of the diesel-electric locomotives was too high, as compared with the capital cost of steam locomotives particularly for the very high powers called for in American road service. (2) Repair costs had proved to be much higher than was anticipated. (3) The working life of the diesel-electric locomotives had been found to be less than half that of the steam locomotives.

The author had supported his arguments by data which he (Colonel Fell) felt must be accepted, and he did not think that anyone in Great Britain could reasonably dispute his conclusions which were based on information obtained over a long period of large-scale diesel operating experience which was unique in the current world.

It was most important, particularly at the present time, that the results published by the author should not be accepted as applying to the programme of dieselization which was going ahead in Great Britain, because those American results could be applied to British Railway Traction only to a very limited extent.

In a paper read before the Institution by himself* in 1933, he had drawn attention to the fact that the diesel-electric locomotive was only likely to be able to compete economically with the steam locomotive in Great Britain in the smaller sizes. He had pointed out that the reason for that was that the price of diesel locomotives advanced at an almost constant rate per horsepower, whereas the cost of steam locomotives advanced on a dry weight basis; i.e. a 2000-h.p. diesel locomotive would cost about ten times as much as a 200-h.p. diesel locomotive, whereas the steam locomotive which was the equivalent of the 2000-h.p. diesel locomotive would only have a dry weight of 3–4 times that of the equivalent 200-h.p. steam locomotive at which power the price differential between steam and diesel was not great.

At the time he had written his paper it had seemed that the diesel-electric locomotive that would be able to take the place of the existing British express passenger and freight steam locomotives of the day would cost at least three times as much as steam. That high first cost had seemed to him prohibitive. The author had pointed out that steam locomotives had existed in the United States prior to the change-over to diesel, of up to 7000 h.p. For the reasons mentioned above the ratio of the first cost of diesel-electric locomotives equivalent to steam locomotives of that very high power would almost certainly be even more than 3 to 1.

Diesel operation on British Railways, however, was following quite a different plan to meet quite different conditions from those which applied in the United States. Short-distance passenger-traffic was still important in Great Britain and that was almost exclusively worked by powered trains. The great majority of those were not diesel-electric, but were provided with some form of much cheaper hydro-mechanical transmission. Under-floor equipment was provided at a fraction of the cost per h.p. of diesel-electric locomotive haulage and with progressively improving standards of reliability and maintenance there seemed to be no doubt at all that the under-floor equipment would prove to be a cheaper and better investment than steam locomotives for the same duty; that was apart from the all-important fact that those diesel services had already proved to be successful in attracting passengers back to the railway from the highways.

The greater proportion of diesel locomotives which would be required to operate British Railways, would be of the types 1 and 2, that is to say, of 1000–1400 h.p., the first cost of which compared sufficiently favourably with that of steam locomotives for the same duty to make it possible for the diesel to show an economy. It was possible that the type 4 diesel locomotives, of 2000 h.p. and upward, would never operate trains as cheaply as their equivalent high-powered steam locomotives, but apart from other considerations it would not be practicable to provide a well-watered oasis for a comparatively few large steam locomotives in the middle of an otherwise arid railway system.

It seemed likely that British Railways had, within their grasp, a golden opportunity which had never formerly presented itself anywhere in the world, namely to make a direct comparison between electrification and diesel operation on two similar trunk lines operating side by side. Ten years of such operation should establish, once and for all, whether the balance of advantage between the two systems was in favour of electrification or diesel operation of a British Railway with high traffic density.

**Mr R. G. Fuller** (Hudson, P.Q.) wrote that from the author's detailed analysis concerning the respective merits of diesel and, more especially, diesel-electric traction in relation to steam traction, had very adequately covered the relative operational, maintenance and depreciation factors.

It might be emphasized that the diesel engine demanded a much higher calibre of service than did the steam locomotive and possessed a greater number and complexity of parts requiring fine fitting and service. The higher cost of the superior labour required and greater time involved by the more numerous and finer fitting etc. was reflected in the substantially higher cost of repairs listed in Table 1*a*. In addition, in the case of diesel-electric locomotives, there was the added cost arising from the necessary duplication of service facilities to take care of electrical maintenance of both rotating machines and the associated control gear.

That would appear to be supported by the curves in Fig. 21 in which the addition of the electric and steam costs would closely approximate the diesel costs shown, after allowing for increases due to the greater complexity of the diesel prime mover.

The dieselization programme of the two major Canadian railroads had only been concluded during the past year, when the age of existing steam stock was close to 35 years. It was therefore far too early to expect operating records of the type presented in the paper, although extensive experience with yard locomotives certainly favoured diesel operation.

There could be no doubt that the diesel locomotive was less reliable than the steam locomotive and, to his knowledge, one railroad alone had had at least five major service

* Fell, L. F. R. 1933 *Proc. Instn mech. Engrs, Lond.*, vol. 124, p. 3, 'Compression-ignition Engine and its Applicability to British Railway Traction'.

interruptions during the past few months due to breakdowns associated with the locomotive. Recently, motorists driving into Montreal had seen five commuter trains held up head-to-tail due, he had been informed, to a scavenge-blower-bearing failure on the engine of the leading train.

So far as it had been possible to ascertain, those five failures were due to the following causes:

(1) Failure of a scavenge blower bearing.
(2) Failure of a heat exchange component.
(3) Failure of an electrical component.
(4) Failure of an electrical controller.
(5) Failure due to overheating.

The low thermal efficiency of the steam locomotive certainly called for improvement, but it appeared that the higher efficiency obtained from the diesel-electric locomotive was penalized by the introduction of unacceptably high maintenance costs and a very questionable degree of reliability in service.

Possibly a compromise solution would be the use of the diesel combustion process in association with a turbo-mechanical drive. That could be met by gasifiers such as the crank system successfully installed in locomotives in Sweden, or the free piston gasifiers installed in locomotives in France and, also, in the United States of America. Of those two alternatives the free piston system would appear to offer some advantage over the crank system, as the use of multiple gasifiers would ensure 100 per cent availability.

Both systems offered the advantages inherent in the use of a turbine as torque converter, giving a performance comparable to that of electric drive without the accompanying penalty in the way of some 15 per cent transmission losses. There was no limitation to the size of locomotive, apart from those imposed by loading gauge and permanent-way restrictions.

It was surprising that the only active development of the gasifier locomotive in Europe was in two countries committed to a policy of full electrification, and it would have been expected that the country which spent money investigating such developments as the Ljungstrom turbo-locomotive, the Kitson-Still hybrid, the open cycle gas-turbine, and other less promising developments to have paid more attention to the gasifier-turbine compound engine with its much higher potential, in regard to both immediate benefits and long-term prospects.

**Mr H. G. McClean**, B.Sc. (Eng.) (*Member*), wrote that those who, like himself, had had substantial experience of dieselization both in the United States and on railways overseas, must feel that the paper presented a misleading picture of the results of dieselization of American railroads, now substantially completed.

Based on I.C.C. statistics for United States railroads as a whole, together with some diesel-electric costs for selected railroads, which readers were asked to assume were typical, and finally some steam costs (all highly presumptive), the author had reached the conclusion that the merits of dieselization on United States railways were largely imaginary; that the publicized statements of its benefits were erroneous; and that dieselization had not been an economic advantage.

Those findings were those of the author alone and were not representative of those of United States railroads, either collectively or individually, and were in conflict with published statements of practically every United States railroad president.

Having established to his satisfaction that modern steam power would have been more economic than diesel, the author had withdrawn from advocating a return to steam operation, leaving a vacuum, presumably to be filled by a recommendation for electrification in his subsequent paper.

It seemed desirable, therefore, to withhold full comment until the author's presentation was complete. But some of his conclusions must be contested immediately as they might otherwise be highly misleading.

The United States railroad system comprised rather more than 100 class I railroads operating primarily for profit, deriving their revenue and profit almost wholly from handling freight, and engaged in intensive competition, both with road haulage, and with one another. Equally, the locomotive builders were aggressive competitors. It was reasonably certain that any decisions made as to the operation of those railroads would each be taken individually by the management of that railroad, based on the figures for that railroad, and for that railroad only.

If the author's presentation was correct, then the fine managements of those many railroads (and of the locomotive builders) were, without exception, by implication incompetent to a point which would constitute negligence, and all those railroads had, by the author's paper, been deliberately misled in their policy of dieselization by the erroneous claims of the locomotive manufacturing industry.

*Locomotive repair costs.* Essentially, had the author attempted to justify his presentation on the basis of the diesel locomotive repair costs presented in Fig. 21, and especially the rate of increase with age.

Those were figures for some selected railroads, and the slopes of the curves were, of course, particularly sensitive to the accuracy of values at about the 10-year life. The slope of the author's curve was unreasonably high.

In Fig. 28, superimposed on the author's Fig. 21, were values for locomotive repair costs from another large United States railroad, well known, and early active in dieselization. Those values were actual costs, not adjusted to 1953 price levels. Such adjustment, obviously, would tend to make the rate of rise with age even less. It would be seen that those figures were very much below those on the author's chart.

However, the figures would be equally misleading if they were used to develop generalized statements since the values were most likely well below the average for most railroads.

Fig. 28 showed for that same railroad the curves for repair costs for successive additions to their locomotive fleet and confirmed the general form of the curves.

It might be repeated that each individual railway would

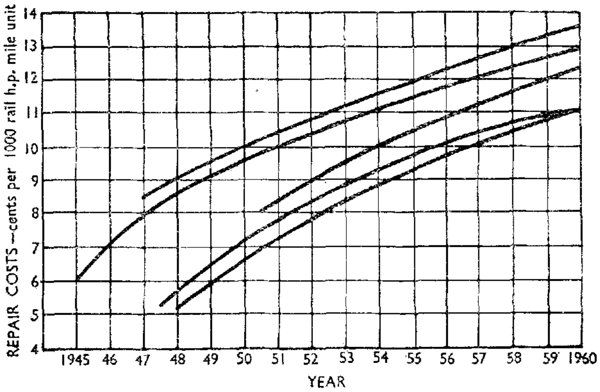



*Fig. 28. Diesel-electric locomotive repair costs for a United States railroad*

Actual values not adjusted to 1953 price levels.

make its decisions on motive power based on its own cost figures.

It was, furthermore, possible to dispute the author's figures by citing statements made publicly by most United States railroad presidents in placing on record the economic benefits of dieselization.

In May to July 1955, there had been correspondence in the American railroad press on the increase with age of maintenance costs of steam and diesel locomotives. At that time Mr. John M. Budd, the President of the Great Northern Railway (a railway which was electrified through the Cascade Tunnel) wrote, '. . . Those who are trying to sell electrification to the railroads have made the same assumptions . . . that there is a constant rise in the unit mile cost of maintaining Diesel locomotives. We have taken exception to that theory and believe have pretty definite proof that it will not stand careful examination. . . . An analysis of carefully kept figures on a unit basis for 92 F–T Diesel locomotives gives definite indication of a cycle in repair costs per unit mile. . . . We made heavy repairs to these locomotives after about an 8-year life. In the following year the cost of repairs per unit mile dropped back to about the same level as that attained in their third year of life, which was slightly higher than the repair costs for the locomotives when they were new. . . . We anticipate our repair costs per unit mile will level off.'

That railway's experience, 1955–60, had confirmed the accuracy of Mr. Budd's forecast, with unit repair costs following the same general curve superimposed on the author's Fig. 21.

*Fuel costs.* Fig. 22 showed comparative costs of fuel on a B.t.u. basis. That was perhaps unfortunate in that it might lead the reader to imagine that the cost of fuel under dieselization had been higher than steam locomotives, coal-fired or oil-fired.

However, the author's text suggested fuel costs for road locomotives was $367,000,000 in 1957 when coal would have cost $408,000,000; and even so his method of calculation might be questioned as unfavourable to diesel.

*Depreciation and obsolescence.* The author had implied that the depreciation allowance allocated to diesel locomotives when they were originally purchased was inadequate. On the information then available, the assumed life of a road locomotive was generally 20 years, and there was ample evidence to indicate that the locomotive was, and was going to be, a satisfactory piece of operating equipment at that age.

But he was critical because the manufacturers, by an active programme of continuous product improvement, with the encouragement of the railways, had made it possible to establish economic justification for replacement or remanufacture of the locomotive before it had reached its 20-year life. Constant product improvement had made it possible to increase the capacity of the equipment by the order of 3–4 per cent per annum average, but with lower maintenance costs.

It was a perfectly legitimate and desirable commercial practice, both for a railroad as for any economic undertaking, to purchase equipment on a well-chosen value of depreciation, but subsequently to seek to obsolete that equipment by something more efficient in less than its assumed full life. There would frequently be a tax advantage to the user in so doing.

Long economic life frequently involved technical stagnation. One of the great demerits, surely, of electrification was that it froze the product in the form in which it was installed because that required such a high first-cost investment. Clearly, the United States locomotive manufacturers were going to try to improve their product at such a rate that the railways would be encouraged to scrap and buy new with economic advantage in so doing.

*Traffic.* The graphical presentation of traffic in Fig. 1 might tend to be misleading unless it were emphasized that 85 per cent of the revenue of the American railroads came from freight traffic, and that, by and large, that was the only traffic of importance. The statistics, as presented, might give the impression that passenger traffic was more important than it was. The exceptions, such as the New Haven Railroad, with which the author was associated, were far from typical.

In Part II there was a reference to the activity of the automotive industry in promoting the sales of diesel-electric locomotives, perhaps with an implication that that was an improper promotion and 'campaign' when the economic claims justifying the purchase of diesel locomotives were inaccurately presented.

For the benefit of the uninformed, perhaps it would have been desirable that the author should have made it plain that the reference to the automotive industry should not be taken to imply that automotive manufacturing facilities were converted to locomotive manufacture.

The diesel locomotive activity in the United States was initiated by a group of men who spent the whole of their lives in railway motive-power activity and who latterly became associated with an automobile manufacturer who provided necessary additional management, philosophy, techniques, and means, especially in the area of skills in volume manufacture of standard units.

*Assumed steam locomotive costs.* The author assumed a steam locomotive cost of $45 per horsepower in 1953 and a typical size of locomotive having 5000-rail h.p. It would be helpful if he would indicate the weight, wheel arrangement, boiler, and grate of a typical locomotive of the class that he had in mind. Experience had shown, in his opinion, that it was difficult to make a proper comparison between the power of a steam locomotive and a diesel locomotive for regular day-in day-out operation. The output from the diesel locomotive varied but little from day to day or year to year, but there was a substantial difference between the performance of a steam locomotive in a new trial (when most of the published tests were conducted) and the average of its performance in day-in day-out service. On the latter basis a steam locomotive having 5000-rail h.p. was a very big locomotive.

*Large-horsepower single-locomotive units.* The author had stated that American manufacturers 'have not been able to build' single units of much more than 2000 h.p. That statement presumed that the several United States manufacturers believed that it was desirable to attempt to build such units but did not know how to do so. In fact, most of those manufacturers had held the belief that the retention of the multiple unit concept of smaller units was a better policy for both operator and manufacturer, and experience confirmed their view.

It was the author's presumption that they could not have done so had they made the attempt. In fact, one manufacturer had produced a larger unit. He was not now actively in the United States railroad locomotive business.

*Economic results of dieselization.* The author's basic conclusion was that dieselization had been a mistake. 'Nothing indicates that the change in type of motive power since 1940 has had a bearing on—operating expenses—unless unfavourably'. That sweeping statement was completely in conflict with the conclusions of every railroad in the United States, without exception. It would be possible to quote almost every United States railroad president to the contrary in statements made at one or other of the annual meeting reports of the past 10 years. The statements were in no way invalidated by the fact that there had been a rise in operating ratios, and the author, in effect, had subsequently disproved his own statement by his reference to the saving in fuel cost alone. If any reader was in doubt he should seek opinions direct from individual railroads.

But perhaps the best refutation of the author's statements came from the action of the Norfolk and Western Railroad. That was a large eastern railroad, heavily engaged in hauling coal and with, therefore, every incentive to use motive power energized by coal, whether steam locomotives or electrification. Some 100 miles of that railroad had been electrified through a mountainous area handling heavy traffic in 1914. The railroad had abandoned the electrification in 1951.

Thereafter it had operated a fleet of modern steam locomotives in a way which was well known and admired throughout the world as a classically fine steam locomotive operation. In 1955 the Norfolk and Western Railroad had made the decision to buy their first diesel locomotive, and in 1958 had decided on complete dieselization. At the time of that decision they had a background of previous experience of electrification. They had excellent comparative operating costs for steam locomotives, possibly the best figures in the United States, and equally, as late starters, they had available to them from all the other railroads that had been dieselized, data on the results of dieselization on those lines to supplement their own diesel experience. The President of that railway, speaking at Roanoke 9th February 1960, said, 'Our dieselization programme was a major factor in enabling us to improve our operating performance so substantially in 1959'. No more outstanding example is available to disprove the author's statement 'Diesel motive power has added to the financial burden of the railways'.

Many persons would reserve further comment until they had read the author's subsequent paper on electrification.

**Mr P. A. McGee,** Mem. A.S.M.E. (Ventnor, N.J.), wrote that the great merit of the paper was the presentation in one paper of important operating data from I.C.C. records. It, however, suffered from the inclusion of unnecessary and confusing details.

Perhaps the chief error was the omission of important operating and cost indices and their substitution by the author's unsupported opinions which were largely refuted by available data and the substantial operating railroad records.

The extraordinary increase in class I railroad yearly operation expenses from 3 billion to 6 billion dollars per year in the short period 1940–45 was naturally the cause of great concern to United States railroad management. Millions of dollars were spent by railroads and manufacturers between the late 1930's and middle 1950's in designing and testing all kinds of direct steam and steam-electric power and gas and solid-fuel turbines.

The results of those tests and the conclusions drawn from them by the most competent and experienced talent available were no secret and were well known to United States railroad management.

The author's assumption of a mysterious hypothetical steam locomotive for a comparative cost study with diesel power was, to put it mildly, quite unconvincing.

The author had stated that after the first flush of successful diesel performance that doubts had arisen as to whether the economies which developed with diesel power were not the result of other factors which, he stated, was a natural development. From his own continued association with responsible railroad personnel and a close study of current operating results—and as could be shown from the record of recent diesel purchases—that erroneous opinion appeared to be confined to the author and his associates at 32nd Street and Church Street, New York.

There was no monopoly in the application of any particular power on United States railroads. If there was a better steam or a better gas-turbine or electric locomotive, all that was required was to produce it; and there would undoubtedly be a ready response by manufacturers, coal, and residual oil suppliers, and the railroads.

The substitution of diesel for steam power was the result of an extensive operating study which would continue as long as operating records were available. The purchase of some $3,900 million of diesel power, as mentioned by the author, required the approval of 110 Boards of Directors and the financing support of banking, financing institutions, and insurance companies throughout the United States.

He himself had had an extensive experience in railroad electrification and diesel operation since its introduction in 1937, and it so happened that he had prepared, at the end of 1957, a record of diesel performance between the years 1941 and 1956.

Statistics were invariably tedious. He had, however, reduced his 1957 study to include only the essential operating indices and costs, with particular reference to fuel, maintenance, engine men, and engine house expenses. He believed that they would be found to be informative and very interesting.

Table 5 with operating details for all class I motive power and freight movement at 5-year intervals from 1941 to 1956 and the available data for 1959 were reduced to 16 items. Those 16 items gave the full pertinent data of total operating costs and comparative costs of actual steam and diesel power for the approximate 220 000 miles of class I railroads.

Item 1 Gross ton-miles (G.T.M.) of trailing freight was fairly uniform from 1946 to 1959.

Item 2 The freight G.T.M. per freight train hour supplied the most significant operating indices of freight movement. It explained the whole tempo of freight movement and what must be its operating cost basis. From 1941 to 1959, that index improved by nearly 90 per cent.

Items 3 and 4 gave the relative G.T.M. of freight hauled by steam and diesel power. In 1941 freight diesel operation was insignificant and in 18 years was over 98 per cent.

Item 5 Total operating expenses which were approximately $3000 million in 1940 doubled to $6,000 million in 1945. In the following 14 years with double the basic material and labour cost, the total increase in operating cost with diesel power was limited to the same amount, $3,000 million dollars. That control of operating cost, as would be shown, was largely caused by the improved operating rate of item 2 and the fuel cost item 13.

Item 6 The large contribution in national taxes should be noted by critics of the profit motive.

*Table 5. Summary of certain United States of America class I railroad operating data for 1941–56 by P. A. McGee on 12–9–1957, to show the influence of diesel power on the performance indices; operating expenses with increased costs*

| Item | Subject | 1941 | 1946 | 1951 | 1956 | 1959 |
|---|---|---|---|---|---|---|
| 1 | Total freight G.T.M., billions | 1,195 | 1,361 | 1,440 | 1,447 | 1,300 |
| 2 | Freight G.T.M. per train hour | 33,000 | 37,057 | 46,407 | 57,102 | 61,926 |
| 3 | Percentage operated by steam | 97·5 | 88·0 | 45·6 | 9·0 | 0·3 |
| 4 | Percentage operated by diesel | 0·2 | 9·7 | 52·5 | 89·1 | 98·2 |
| 5 | Operating expenses, millions of dollars | $3,664 | $6,357 | $8,041 | $8,106 | $9,077 |
| 6 | Taxes in millions of dollars | $547 | $498 | $1,203 | $1,121 | $1,048 |
| 7 | Average yearly compensation per employee | $2,045 | $3,068 | $4,133 | $5,102 | $6,100 |
| 8 | Ratio of average yearly compensation per employee, basis 1941 | 1·0 | 1·5 | 2·0 | 2·5 | 3·0 |
| 9 | Ratio of cost of rails; freight cars; signal equipment | 1·0 | 1·2 to 1·4 | 1·8 to 2·1 | 2·2 to 2·7 | |
| 10 | Basic cost per h.p. typical 130-ton diesel railroad unit | $90 | $93 | $108 | $101 | $94 |
| 11 | Fuel unit cost: | | | | | |
| | steam coal per ton | $2·3 | $3·6 | $5·00 | $5·7 | $6·4 |
| | steam oil per gallon | 2·1c. | 3·0c. | 4·6c. | 5·4c. | 4·9c. |
| | diesel oil per gallon | 4·5c. | 5·5c. | 9·5c. | 10·2c. | 9·8c. |
| 12 | Fuel and power total road and yard: | | | | | |
| | steam coal, million tons | 98 | 100 | 48 | 8·5 | 0·3 |
| | steam oil, million gal. | 3484 | 3878 | 2031 | 180·0 | |
| | diesel oil, million gal. | 186 | 511 | 2262 | 3581 | |
| | electric, million kWh. | | 1893 | 1672 | 1566 | |
| 13 | Fuel 1000 G.T.M. per $1·00 cost: | | | | | |
| | steam coal | 6,250 | 3,900 | 3,030 | 3,087 | 2,570 |
| | steam oil | 4,700 | 3,470 | 2,140 | 1,959 | 2,376 |
| | diesel | 12,250 | 10,250 | 6,420 | 5,299 | 5,165 |
| | electric | 3,800 | 3,700 | 3,300 | 2,959 | 2,457 |
| 14 | Fuel and power total cost all services, million $ | $322 | $518 | $562 | $441 | $419 |
| | Fuel and power total cost all services, million $ *at 1959 unit cost* | $855 | $912 | $652 | $436 | $419 |
| 15 | Locomotive maintenance road and yard | 314 | 576 | 635 | 512 | |
| | Locomotive maintenance road and yard, million $ *at 1956 unit cost* | 635 | 721 | 634 | 512 | |
| 16 | Engine house and engine men road and yard, million $ | 369 | 632 | 744 | 759 | |
| | Engine house and engine men road and yard, million $ *at 1956 rates* | 924 | 1,260 | 1,160 | 759 | |

Items 7 and 8 The average employee compensation increased by one billion dollars every 5 years. Its effect on items 2, 15, and 16 should be noted.

Items 9 and 10 The increase in material costs was less than labour increase items 7 and 8. A very interesting development in diesel power showed practically no increase in cost on a h.p. basis over the years since diesel road power was applied.

Item 11 All fuel costs had increased about 100 per cent in the 14-year period. Its effect on items 13 and 14 should be noted.

Item 12 Total fuel quantities. This item deserves the special attention of all railroads of the world. In 10 years 1946–56 the application of diesel power saved over 90 million tons of coal; 3700 million gallons residual oil; 330 million kWh with an increase of about 3000 million gallons of diesel fuel. On the basis of 1959 unit costs, that represented a saving of approximately half a billion dollars per year. The total amount of diesel fuel required with practically 100 per cent diesel operation was considerably less than the total residual oil consumed in 1946 with about 18·5 per cent of the total freight movement.

Item 13 G.T.M. per $1 fuel cost. That important index, not commonly published with year statistics, confirmed the savings mentioned in items 12 and 14.

Item 15 Locomotive maintenance. That item represented for recent years about 30 per cent of total equipment maintenance and with succeeding years and more labour content in freight and passenger-car maintenance would become progressively less. At 1956 maintenance rates, diesel power for 1946 showed a yearly saving of about $200 million.

Item 16 Engine house and engine men. Those very important cost items were practically all employment compensation and very sensitive to the requirements of locomotive servicing and the crew costs which were largely influenced by item 2. At 1956 rates, the diesel power showed a saving in 1946 operating cost of over half a billion dollars.

Table 5 did not by any means represent the complete savings derived with diesel power. The large potential savings in maintenance of way was not included which, without going into details, might exceed those of maintenance of equipment. Nor were the very large savings with the extensive closing down of the mandatory tunnel, terminal, and grade electrifications included.

The total out-of-pocket savings of approximately $1,200 million per year with diesel operation as developed in Table 5, however, sufficiently refuted any opinion or suggestion that diesel motive power, with a claimed investment of $3,880 million dollars, represented any financial burden to the United States class I railroad system.

An investment which paid for itself in less than 3½ years, and thereafter saved probably over a $1500 million per year, spoke for itself.

**Mr J. E. Owen** (Doncaster) wrote that on p. 265, under Locomotive Expense Items, the author had dealt with the subject of depreciation and had stressed the importance of using a correct depreciation rate in the accounting process. That rate was shown to be dependent on the economic life of the asset, and figures of 30 years and 12–14 years were quoted for the economic life of steam and main-line diesel locomotives respectively. That economic life was determined largely by three considerations: (1) The increasing cost of maintenance as the life of the asset was prolonged. (2) Technical obsolescence. (3) Non-technical considerations, such as, for example, Company policy, the incidence of taxation, or, in the author's words on p. 265, 'a ruling of the I.C.C.'

There was little doubt that the rate of increase in maintenance costs would be somewhat greater in the case of the diesel engine than the steam engine, and the diesel engine was probably more vulnerable to technical obsolescence. Already, particularly in Germany, a strong movement could be seen away from electrical transmissions to various systems of hydromechanical transmission. But he questioned whether those two things alone were sufficient to reduce the economic life of the diesel locomotive to only 14 years.

He would like the author to state to what extent that relatively short life of 14 years or thereabouts had been due to entirely non-technical considerations which might have been used to support a 'scrap and build' policy.

The importance of the depreciation figures in that case could scarcely be over-stressed, since it appeared on reference to Table 4, column 4, that the saving of 71·6 million dollars attributed to steam traction became in fact a saving of 11 million dollars to diesel traction if the same rate of depreciation had been applied to both steam and diesel locomotives.

# Author's Reply

**Mr H. F. Brown** wrote, in reply to the discussion and communications, that before replying to the various questions and commentary, it was necessary to repeat some of the statements he had made on presentation of the paper.

The paper neither advocated nor deprecated any type of railway motive power so far developed. All types—steam, electric and diesel—still continued to have their economic place and function, depending on traffic density, fuel type and supply available, electric power supply, and other national economic factors involved.

The total costs of *owning* and *operating* each type, however, was important and should be known before making any general substitution of one type for another type. The paper was offered simply as a contribution to the knowledge of some of those costs for diesel motive power, determined from the records of the performance of that type on the class I railways of the United States as a whole from 1940 up to the end of 1957.

In no place in the paper had it been stated that the application of diesel power to those railways was a mistake. In no place in the paper, other than in the discussion and in the reply, was railway electrification mentioned, other than in a footnote stating that the paper was to be used as a datum for a paper under preparation relative to the results of electric operation on the United States railways. The paper simply stated, and it was believed demonstrated, that the widely publicized and all-embracing claims for the large economies made by diesel motive power on the railways of the United States of America could not be substantiated from the statistical record. The comparative analysis made in the paper showed its economic performance to be about on a par with that of steam on its overall application on the United States railways—no better, no worse. Economy had been shown in its general application in yard and shunting service. In line-haul, or 'road' service, as it was commonly called in United States railway parlance, the paper showed it to be more expensive than equivalent modern steam might have been. Why? Because the first cost of diesel motive power was about double that of steam, and its economic life as well as its service life, *so far*, was shorter, by approximately one-half. The capital costs had just about cancelled the operating savings.

It was that short life which prompted the present study.

Diesel railway motive power was not something brought recently to his attention, he had followed its development from its earliest application to the railways in Europe and in the United States. Before starting his railway career, as early as 1908, he was familiar with the electric drive for gasoline rail-cars being developed by the large electrical manufacturer then employing him. The diesel electric locomotive, as known currently in the United States of America, was the development of the two leading electrical manufacturers jointly with the two leading steam locomotive manufacturers after the 1914–18 war, regardless of the recent claims made by the automotive industry. Each step in its development over the period 1918 to the present time had been recorded by technical committees in reports and papers in the various railway and engineering Associations and Institutes; and his activities on some of those committees was also a matter of record.

The railway with which he was associated from 1910 to 1952 acquired its first diesel in shunting service in 1931. They were called 'oil-electric' locomotives in those days and regarded as a special type of electric locomotive carrying its own (albeit limited) power supply. By the end of 1940 that railroad had 38 in shunting service, but none in line-haul service. Its first line-haul diesels were acquired in 1942. By the end of 1951 that railroad had over 300 diesel electric units in yard and line-haul service together with 110 electric locomotives. During the ten-year period 1942–51 he had ample opportunity to study comparative repair costs. In 1953 he collaborated in a study of the comparative economics of those two groups of motive power.

In 1955 he collaborated in a study of diesel maintenance costs for a large United States railway to determine the economic life of diesel motive power for tax purposes. That study included repair costs, all related to their age, of over 3000 diesel units of all types and manufacture on seven class I railways. Repair costs were found to rise with age, indicating, when considered with first cost and proper depreciation rates, an economic life of from 12 to 14 years for road locomotives and about 18 years for yard diesels. He had assisted in presenting that evidence before the Federal bureau in charge of taxation, the Internal Revenue Service (I.R.S.), who had allowed that railway to use a life of 15 years for road, and 20 years for yard diesel motive power, with depreciation rates based on those lives and a scrap value of 10 per cent of the original cost. Such a short life as 15 years was as startling to the I.R.S. (and to himself) as it had been to many of those commenting on the paper. The evidence, however, was there, and it was more indisputable today, five years later, than in 1955, as would be shown.

That relatively short life immediately raised the question in his mind: Just how does that shorter life than the other types of motive power in use affect the overall economic status of the diesel?

After 1950, the diesel had been generally accepted by all but two or three of the railways of the United States, more or less without question or further detailed studies. Substantial savings in fuel costs were quite apparent, owing to the higher thermal efficiency of the diesel. Lower maintenance costs and greater availability of that new power were apparent in comparison with the older steam. A large per cent of the steam power units was then nearly worn out because relatively few new steam locomotives had been built since 1930 (see Fig. 4).

Traffic was being handled adequately each year by fewer total units of motive power than operated the previous year. Statisticians were pointing each year to apparently greater operating efficiencies indicated by the rise in such statistical averages as 'car-miles per train-mile', 'ton-miles per train-mile', 'train-miles per train-hour', and 'gross ton-miles per train-hour'. Few of those statistical averages were recorded in the I.C.C. statistics prior to 1945. The years following 1945 were also contemporaneous with the rapid acquisition of diesel motive power.

The proponents of diesel operation were not slow in relating *all* of those apparently improved factors in railway operation to the substitution of diesel power for steam. Manufacturers could not be criticized for giving wide publicity to any factors which would stimulate the sales of their product, if they believed they were true. No sales promotion activities whatever of other types of railway motive power were being made in the United States, even by the former steam locomotive manufacturers.

The following claims for the diesel and its performance on the railways of the United States had been given wide publicity:

(1) Each diesel had replaced two steam locomotives, and could perform the work formerly done by two steam locomotives.

(2) Diesels, by multiple-unit operation, had enabled the railways to reduce the number of trains, by their ability to haul longer trains.

(3) They were responsible for large savings made in wages of train and engine crews due to the reduction in the number of trains operated.

(4) They had greatly increased the speed of trains.

(5) They were responsible for a great reduction in locomotive repair costs.

(6) They had enabled the railways to make operating savings of up to 30 per cent annually on the investment made in them, after interest and depreciation charges; or enough to return the investment in three years.

(7) They had enabled the railways to increase their dividend payments since 1935.

If those claims were true, the short life of 12–15 years for the diesel was not important. The railways could well afford to replace equipment responsible for such large economies more often.

Also, if all that were true, there would be little point in giving further serious consideration to electric operation in the United States, for which such savings as 30 per cent on the investment had never been shown.

In 1957, he had been asked to report on just what were the comparative economic results of electric operation on the railways of the United States. Electric operation was being rapidly adopted in Europe and elsewhere about the world, but in the United States it was still handling less than 2 per cent of the traffic, or about the same as in 1942. Diesel operation, because of its cleaner exhaust than that of steam, had already replaced electric operation in a number of short installations in connection with long tunnels.

Before such a study could be made, it became necessary to investigate the background influencing railway operating costs over the years prior to, and during which, steam had been replaced by diesel operation, and sift out all the facts related to motive power. The paper was *part* of the result of that investigation.

It was found first that something quite drastic began to affect the railways of the United States about 1920–24. That was shown throughout the entire statistical record: in road (line) milage operated; in number of line-haul locomotives; in train-miles performed; in freight tonnage and passengers hauled; as well as in the fuel consumed. All showed a similar pattern in the continuing downward trend, if due allowance was made for the abnormal drop during the 1930–39 business depression, and the rise during the 1941–45 period due to the war. Those associated with railway operation prior to and since 1920 would be well aware that all that was related to the loss of the branch line and short-haul traffic to the rapidly growing number of automotive vehicles on the highways, which began to be felt about 1920, and increasingly since, except during the war years.

The reduction in line milage operated was mentioned in the text of the paper, but not illustrated. At the presentation of the paper, Fig. 29 was shown to illustrate how closely the reduction in motive power had kept pace with that reduction in line milage operated. That same trend was found in Figs. 1, 7 and 36.

It could be possible to relate the reduction in the number of line-haul motive power units since 1940 to the first of the claims for the diesel, listed above—that each diesel unit has replaced two steam units. To do that, however, the fact must be ignored that that reduction in motive power units was started some twenty years before the advent of diesels in line-haul service, and had been and still was contemporaneous with the reduction in line milage. The *evidence* (not proof) pointed more strongly to that relation for the decline in motive power units, rather than to a change in type. Thus, the statistical evidence immediately cast considerable doubt on claim (1) made for the diesel.

Because the paper, by other statistical evidence, had cast similar doubt on *all* the claims made for the diesel, listed above, it had cut across views and opinions concerning diesel motive power held by many to be self-evident truths, and had evoked considerable valuable discussion.

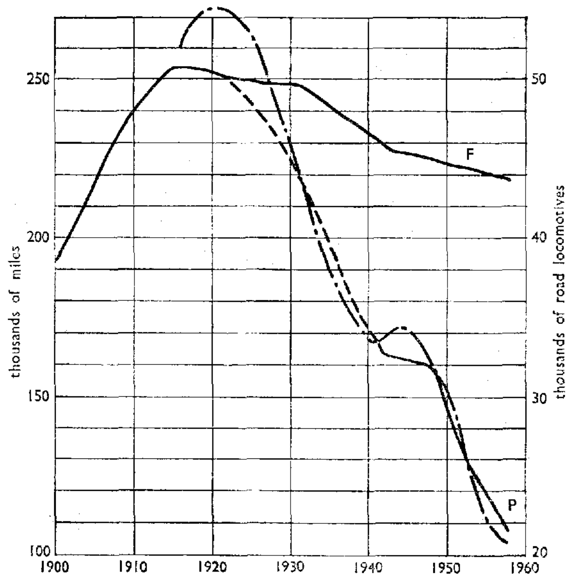



*Fig. 29. Road milage operated and road locomotives in service on classes I and II railways of the United States of America*

From I.C.C. Annual Statistics, Tables 16, 55A, 55B and 155.

There is no exact record of milage operated for passenger service from 1918 to 1940.

———— Road milage, upper line freight, lower line passenger.
— — — Number of road locomotives.

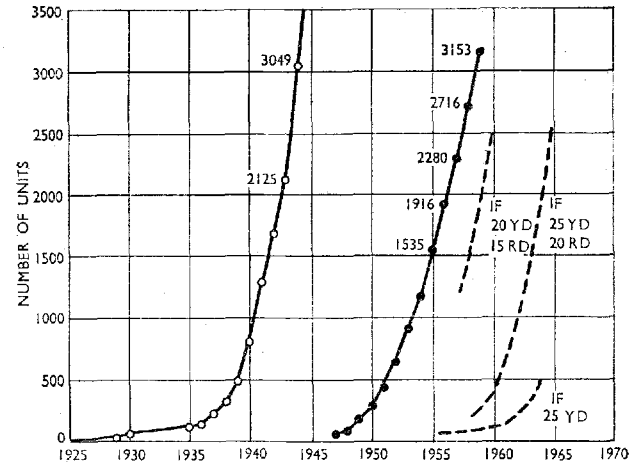



*Fig. 30. Diesel retirement record*

From I.C.C. statistics.

○ Acquisitions.
● Retirements.

The outstanding statement made in the paper causing the greatest amount of discussion appeared to be the short economic life used by him as 15 years for diesel motive power in line-haul service. That was one of the basic factors in the economic analysis, and had created doubt or amazement as expressed in the discussion by Mr Cock, Mr Warder, Sir Ralf Emerson, Mr Lambe, Mr Sykes, Mr Beavor, and Dr de Inza.

That short life was so intimately associated with the high rate of rise in repair costs, that to demonstrate one was to provide incontestable evidence of the other. The best evidence of the short life that could be offered was the record of retirements of that type of motive power. In Fig. 30 the cumulative total number of diesel unit retirements up to the end of 1959 were shown in comparison with the cumulative acquisitions of the same number of units.

It would be noted that the actual retirements were along a line approximately parallel to the acquisitions, some 12–14 years later. Most of the diesel units in service prior to 1939 were in yard or shunting service. If those units had retained the ability to give the service life of 25 years, originally assumed, those earlier units would still be awaiting retirement, along the broken line labelled 'IF 25, YD'. Those actual retirements had not been differentiated as to yard or line service, but if retirements had been made on the basis of a life of 25 years for yard, and 20 years for road units, allowed by the I.C.C. for depreciation purposes, according to the ratio of numbers in each class of service, the retirements would have been approximately along the broken line labelled 'IF 25 YD, 20 RD'. Or had the actual retirements been based on the 20-year life for yard or 15-year life for road diesels, as allowed by the I.R.S. for the study mentioned above, they would have followed the broken line labelled 'IF 20 YD, 15 RD'.

It was to be noted further, that since most of those retirements were made after 1950, most of those units were among the number making the experience and performance which caused the American diesel manufacturers to recommend, and the American railway administrations to adopt, the diesel locomotive after 1950 without further study. Further study after 1950–52 would have been pointless, because the manufacture of steam locomotives was discontinued.

Those actual retirements, shown in Fig. 30, substantiated the rate of rise in repair costs shown in Fig. 21. They also indicated a higher actual depreciation rate than assumed in Fig. 14 and in Table 4.

Another point mentioned by at least two of the commentators (Mr Tritton, Mr Cock) was his use of statistics. He was well aware of the well-known saying 'Figures don't lie, but . . .' He had endeavoured throughout the paper to use statistics in accordance with the definition, 'Statistics are classified facts, usually expressed in numbers, for the *inference* of general truths'. In no case had he 'generalized from specific instances', nor had he selected some data and knowingly omitted others. He had anticipated that criticism, and for that reason had incorporated in the paper *all* the cost statistics relating to railway motive power available from the best source. Those were all shown in Tables 1a and 2a. All operating statistics other than motive power costs had been shown graphically. He was of the opinion that engineers could more readily visualize the relations in graphs and curves to each other than in parallel columns of figures.

He had purposely avoided the use of index costs. He

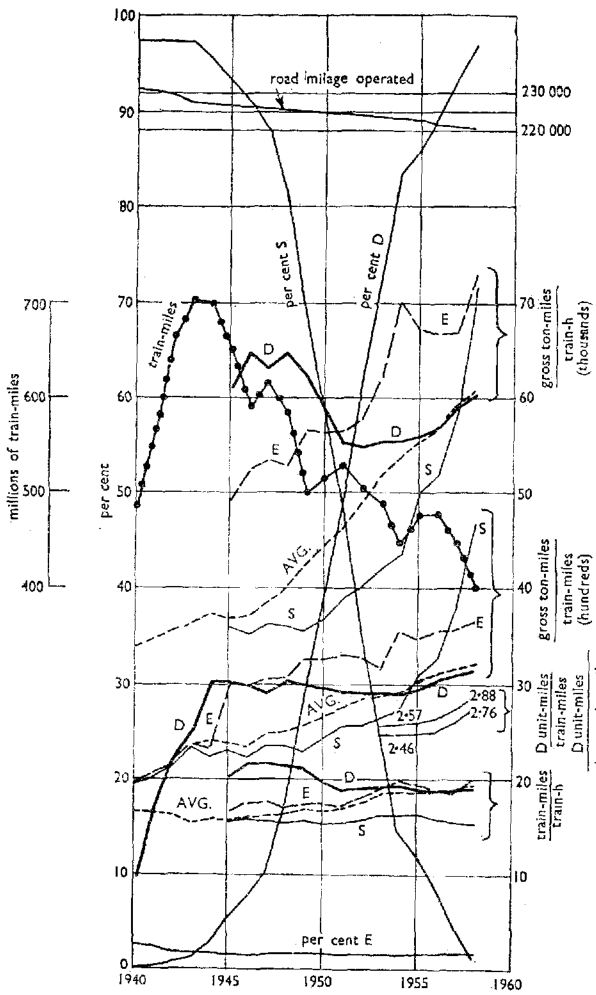



*Fig. 31. Freight train operating performance, all class I railways*

From I.C.C. Annual Statistics, Tables 55A.

S Steam.
D Diesel.
E Electric.

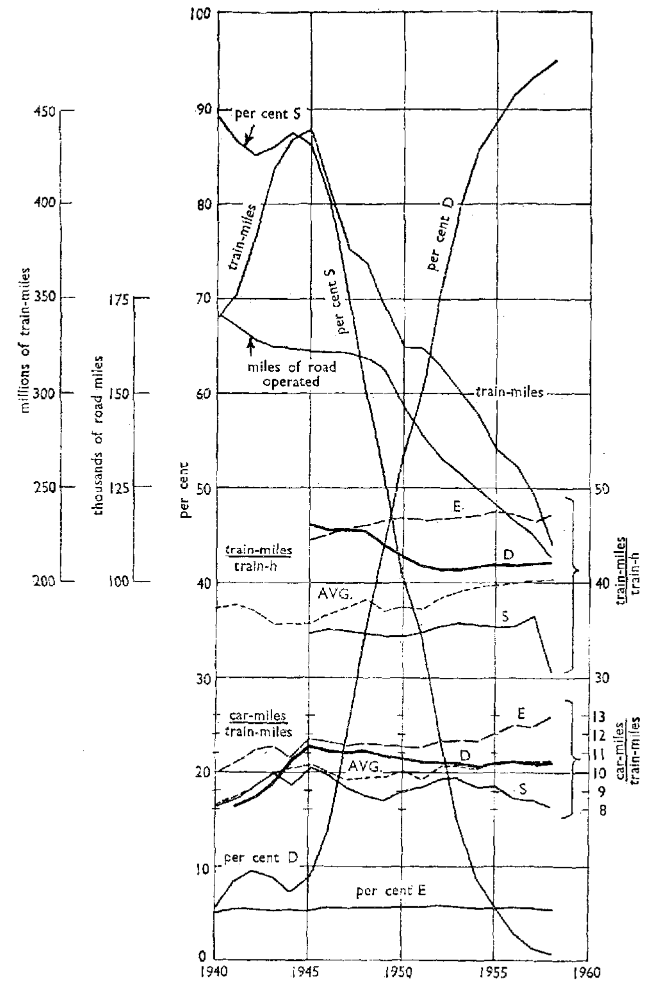



*Fig. 32. Passenger train operating statistics, class I railways, United States of America*

From I.C.C. Annual Statistics, Tables 55B.

Locomotive propelled only.

S Steam.
D Diesel.
E Electric.

was well aware of the care required and the dangers to be met in their use. The one place where he had used an index cost had drawn considerable discussion. He had converted all the motive power cost figures into ratio costs for comparing the costs of one year with another. That had the sanction of long usage in railway statistics, for example, 'operating ratio'.

All the statistics, numerical and graphical, were offered, not as *proof*, but as *evidence*, of what he had derived from his study of them relative to the subject of the paper. The reader, if interested, was invited to weigh carefully the evidence offered, not only in the paper, and in the reply, but any evidence offered by those who might have disagreed with his conclusions. The reader must form his own conclusions. He had no mission to try to convince anyone, or to make converts to his own thinking. He had believed for several years that the thinking on that subject had been misdirected, and the paper was his attempt to stimulate some new thinking.

After the paper was written, some further statistical evidence had been developed in graphical form and had been shown at the presentation of the paper. That was shown now for the benefit of those who were not present, but had submitted discussion. In Fig. 31 were shown the well-known 'statistical averages' of freight train performance on the class I railways for the years 1945–58, divided as between diesel, steam and electric, making up the total or average usually given. In Fig. 32 were similar data for passenger train performance. Those figures were necessarily complicated, because many items must be compared, but when carefully studied would furnish additional startling facts.

In Figs. 31 and 32, diesel performance was indicated by the heavy lines marked D; steam performance by the lighter continuous lines marked S; electric performance by the broken lines marked E; and the total or average performance, which was that usually reported in the statistics, by the fine dotted line marked AVG. In those diagrams also were shown the reduction in line milage operated, the total train-miles operated, and three 'percentage' lines indicating the per cent train-miles hauled by steam, diesel, and electric motive power. There were three major groups of graphs shown in Fig. 31 for freight train performance, each enclosed in brackets: gross ton-miles per train-mile; gross ton-miles per train-hour; and train-miles per train-hour. A small minor group indicated diesel unit-miles per train-mile, and per locomotive-mile. In Fig. 32 there were two major groups, each enclosed in brackets: train-miles per train-hour; and car-miles per train-mile.

The rise in the fine dotted lines, which was the average performance of all trains, had been used by statisticians as indices of increased railroad 'operating efficiency'. The increase in gross ton-miles per train-hour was an important factor used by the leading diesel manufacturer (as would be shown later) to show that that had been due to the substitution of diesel power for steam since 1945. So far as he knew, no one heretofore had taken the trouble to break down those averages to show performance, and the part each type of motive power had played in producing the average.

Mr Tritton had expressed a plea that the cost of speed be given greater account in the statistics. He was referred to 'train-miles per train-hour' in Figs. 31 and 32, and asked to note how little had been the increase in average train speeds, in either freight or passenger service, on the railways of the United States since 1945; also to note what little evidence there was, that any increase in speed was related to any type of motive power, unless electric. The evidence pointed rather to the fact that the slight rise indicated was due to the reduction in train-miles, which was mainly the loss of the slower speed, short-haul traffic.

In his discussion, he had misapplied the statement taken from the paper: 'No indication can be found that the change in type of motive power has produced any savings in this field'. That statement was made in the paper in connection with savings in expense of maintenance of way and structures. The statement relative to the ratio of diesel to steam operating costs was: 'The all-embracing economies claimed for diesel motive power on the class I railways of the United States, as a whole, do not appear in the statistical record'.

He had also asked, since he was in agreement with himself on the relative thermal efficiencies, 'why that advantage had not shown up in the figures for savings in locomotive operating costs?' The answer was that those advantages did show up in Table 4 and in Figs. 12*a* and 13*b*. Those fuel savings with others had been more or less cancelled by increased maintenance costs and investment charges (interest and depreciation).

His views relative to the Government operation of railways coincided with his own. However, in nearly every country except the United States, that type of administration prevailed—and it could not be denied that the railways were a vital part of any national economy. One enthusiastic diesel proponent had told him that diesel operation was the one factor that had saved the American railways from Government operation. The absurdity of that statement was obvious from all the statistical data shown in the paper. The claim had also been made that the diesel saved the American railways from Government operation in the 1939–45 war, since they had been so operated in the 1914–18 war. The absurdity of that statement was apparent when the small percentage of diesel operation was noted in Fig. 31. Steam and electric locomotives, in spite of being badly undermaintained during the economic depression immediately preceding the 1939–45 war had carried the United States railways through the war and were worn out in doing so. If the truth were known, the railways of the United States were more in danger of becoming Government operated today than they were in 1940, before the advent of the diesel. Type of motive power, however, had absolutely no bearing on the subject of Government operation.

Mr Cock, Mr Lambe, and Sir Ralf Emerson had questioned his assumption of $45 per h.p. used for hypothetical steam locomotives in the comparison of equivalent steam investment with that for diesel, assuming each investment was made in or about 1953. He had used an index factor of 1·49 to convert 1929 cost of steam locomotives to 1953 costs. That factor, in addition to being questioned by the above, had also been questioned by Mr Barton.

He had already conceded that the use of index factors had its dangers and could always be questioned. There were as many index cost tables as there were statistical bureaux and commodities. In that instance the Consumer Price Index of the U.S. Bureau of Labor Statistics had been used, based on prices between 1900–15 as 1·00. In that table 1929 index costs were 1·79 and 1953 index costs were 2·67. The ratio 2·67/1·79 was 1·49.

However, he had made some careful checks before using that index factor. In Table 6 were shown the actual costs of all the new steam locomotives acquired during the final five years of their manufacture (1949–53). The price per horsepower was calculated from his estimate of horsepower from the tractive effort. But the cost was also shown, as a check on that estimate, per ton of weight. If, during that five-year period those 132 steam locomotives were manufactured for an average cost of $44 per h.p., certainly a greater number could have been manufactured for $45, had production been continued. The index factor, right or wrong, became unimportant. It had been used in the Appendix to the paper to save words and space, because it seemed applicable. It did verify the actual costs.

He had specifically stated at the presentation of the paper, 'it is conceded that the figures for hypothetical equivalent steam operation may be debatable on certain points, but they cannot be wrong by more than a few per cent either way'. In Table 4 the costs for diesel operation were the actual costs incurred. The calculations for each item of 'equivalent steam' operating cost were outlined and explained in detail in the text of the paper in the section headed 'Analysis of

*Table 6. New steam locomotive units installed*

Source: I.C.C. Annual Statistics, Table 37, p. 36.

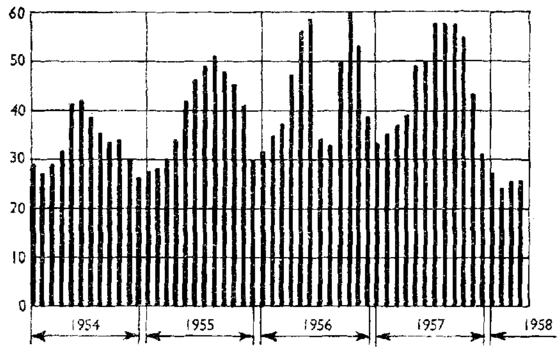
| | 1949 | | | | 1950 | 1951 | 1952 | 1953 |
|---|---|---|---|---|---|---|---|---|
| *Freight:* | | | | | | | | |
| Number of units | 10 | 1 | 32 | 17 | 8 | 7 | 6 | |
| Type | 2–6–6–2 | 2–6–6–6 | 2–8–4 | 2–8–8–2 | 2–6–6–4 | 2–8–8–2 | 2–8–8 2 | |
| Weight, tons | 228 | 424 | 281 | 327 | 322 | 327 | 327 | |
| Tractive force, lb | 77 900 | 110 200 | 74 612 | 126 838 | 114 040 | 126 838 | 126 838 | |
| Average cost, $ | 208 938 | 376 245 | 255 069 | 228 089 | 289 772 | 244 524 | 269 591 | |
| Estimated h.p. | 6000 | 6000 | 5000 | 6500 | 6000 | 6500 | 6500 | |
| Cost per h.p., $ | 35 | 63 | 51 | 35 | 48 | 38 | 31·5 | |
| Cost per ton, $ | 915 | 877 | 910 | 700 | 900 | 750 | 825 | |
| *Passenger:* | | | | | | | | |
| Number of units | | | | | | 3 | | |
| Type | | | | | | 4–8–4 | | |
| Weight, tons | | | | | | 293 | | |
| Tractive force, lb | | | | | | 80 000 | | |
| Average cost, $ | | | | | | 251 524 | | |
| Estimated h.p. | | | | | | 5000 | | |
| Cost per h.p., $ | | | | | | 50·5 | | |
| Cost per ton, $ | | | | | | 860 | | |
| *Switching (shunting):* | | | | | | | | |
| Number of units | 3 | | | | | | 15 | 30 |
| Type | 0–6–0 | | | | | | 0–8–0 | 0–8–0 |
| Weight, tons | 57 | | | | | | 144 | 144 |
| Tractive force, lb | 29 400 | | | | | | 62 932 | 62 932 |
| Average cost, $ | 53 946 | | | | | | 102 432 | 106 959 |
| Estimated h.p. | 1500 | | | | | | 2500 | 2500 |
| Cost per h.p., $ | 36 | | | | | | 41 | 43 |
| Cost per ton, $ | 947 | | | | | | 710 | 745 |

Locomotive Operating Expense Items'. In that comparison any one item for steam could vary by possibly several million dollars either way, but to substantiate the claims made for diesel savings, the cost of hypothetical equivalent steam operation in Table 4 would have to be *one thousand million dollars greater* (£350 million sterling).

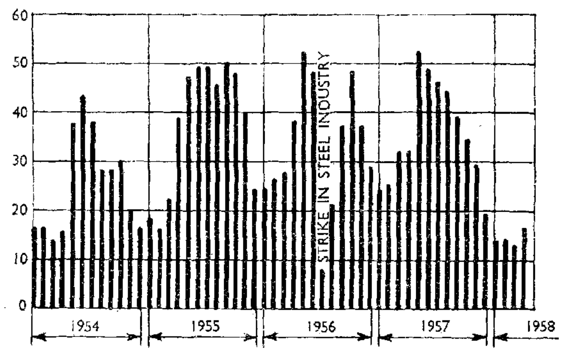
In that comparison, no specific 'huge steam locomotives up to 7000 h.p.' were assumed to be the *average*. In the Appendix a total of 11 800 steam locomotives having a total of 43 000 000 h.p. was assumed to be the equivalent to the existing 18 959 diesel units in line-haul service, having a total of 28 500 000 h.p. (approximately), on the basis that 2·41 diesel units were equal to one locomotive, and on the basis of the ratio of availabilities of 90 per cent for diesel and 60 per cent for steam. That was tipping the scales heavily in favour of the diesel, for few locomotives of any type under current traffic conditions in the United States were being used to the limit of their ability.

In Fig. 33 the utilization of diesels in both shunting and in line-haul service was shown for one of the very busy freight railroads having dense traffic, completely dieselized in 1953. He had calculated that the utilization on all the class I railways was 40 per cent in 1958 and 38 per cent in 1959. With such low utilization, *in general*, one locomotive of any type could be substituted for a locomotive of another type of the same age without regard to relative availabilities. Even with dense traffic, 'fleet' movements or the necessity of meeting specific departure and arrival times might greatly impair utilization.

On the basis of total horsepower and total number of




*a* Diesel shunting units.




*b* Diesel line-haul units.

*Fig. 33. Per cent of overall utilization based on hours available*

Railroad completely dieselized in 1953.

steam locomotives assumed in the Appendix, the average steam horsepower per locomotive would be 3650—not exceptional for 'modern steam power'. There would be as many types of steam, some larger and some smaller, as there were types of diesel power today. For in spite of so-called 'standardization' there were at least 30 different types of diesel units in service on the railroads of the United States today.

One 3650-h.p. steam locomotive would have the same hauling capacity as the 2·41 average diesel units shown in Fig. 3 as being in use for the average train. Such a steam locomotive would require but one crew, and not 2·41 crews, as Sir Ralf Emerson had suggested. Such steam locomotives had in the past, and would under the assumed conditions, operate over any grades currently being operated by diesels. A 5 per cent increase in helper service was assumed in the comparison.

A word was necessary concerning the idea expressed by Mr Cock and Mr Durrant, and which seemed to be prevalent in the United States and abroad: That trains of 10 000–15 000 tons had been made possible by the use of diesels in multiple operation, and that single locomotives (even composed of multiple-units) were hauling such trains over heavy grades. Trains of such tonnage had been operated by heavy steam power in the past, and might be operated today with diesel power over rolling profiles, of slight gradients, in coal or ore service where the entire train was made up of special cars equipped with adequate drawbar and coupler capacity. The average freight car, or wagon, on the United States railways was about 20–25 years old and had a rated drawbar capacity of not much more than 200 000 lb. The conversion from steam to diesel motive power had not changed those factors. In fact, where diesels had been substituted for some of the very heavy steam power formerly used in hauling those heavy trains composed of special draught gear, expensive strengthening of under-frames and draught-gear had been required on the diesels.

Trains made up of average or ordinary cars or wagons rarely exceeded 5000 tons. The increase in that average over the years had been shown in Fig. 8, and more especially for diesel trains in Fig. 31. In 1959 on 16 railways hauling the heaviest ton-miles per train-mile, those averages were of interest and were as follows:

| *Coal or ore traffic predominant* | | *General freight traffic* | |
|---|---|---|---|
| 1 Norfolk & Western | 5430 | 9 Erie | 3780 |
| 2 Virginian | 5250 | 10 Atchison T. & S. F. | 3650 |
| 3 D.M. & I.R. | 4900 | 11 Union Pacific | 3640 |
| 4 Bessemer & L. Erie | 4750 | 12 Illinois Central | 3620 |
| 5 Chesapeake & Ohio | 4500 | 13 Southern Pacific | 3620 |
| 6 Pittsburgh & L. E. | 4180 | 14 New York Central | 3600 |
| 7 Western Maryland | 4100 | 15 Pennsylvania | 3550 |
| 8 Baltimore & Ohio | 3800 | 16 Great Northern | 3510 |

Heavy freight trains were no heavier, and fast passenger trains were no faster, because of diesels. It had been to the interest of the diesel manufacturers to foster that belief because of the necessity of using diesels in multiple to replace the average steam power formerly used. Reference to Fig. 31 would show that since 1945 electric locomotives had out-performed diesels in ton-miles per train-mile, and since 1956 steam locomotives had out-performed both electrics and diesels in that capacity. That was not a function of type of motive power, but of the type of traffic in which the motive power was used.

Mr Cock had stated that it was believed that were it not for the diesels, the American railways would have gone bankrupt. Mr John W. Barriger, now President of the Pittsburgh & Lake Erie, in an address before the American Railway Engineering Association at Chicago, in March 1950, first made the following statement relative to the 'Monon' (Chicago, Indianapolis & Louisville Railway) of which he was then President: 'Complete dieselization of this railroad (and it was one of the first to become completely dieselized) had saved this line from bankruptcy'. Naturally the diesel manufacturing industry had not allowed such a statement, valuable for sales promotion, to be forgotten. Even at that meeting, however, the statement had been contested.

He would indeed be rash to express opinions contrary to those of such well-known and well-informed men as Mr Cock and Mr Barriger, for both of whom he had the highest regard. Nevertheless, if such a statement was to be applied to all of the railways of the United States, as a whole, there should be some definite evidence that all of those railways had been facing insolvency prior to 1940. Of course, a number of them had, but it was due to conditions shown in Fig. 1: lack of traffic, not inadequate motive power. The restoration of traffic restored solvency and earnings as shown in Fig. 23. There again, the restoration of traffic, solvency and earnings were contemporaneous with the general application of diesels. If the evidence could be made to show that traffic was restored by the change in type of motive power, from steam to diesel, then he would agree that the railways were indeed saved from bankruptcy by diesels.

The financial condition of many railroads in the United States was worse today than in 1949 when steam motive power was still predominant. It was entirely possible that in the case of some railroads it could be said that the diesel had been a factor in that state of affairs (he knew of at least one case where that could be proved). But in general, it was the continuing loss of traffic, principally to the automotive vehicles on the highways, that was causing the poor financial showing on the railways.

Mr Cock was quite correct in stating that the diesel was 'becoming permanently established on the railways of the world, and will survive on merit'. He had nowhere in the paper questioned that. He had only questioned the greatly exaggerated economies claimed.

In reply to other commentary made by Sir Ralf Emerson, he agreed that few of the costs mentioned in the paper were applicable to Great Britain. At the presentation of the paper he had stated:

> 'The paper points out the items of operating costs where savings may be expected, or where expenses may be increased by the substitution of diesel power for

steam. These savings or increases may or may not agree with those indicated in this paper, because comparative fuel costs or the availability of the supply may be greatly different. Other costs, particularly repair costs, may vary because of the difference in labour wage rates and material costs. These costs largely determine the economic life. This could be longer in Europe than it has been *so far* in the United States, if the rate of rise in these costs, with age, is lower. Regardless of relative labour and material costs, however, it does not appear likely that the relative position of steam, electric, and diesel motive power will be greatly different than shown in Fig. 21 for repair costs.'

He was in full agreement with all those who had pointed out that his conclusions regarding economies and costs in the United States must be studied carefully before being applied to some other country.

He had accepted Sir Ralf Emerson's suggested correction of his statement on p. 20 and had made an appropriate correction, and was also inclined to agree with him in his final statement. There were many factors of convenience relative to the use of diesels, mainly connected with the liquid fuel used: It was cleaner, more completely consumed with less smoke, more easily handled and stored, and in many countries today, more easily procured than coal. In the United States many people had changed from coal to oil for the central heating of their homes for the same purpose—convenience—but not always for economy. There was no doubt in his mind that for light traffic lines, especially in districts where all fuel might be scarce, the diesel could be the right motive power to use.

Mr Warder had seen from some of his own studies and investigations of railway motive power in his visits to the United States much that in the paper he had endeavoured to present to others who might be inclined to question many statements made in the paper; he was grateful for his support and for the endorsement of many of his views. Another noted European railway engineer, Dr Th. Thelander, formerly Director of the Electrical Department, Royal Board of Railways, Stockholm, Sweden, had reported in his admirable paper*, relative to his own visit to the United States as follows:

'In 1946 I got an opportunity to study diesel-electric traction in the United States for the first time. I found that it was easy to obtain statistical data on the economics of diesel-electric traction from the leading manufacturer of diesel-electric locomotives, the General Motors Corporation, while it proved difficult to verify these data in a satisfactory manner by means of comparisons. Not until after having travelled for a few months did I achieve my purpose when I came to Barstow and met one of the top executives in the diesel-electric division of the Santa Fe Railroad . . . and he kindly supplied me with the data that I needed. . . .

'At the time in question, the Santa Fe Railroad had to a large extent replaced steam operation by diesel-electric traction, and owned a considerable number of multiple unit locomotives rated at 4×1350, i.e., 5400 h.p., each. These diesel-electric locomotives were 2 to 5 years old. The railroad still had some 30 steam locomotives in operation, which were able to develop approximately the same draw-bar pull as the diesel-electric locomotives, as was demonstrated by draw-bar pull curves. The costs of maintenance varied within wide limits, but the average maintenance costs of the new diesel-electric locomotives were not lower than those of the old steam locomotives. Yet the maintenance of the diesel-electric locomotives was rationalized in a high degree. For this purpose, the overhaul which the locomotives had to undergo after having covered certain definite distances was carefully systematized. Moreover, the workshop operations were facilitated by first-rate equipment and were very well organized.'

There were two discerning European railway electrical engineers expressing almost identical views concerning their investigations of diesel economics in the United States. That was not strange, for the railway electrical engineer had learnt from long experience with railway electrification that economies must be earned by motive power, and those economies must be based on factual, and not hearsay, evidence.

He had purposely refrained from making economic comparisons between diesel and electric traction in the paper, its main purpose being to discuss the economics of diesel motive power in the United States in comparison with the economics of the steam motive power it had superseded. Mr Warder had correctly summarized the conclusions reached by himself in that comparison. Since the subject of railway electrification had been introduced in the discussion, he had no reticence in stating that his views on the subject fully coincided with those of Mr Warder, and he was gratified if the paper was any justification for the work Mr Warder was planning. He was also glad to accept Fig. 24 as a supplement to Figs. 17 and 18.

Replying to Mr Warder's question relative to the average number of unserviceable locomotives on any of the important American railroads, that information was included in the I.C.C. Annual Statistics as Table 17, until 1954, after which year it was discontinued for reasons not stated. In Table 7 would be found the salient features of those reports from 1939 to 1954 inclusive. It might seem strange to refer to the present fleet of diesels as being old at an average age of 7 years. But even in 1954, when, as would be seen from Fig. 5, their average age in line-haul service was just under 4 years and as seen from Figs. 31 and 32, that they were performing about 85 per cent of the train-miles, the unserviceable locomotives were just under 11 per cent. A 'shopping margin' of 10 per cent seemed to be a conservative estimate for diesel motive power. On one railroad with which he was acquainted, the unserviceable diesels for the past two years had been 21 per cent. But that railroad had had a poor record for equipment maintenance for several years.

The answer to his question as to whether 'the realization

* THELANDER, TH. 1956 'Analysis of Competitive Relations between Railway Operation Systems', p. 34.

*Table 7. Unserviceable locomotives*

Compiled from I.C.C. Table 17

| Year | Average No. of locomotives in service | | | | | Number serviceable | Number unserviceable | Per cent unserviceable |
|---|---|---|---|---|---|---|---|---|
| | Steam | Diesel | Electric | Other | Total | | | |
| 1939 | 41 622 | | 796 | 428 | 42 846 | 31 843 | 11 003 | 25·7 |
| 1940 | 40 297 | | 811 | 657 | 41 765 | 32 665 | 9100 | 21·9 |
| 1941 | 39 353 | | 804 | 1007 | 41 164 | 34 043 | 7121 | 17·3 |
| 1942 | 39 155 | | 806 | 1402 | 41 363 | 36 504 | 4859 | 11·7 |
| 1943 | 39 297 | 1653 | 786 | 18 | 41 754 | 37 313 | 4441 | 10·6 |
| 1944 | 39 309 | 2205 | 796 | 20 | 42 330 | 32 678 | 4652 | 11·0 |
| 1945 | 38 948 | 2833 | 787 | 25 | 42 593 | 37 431 | 5162 | 12·1 |
| 1946 | 37 575 | 3304 | 775 | 18 | 41 672 | 35 543 | 6129 | 14·7 |
| 1947 | 35 869 | 4019 | 756 | 28 | 40 672 | 35 003 | 5669 | 13·9 |
| 1948 | 33 585 | 5098 | 760 | 28 | 39 471 | 34 056 | 5415 | 13·7 |
| 1949 | 30 493 | 6669 | 734 | 22 | 37 918 | 32 222 | 5696 | 15·0 |
| 1950 | 26 575 | 8643 | 718 | 22 | 35 958 | 29 965 | 5993 | 16·7 |
| 1951 | 23 601 | 11 057 | 705 | 17 | 35 380 | 29 713 | 5667 | 16·0 |
| 1952 | 18 129 | 13 473 | 687 | 18 | 32 307 | 27 791 | 4516 | 14·0 |
| 1953 | 13 461 | 15 380 | 648 | 20 | 29 509 | 26 089 | 3420 | 11·6 |
| 1954 | 10 017 | 16 624 | 597 | 28 | 27 266 | 24 301 | 2965 | 10·9 |

Prior to 1943, diesels were included with 'other'.

was growing in the United States that a more effective use of the natural resources of the country might have to be directed on a national basis, and the prospects of its implementation', in so far as the railways were concerned was, unfortunately, 'No'. There was a certain amount of oil production control, and restrictions on the use of natural gas, but there seemed to be no outstanding realization in Congress that the railways should be protected in any way from the increasing automotive competition on the highways. New super-highways were being built contiguous to important main railway trunk lines, sometimes for 20 miles at a stretch, thus cutting off the ability of either to expand and serve new industries. He knew instances of where that had been deliberately planned with connivance of the highway trucking industry. Those were some of the important factors causing the present trend of declining traffic on the American railways, and he saw no immediate concern on the part of any civic body, municipal or state, or on the part of the Federal Government, to take action to change that trend.

Mr Lambe's discussion, with Fig. 25, showing the effect of cyclic heavy repairs on the rate of rise in those costs, was of interest. It was factual that diesel repair costs were quite cyclic in 3–6-year steps, depending on the repair programme set up. In Fig. 25, where both steam and diesel costs were treated in that manner, the general relation between the two types was not greatly changed from that shown in Fig. 21, which showed the general-trend lines only. Both general-trend line slopes would be slightly less, which would indicate a slightly longer economic life for each. As Mr Cantlie had pointed out, any locomotive could be maintained to last indefinitely. The point at issue was how many new engines, with possible changes in accessories in a diesel, or new boilers, with possible changes in pressure or superheat, in a steam locomotive, could be installed before the *economic* life had been reached?

The economic life involved several factors: the original cost; the average rate of rise in repair costs; and (if different from the original cost) the replacement cost and depreciation rate. He had treated that subject at length in a separate paper*, to which he would refer Mr Lambe.

In regard to graph A in Fig. 21: The slope of the trend line of repair costs gave the rate of rise in those costs with age, and that determined (largely) the economic life. The steeper the slope of the trend line, the greater was the rate of rise, and the shorter was the economic life. It was found that the graphs B, F, G, H, indicated economic lives of from 12 to 14 years. It was then possible to calculate the lesser slope of the trend line that would correspond to a 15-year life. That was graph A. It seemed, when the paper was written, more conservative to compare steam with graph A than with an average of graphs B, F, G, and H. At that time Fig. 30 had not been produced.

Relative to cost of repairs to 'overhead equipment': by that term it was assumed the entire power distribution system (including catenary contact system, supporting structures, sectionalizing, circuit breakers, etc.), was included. All that, in American railway accounting, came under maintenance of way and structures expense, and not under maintenance of equipment expense. In the United States, on the existing electrified railways, that had been from $300 to $1,000 per track-mile per year, depending on type of 'overhead' and traffic density (i.e., pantograph passages). The rate of rise in such costs, with age, was so low it was difficult to forecast the economic life, but it was

* Brown, H. F. 1960 *Amer. Inst. elect. Engrs*, Paper No. CP60-599, 'Locomotive Repair Costs and their Economic Meaning to the Railways of the United States'.

a fact that the oldest installation, still in use, was 55 years old and good for at least another 25 years, given the same care. In magnitude, for comparison with motive power costs on electrified railways studied, they would be comparable to motive power lubrication costs. (Those were among the factors he had in mind to discuss in a later paper on the results of electric operation on the railways of the United States of America, which, after the present paper with its discussion, might be quite unnecessary.)

The comparative maintenance costs of the electrical parts of diesel locomotives and on electric locomotives were also outside the scope of the paper. But Mr Lambe might be assured they were much higher for the diesel than for a modern type of electric locomotive, per 1000-rail h.p.-mile of service. If a modern 4500-h.p. rectifier-type electric locomotive were visualized with all-electric equipment static, except the motors (which in France would be two or four, but in the United States might be six), then to equal the starting tractive force and equivalent tractive force at high speed (say, 85 mile/h), a multiple-unit string of four 1750 *rated* h.p. diesels (each 1435 *rail* h.p.) were visualized each with four motors and each with a generator of the capacity of four motors, with its attendant exciter. The electrical control equipment on one diesel unit might be about the same as the control equipment on the single electric unit in so far as maintenance was concerned. Now if the engine were kept idling continuously with its generator, during terminal lay-over time, to keep the engine warm, and oily exhaust fumes were continuously blown through the four diesels, standing or running, after six months of operation of both types, without spending any labour for cleaning, it could be decided which of the two types would require the least labour cost to clean, inspect, replace commutator brushes, contactors, etc.

There were also the mechanical parts: in the electric there were two bogies, with at the most, six axles and 12 wheels (each with two brake shoes), making 24 shoes. There were also two sets of brake rigging, one set on each bogie. Now if was added maintenance of air brake valves, air compressor, blower motors and draught-gear, then for the diesel all that was multiplied by 4, except possibly the wheels and brake shoes, there would be 16 axles, 32 wheels, 64 brakeshoes, 16 pinions and gears against the maximum assumed above for the electric. If the maintenance of the diesel engine with all of its accessories was added, one more look at Fig. 21 would show those relative cost differentials.

In reply to Mr Cantlie, the 10 per cent used as salvage value in connection with the 15-year life was that specified by the I.R.S. in the study referred to above. The 40 per cent trade-in allowance he had mentioned was mentioned in advertising 3 years ago for 10-year-old units. Actually a 5 per cent scrap value at the end of a 15-year life could be more nearly correct because of the high labour cost of sorting out the different metals in the multitude of relatively small parts.

The statement relative to little study having been given by the railways to the change from steam to diesel after 1950, commented on also by Mr Cock, was made by himself at the presentation, and was factual. Prior to 1950 numerous studies were made by the manufacturers without cost to the railroads to induce them to make the change. After 1952 the railways had no choice—steam was no longer manufactured. He had no knowledge of any published comparative cost studies relative to railway motive power made after 1950. (See also his reply to Mr. McClean.)

The diesels in line-haul service at the end of 1939 were on the following 14 railroads:

| | *Number Horse-power* | | *Number Horse-power* |
|---|---|---|---|
| C. & A. | 2 at 1800 | F. E. C. | 2 at 2000 |
| A. T. & S. F. | 15 at 1800 | K. C. S. | 2 at 2000 |
| A. C. L. | 2 at 2000 | M. Pac. | 2 at 2000 |
| B. & O. | 12 at 1800 | S. A. L. | 19 at 2000 |
| C. & N. W. | 4 at 2000 | U. P. | 17 at 1400 |
| C. B. & Q. | 6 at 1600 | C. G. W. | 2 at 500 |
| C. R. I. & P. | 8 at 1400 | N. Y. C. | 1 at 600 |

Total 94 units 159 400 h.p.

In shunting service, up to the end of 1939, 41 railways had 472 diesel units in service, divided as follows:

| | *No. of Units* | |
|---|---|---|
| N. Y. C. | 82 | 7 railways had from 10 to 15 units. |
| A. T. & S. F. | 39 | 6 railways had from 5 to 9 units. |
| C. R. I. & P. | 39 | 9 railways had from 2 to 4 units. |
| I. C. | 29 | 10 railways had 1 unit. |
| L. V. | 29 | |
| G. N. | 27 | |
| N. Y. N. H. & H. | 24 | |
| C. B. & Q. | 22 | |

The record of the growth of diesel power on the railways to the end of the 1941–45 war was:

| Year | Shunting units | Line units | Year | Shunting units | Line units |
|---|---|---|---|---|---|
| 1925 | 1 | — | 1935 | 112 | Several |
| 1926 | 10 | — | 1936 | 163 | 22 |
| 1927 | 14 | — | 1937 | 221 | 40 |
| 1928 | 21 | — | 1938 | 298 | 64 |
| 1929 | 22 | — | 1939 | 472 | 94 |
| 1930 | 74 | — | 1940 | 700 | 154 |
| 1931 | 77 | — | 1941 | 1058 | 273 |
| 1932 | 77 | — | 1942 | 1314 | 428 |
| 1933 | 79 | — | 1943 | 1585 | 605 |
| 1934 | 97 | — | 1944 | 2025 | 1148 |
| | | | 1945 | 2375 | 1571 |

It will be seen from the above how few railways had any real experience with diesel power prior to the 1939–45 war, and that most of their experience was with yard or shunting power.

*Rising operating ratios* might be due to either increased operating expenses or reduced operating revenues, each with respect to the other. The paper had carefully analysed the effect of change in type of motive power on the total operating expenses. It had stated little about operating revenues because change in motive power had had no bearing on that. Average revenue per ton-mile and per passenger-mile showed increases in keeping with rise in expenses from 1915 to 1921. After 1921, drastic reductions in both were made until 1945, in an attempt to stem the growing loss of traffic to the automotive vehicles on the highways. Since 1945, those average revenues had again been rising, but not as rapidly as the rise in expenses. Average freight revenue per ton-mile in 1959 was about double that in 1900–15. Average revenue per passenger-mile in 1959 was about 1·5 times that in 1900–15. All expenses were about three times the 1900–15 level. That was the principal reason for the increase in the operating ratio.

Figs. 26*a* and *b* were interesting and valuable additions to the paper, for they illustrated (1) the difficulty facing the analyst in making the correct interpretation or 'inference of the general truths' from his combinations of the statistics; and (2) the necessity of observing 'parity' in making comparisons of one year's statistics with those of another distant year.

Since Mr Cantlie's discussion was the only one in which there was a sparkle of humour to brighten what had been referred to by a previous commentator as a 'rather gloomy analysis', he had possibly designated in Fig. 26 the areas showing the sharp rise in costs as 'Change-over to Diesel Traction' simply to point out to those who had claimed that the reduction in numbers of locomotives and in train-miles during that period was due to the change from steam to diesel: 'If these factors have been caused as claimed by this change-over, see what it has done to motive power costs'.

That might be the best way to let the matter rest—but he himself in his study must stick to literal facts, and point out that the rise in those graphs in Fig. 26 was *not* related to the 'Change-over to Diesel Traction'. In Mr Cantlie's analysis, the numbers of locomotives or the train-miles had been placed in the denominator of the cost ratio plotted. The rise in the graph simply demonstrated that during the years reviewed by that process, the denominator had shown a greater relative drop than the numerator. Fig. 26*a* simply became a reflection of the 'numbers' graph shown in Fig. 29, which earlier in the closing summary was shown to be related more to the loss of traffic since 1920–25 than to the change in type of motive power after 1945. Fig. 26*a* showed the slight rise commencing in 1925. Being a reflection of Fig. 29, it was also, by the evidence, related to the decline in traffic.

He had also shown that the decline in train-miles, as shown in Fig. 7, was also related to that same decline in traffic, if due allowance were made for the abnormal drop during the 1930–39 business depression, and the rise during the 1941–45 war. Thus Fig. 26*b*, being by construction a reflection of Fig. 7, also reflected the decline in traffic, with allowances for the depression and the war.

The evidence presented in Fig. 26, stated: 'Motive power ratio operating costs per unit had been rising as the number of locomotives had declined (with the traffic), and as train-miles had declined (also with the traffic). To answer the question why? the concept of *parity* must be applied. In Fig. 2 it was shown that the average tractive force for all locomotives had been slowly increasing through the period under review. In Fig. 3, it was shown that the horsepower per unit (for new locomotives) had been gradually rising. That meant that the unit cost of operating and maintaining those locomotives, gradually increasing in capacity, would increase provided they were performing more work. The evidence shown in Fig. 31 and in Fig. 8 clearly showed that trains had been slowly increasing in tonnage, and the evidence was strong in Fig. 31 that that had been due to the loss of the lighter trains in short-haul traffic. Thus the pattern was complete, and the evidence was all confirmed: Fig. 26 indicated how unit motive-power costs had risen: (*a*) due to the increasing predominance of the heavier motive power required; (*b*) to move the heavier train-miles made heavier largely by the loss of the lighter weight trains making up the total aggregate train-miles. The average motive power unit was not the same in weight, capacity, or cost of operation and maintenance, each year. That was the prime reason why the unit 'Cost per 1000 rail-h.p.-mile' had been chosen for comparing repair costs as between types and between years. That unit did not vary as did 'cost per locomotive mile'.

Similarly, it was equally evident that the 'train-mile', as a yard-stick of performance, had not been the same from year to year especially over the period under review. The train-mile of 1957 was a far heavier unit than the train-mile of 1940 or 1920. Parity in statistical units was very important and was one of the major reasons why the claims that had been made for the diesel cost savings could not be confirmed. Parity had not been observed in applying fuel costs, repair costs, train-mile costs or ton-mile costs, as between types of motive power and between years. That would be discussed further in reply to Mr McGee's discussion.

He agreed that 60 per cent availability for new modern steam power was low. But there again he wanted to keep the comparison conservative to favour the diesel at every point.

Regarding repair costs of diesels being higher than those of steam or electric: there was a vast difference in the wear on the mechanisms involved. In the steam locomotive a large mechanism consisting of two groups of heavy reciprocating parts performed 300 times a minute under pressures not usually in excess of 300 lb/in$^2$. In the diesel, 16 or more groups of lighter reciprocating parts were performing from 1000 to 1200 rev/min under pressures up to 2500 lb/in$^2$ and at temperatures so high that water cooling under forced circulation was required. That was but a partial comparison of steam *versus* diesel wear and tear. In addition, dust and dirt had little effect on steam locomotive maintenance or performance. In the diesel the fuel must be filtered before injection; the air must be filtered before admission to the cylinders or superchargers. Lubricating oil must be filtered. All filters must be cleaned periodically. A substantial amount of maintenance cost was along the lines of fighting dirt. It must be admitted that the application of such an engine to a dusty railway was in itself a noteworthy achievement. However, it was not essential to keep a steam or an electric locomotive so scrupulously clean as to fuel, air or lubrication.

The 'two-stroke' or 'two-cycle' engine largely in use on the diesels manufactured in the United States, exhausted a larger percentage of unburnt fuel than the four-stroke or four-cycle engine. That unburnt fuel accumulated on, and was drawn into, the locomotive when standing and idling. It got into the electric wiring and was blown through the windings of the motors and generators unless the air was filtered. Oil and some insulating materials were not compatible. In more recent years new insulating materials such as epoxy resins and glass tapes had been found which were less affected by oil. Some of those newer insulating materials were hard and more brittle and were more affected by vibration. All of those factors affected maintenance costs. That subject was further covered under his reply to Mr Lambe's discussion.

There was no doubt that it required a higher degree of skill to maintain diesels than steam locomotives; and certainly as many electricians, plus a few more other mechanics, than were required to maintain an electric locomotive.

The reduction of engine crew to one man on diesel and electric locomotives in yard and freight service had been accomplished generally on the Continent and more recently in Canada. The railways in the United States were trying to get the unions to agree to that—so far without success. It would save the class I railways at least $250 million annually in wages.

Relative to diesel operation in 'closed terminals'. He had reference to such terminals as the Grand Central and Pennsylvania Terminals in New York City. Those were entirely enclosed with terminal tracks served by long tunnels, having little forced ventilation, all over-built by streets and buildings. By New York State laws, enacted after a serious accident in the Park Avenue Tunnel in 1902, those terminals may not be operated by other than 'electric power'.

The effect of diesel locomotives on track maintenance had been debated pro and con over the period 1940 to date in the proceedings of the American Railway Engineering Association by the various committees on Track, Rail, Wood Bridges and Trestles, Iron and Steel Structures, and Impact and Bridge Stresses. The diesel manufacturers claimed reduction in track and bridge stresses and damage due to elimination of dynamic augment of reciprocating parts of steam locomotives and lower concentrated live-axle loads. On the other hand, track and rail committees pointed to greater rail damage due to smaller driving-wheel diameters with increase in damage due to more frequent wheel slippage with attendant rail 'burns'. A careful survey of track and way maintenance costs over the period 1940–57 showed no reduction in ratio costs (see reply to Mr McGee's discussion).

The author agreed that the future of the diesel was without question tied to the supply of cheap diesel fuel. There was much evidence when oil prices were studied (see Fig. 22), that the price of diesel oil was being controlled by the producers. It had remained relatively stable with minor fluctuations since 1948; whereas the costs of crude, residual fuel oil, and gasoline (petrol) had steadily increased in costs.

Dr Barwell's remarks touched on interest rates and the methods of financing railway motive power in the United States. It was true that for many years nearly all of the railways had acquired most of their rolling stock and motive power by the 'chattel mortgage' method. Indeed, nearly all private automobiles in the United States were acquired on that same basis.

The interest rates had varied from 3 to 5½ per cent depending on the credit of the individual railway and the 'tightness' of the money market. An average rate had been about 4 per cent during recent years. The principal sum was usually amortized by a series of equal annual (or shorter term) payments over a term varying from 12 to 15 years. The interest paid during the term of payments would be on the unpaid balance. If the rate was 4 per cent, 2 per cent on the principal sum during that term would be the average. That was the reason for using 2 per cent for interest charges in the paper in Table 4.

The difficulty of financing the necessary new investment in fixed equipment required for electrification might be financed by new mortgage bonds, were not most of the railways already mortgaged to the limit of their capital investment. New investment capital could not be increased by new stock issues unless the existing stock was selling on the market at par, or above. The market price was determined by earnings, which were insufficient in many cases to attract investors because of declining traffic.

He was in full agreement with Dr Barwell's concluding statement. That was the principal reason why the short economic life of the diesel would become an increased financial burden to many of the railways of the United States within a very few years.

In reply to Mr Sykes's question concerning utilization and availability, he had endeavoured to express his meanings in the paper as clearly as possible without any implied meanings or ulterior motives. All the larger railroads in the United States had spent and were spending countless hours in planning the scheduling of their best motive power to make the fullest possible use of it. It was a very large investment, and it must not remain idle any longer than necessary. It was possible to take a single locomotive, or even a few locomotives, and keep it or them constantly in service up to the full limit of their availability by carefully planned elimination of terminal layover time, by immediately dispatching over different routes served from the same terminal, or by short light runs to another terminal. That was done with the first several hundred diesels acquired in the United States. When, however, such utilization was attempted for the entire fleet of motive power, terminal layover time became longer. Power must be provided for *all* schedules (regardless of late arrivals), special moves, extra traffic, and all such exigencies with which every railroad operator was familiar.

The average utilization of *all* motive power on any railway was much less than the availability of a single unit, even when all were of the same type and there was no reason for favouring one particular locomotive or group.

In regard to rising repair costs, the assumption was that comparable service was performed each year for the first few years. If, after a few years, the locomotive was assigned to less active service, repair costs should fall somewhat. It was often difficult to relate such costs to individual units or to the age and to the miles performed by the individual unit. Not every railroad kept its records so that all those factors could be related. Nevertheless, the diesel repair costs and their rise with age shown in Fig. 21 had been carefully compiled. They had to be for the purpose they were to serve.

The milage mentioned of 67 000 per year for electric freight locomotives should result in quite low and very slowly rising repair costs. With such low annual milage, an electric locomotive of the size mentioned should have a life of well over 40 years.

The same low costs, with imperceptible rise with age, had been noted by himself for electric locomotives in France and in Switzerland. It might be due to the higher skilled and lower paid labour than in the United States, but he had no detailed knowledge of how such cost records were kept.

Average train speeds with diesels were little different from average train speeds with steam, as might be seen from Figs. 31 and 32. Train-hours were usually computed from the time the locomotive was attached to the car or cars forming a 'train' on the departure track to the time the locomotive was detached (or the markers were removed and the crew left) at the receiving terminal, and included all time consumed at way stations.

In reply to Mr Beavor's suggestion that the high cost of diesel repairs might be due to the 'American habit of replacing component parts by new ones instead of reconditioning them', and also that 'the terms of mortgage might stipulate maintenance standards which obligated the railways to buy new components at overhaul': the reconditioning of most of the small parts involved in diesel engine maintenance would be a far more expensive operation at prevailing railway wage rates in the United States than to replace them with new parts made to exact measurements under mass-production methods. That was generally true of all automotive vehicle repairs in the United States today where labour costs were quite high and material costs were relatively low. In Europe the reverse was true—materials were more costly and labour costs were much lower.

There were no stipulations as to maintenance standards in the mortgages under which railway stock and motive power were acquired by the railways. The banks, insurance and other financial companies lending the money and who were the 'trustee owners', were only interested in receiving the regular-term payments with interest due on the unpaid balance. A number of railways today had unserviceable equipment which might never be operated again but was left standing on storage tracks because of being unpaid for. When the final payment had been made to the 'trustee owner' his plate was removed and the equipment might then be scrapped, but not before.

He thanked Mr Birch for Fig. 27 and his statements relative to the difference between electric and diesel repair costs as shown in other types of automotive vehicles used in regular transportation services. The rise in those costs with the age of the equipment supported and confirmed Fig. 21 relative to railway motive power, by their general relationship.

To Dr de Inza he acknowledged that actual costs always carried more weight and conviction than those developed by any hypothetical studies, or those projected into the past or future by index costs. Yet in the determination of the economies made by the almost complete change in motive power that had been made on the railways of the United States, he believed that Dr de Inza, as an internationally known engineer and economist, would agree to the two following statements:

(1) Such a general replacement of railway motive power would not have been made in the United States so soon after the war, were it not for the fact that most of the railway motive power was really worn out and inadequate for further economic maintenance. That was confirmed by the rise in the average age shown in Fig. 5 and by the relatively few new locomotives acquired between 1930 and 1945, as shown in Fig. 4. Those few new steam locomotives were, in general, those retained in service or held in reserve in decreasing numbers down to the present time. Of course, in the sales campaign made to 'completely dieselize' the railways, there was no doubt that a number of railways retired perfectly good steam motive power.

If he was in agreement with the above then it must be admitted that the only alternative to the acquisition of diesels would have been the acquisition of the equivalent capacity of modern steam locomotives, *within approximately the same period* in which the diesels were acquired. (And the retention of the good steam locomotives retired, would have reduced the new investment in that steam power.)

(2) Having acquired the diesels, we wish to determine the actual economies made by that change in motive power. The true savings were not found by comparing the actual costs of today's operations with the former costs of the former type operated in 1930–40. Conditions had become vastly and radically changed by general economic conditions completely disassociated from railway motive power. Today's actual costs must be compared with costs which must be calculated in part from former costs of new motive power of the former type, of sufficient equivalent capacity and operated under current conditions.

That was the attempt made in Table 4, simply as a check, to see whether any of the large economies claimed for the diesel had in some way been overlooked in the analysis of the operating statistics.

Dr de Inza's suggested clarification and reassessment of the high depreciation figures for diesels had been made owing to his justifiable doubts concerning the short economic life shown in the paper. Possibly Fig. 30, which Dr de Inza had not previously seen, might serve to dispel those doubts concerning the high depreciation rates required for diesel power in comparison with steam.

Mr Durrant, in addition to matters already discussed, had touched on matters on the British Railways somewhat out of his (the author's) immediate knowledge and the scope of the paper. It was well known and recognized that diesel rail-cars had played a successful role on the lighter traffic lines on the European railways and on some of the branch lines still operated in the United States. That traffic and service in the United States was vanishing rapidly.

Lt-Col. Fell was to be congratulated for having recognized, as early as 1933, the high capital cost of diesels in comparison with steam. In that same connection he would like to quote some pertinent excerpts from a paper delivered by Robert S. Binkerd, then Vice-President of the Baldwin Locomotive Works, Philadelphia, before the New York Railroad Club on 25th April 1935, at which meeting he himself had been present:

'Tonight I propose, . . . to speak without prejudice. I think I am in a position to do so, and when I say this, I say it not only on behalf of Baldwin Locomotive Works, but *on behalf of the three recognized locomotive builders* in this country. Each of us has the engineering brains and the manufacturing ability to build any kind of a thing that moves on wheels . . . we want to give that client sound and intelligent advice free from the fads and fancies of any given moment—advice that ten or fifteen years from now he will have been glad to have received and acted on.

'Today we are having quite a bally-hoo about streamlined, lightweight trains and diesel locomotives. . . . The speeds that are being made with these diesel streamlined trains are not because of any fundamental characteristics of the diesel engine, but in spite of them . . . a fundamental characteristic is a rapid loss of draw-bar pull at speed, so that at 70 or 80 miles an hour a diesel locomotive can hardly exert one-tenth of its starting power. . . . (Here is) the tractive force curve of a better diesel locomotive than has yet been built. We designed it, but nobody yet has come forward to pay $400,000 or $500,000 which would cost to build it. This diesel locomotive has the advantage of two 1975 hp. engines that weigh only about 13½ pounds per hp. It has the advantage of special and expensive electrical and mechanical equipment designed to overcome, as far as possible, that characteristic loss at speed of power delivered at the rim of the wheel. But . . . at 80 miles an hour this diesel locomotive has hardly 15 per cent of its original tractive force left.

'On the other hand, turn to the tractive force curve of the Northern Pacific 4–8–4 which we built last year. . . . Note that it has a tractive force at starting of only 70,000 pounds. But at 80 miles an hour, it still has nearly one-third of its original tractive force. . . . And lastly, note that this steam locomotive . . . would be reasonably priced at not more than one-third of what it would cost to build the diesel locomotive with which it is compared.

'But I wish to point out with equal clearness that no one can predict with any certainty as to what the maintenance costs of a diesel locomotive may be over a life of 20 or 25 years. And I do wish to say unequivocally that there is not one scintilla of evidence to justify the claim that a diesel locomotive of equal weight on drivers can be maintained at a cost as low as that of a steam locomotive of the same age after the first year or so. Everything points to the probability of a substantially higher maintenance cost for diesel locomotives than for equivalent steam locomotives of the same age. The only thing nobody knows is how much higher.'

Those statements were in agreement with many of those of Lt-Col. Fell.

Those were some of the reasons why the *steam locomotive builders* did not push the sales of diesel locomotives. They saw the truth from their years of experience and knowledge of railway motive power. The only things they could not foresee in 1935 were the five more years of economic depression; the war; the worn-out steam power and the necessity of wholesale replacement of it; the sales promotion and capture of the business by the automotive industry; and their own exit from steam locomotive building in 1952.

If American steam locomotives sizes and capacities had remained the same as prior to 1915, and trains had not become so heavy, the economy of diesel operation might present a different picture. For example, if the railways of the United States could operate trains today similar to those operated in England and on the Continent of 30–50 wagons with a crew of 2 men, 2·5 times the present number of trains could be operated. Better service could be rendered, all with no additional motive power and with no additional labour costs, and with no curtailment in the number of train employees. The union agreements, however, precluded the possibility of such operation, and the longer, heavier trains were the result.

Mr Fuller's interesting contribution was the somewhat logical suggestion that diesel-electric repair costs were the addition of the repair costs of the electric locomotive and those of the steam locomotive. That was to a certain extent true. However, as pointed out in the discussion and reply to Mr Lambe and Mr Cantlie, the maintenance costs of the electrical equipment on diesel-electric locomotives were higher than on a simple electric locomotive. The duplication of motors and the generator, together with the necessity of multiple-unit operation with the diesels to achieve capacity, could always be built into a single steam or electric unit.

Reliability was to a large extent dependent upon experience and a thorough knowledge of the equipment by those who maintained it. Good preventive maintenance and where to look for trouble were first essentials.

It had often been said, and with a certain amount of truth, that the difference between a steam locomotive and a diesel was that on a steam locomotive it took 5 minutes to locate the trouble, and 5 hours to 'fix' it; whereas on a diesel, it took 5 hours to locate the trouble, and 5 minutes to 'fix' it.

He agreed with Mr. Fuller, that the possibilities of developing a more economic type of locomotive having an internal combustion-type prime mover had not been exhausted, and must be pursued. The railways of the United States, however, had no joint research organization for that type of development and must look to the manufacturing industry to produce such a locomotive That industry had no incentive to destroy their present renewal part business or to produce equipment having a longer life between renewals.

In regard to Mr Owen's query relative to the extent the short life of diesel-electric motive power had been due to non-technical considerations, such as company policy, incidence of taxation, or rulings of regulatory bodies such as I.C.C., it was his considered opinion that those factors had had little bearing on the retirements made to date, shown in Fig. 30. That figure confirmed the short economic and service life, regardless of analysis of statistics. Increasing repairs with age and obsolescence had been the real factors.

Several railways had attempted to rebuild diesel locomotives in their own shops, as steam locomotives once were, but it had been found to be usually too expensive. The heavy overhaul of a steam locomotive was not greatly different from its original manufacturing procedure, and nearly all large railways had shops with trained labour and supervision to handle such procedure. In fact, several large railways built their own steam locomotives.

An entirely different type of motive power had then entered the scene. The former shops, facilities, machines and type of skilled labour were all rendered inadequate—all had to be replaced by something different (see Fig. 16). On that new equipment new unit assemblies replaced an entire assembly on which a lesser item had failed. After removal the faulty item was found and replaced and the assembly awaited another replacement. There came a time, with age and service, when too many units and assemblies were out of service because too many items needed attention. Few shops equipped for simple part renewals or unit assembly replacements could cope with complete heavy overhauls, except in special cases. One diesel manufacturer, as part of his 'service' to the railways, had even designed the shops for their repair up to that point. For the final heavy overhaul, after about the twelfth year, he said, 'let us rebuild it'. But he would not tear down and rebuild it in kind. It must always be a 'later model' like an automobile, not only with increased capacity, but with greatly changed appearance. 'Streamlining', once the trade-mark of the diesel locomotive, had become old style—obsolete. Even the underframe, or car-body, as it was called in American railway parlance (Sir Ralf Emerson in his discussion had called that the hull), was no longer adequate. So the old unit was perforce—retired—sold back to the manufacturer for a small fraction of its original cost. In time, a new (i.e. rebuilt!) unit was received in return, costing more than the original unit, and which must be paid for anew, on the 'chattel mortgage' basis.

An important question being asked today in the United States by all consumers of modern automobiles, household appliances, even railroad motive power, was, 'how much built-in obsolescence is there in this apparatus when it is purchased new?' It was a legitimate question and a serious one.

Mr McClean had found that the paper presented a 'misleading picture' to one like himself having substantial experience of dieselization in the United States and on oversea railways. He himself had had a little *railway* experience in both areas. He quite understood that Mr McClean, from his position as Manager of Export Sales of the largest American manufacturer of automotive highway vehicles and railway diesel motive power, could not be otherwise than at wide variance with the paper at every point possible.

In the second paragraph of his discussion, he had correctly, and with precise wording, summarized the conclusions reached in the paper. To state, however, that 'those findings were those of the author alone', however complimentary that might be intended, indicated that he had been more attentive to the sales than to the performance of railway motive power in the United States during the past few years. That again was to be expected from his position.

Three times in his discussion he had invoked all the United States railroad presidents to support his opinions against those expressed in the paper. A poll of opinion could hardly be accepted as conclusive evidence. If he actually could show from his own or from any other investigations, evidence to refute that offered in the paper, it would seem more factual than to 'call upon all the gods at once' to blast that base traducer of the good name of the American diesel.

Possibly he felt that the gods were on his side in that matter. About three years earlier the diesel manufacturing company he represented, in a series of front-cover advertisements on the leading American railway weekly magazine, had honoured in turn many of the prominent railway presidents. Their portraits were presented in colour over the trade mark of the manufacturer, with the caption, 'Men who have built the future of the American Railroads' (obviously, no doubt, by purchasing diesels from the sponsor).

Few railroad presidents in the United States had achieved that position of responsibility because they were motive power experts. For a large railway supplier to couple their names in that manner with its product might have been dramatic sales promotion, but it could be considered to be pointing in too many directions in these days when the sale ethics of so many large American business enterprises were under fire. He would simply point out to Mr McClean that that action of his company had possibly placed those busy officials in a position where to call upon them for testimony in that matter, either pro or con, might be somewhat embarrassing to them.

Mr McClean had then made a serious charge, which he himself could not accept and must counter:

> 'If the author's presentation was correct' (and the author will continue to endeavour to show that it is) . . . 'then the fine managements of those many railroads (and of the locomotive builders) were, without exception, *by implication* incompetent to a point which would constitute negligence, and that all those railroads had, *by the author's paper*, been deliberately misled in their policy of

dieselization by the erroneous claims of the locomotive manufacturing industry.'

He wished it to be clearly understood: that the association of all those ideas in that statement was made by Mr McClean. He himself had made no *implications* of any kind in the paper. He had been extremely careful *not* to couple any 'claims found to be erroneous' with any 'locomotive manufacturing industry'. No statements of any kind had been attributed to any individual or group, unless it was clearly on the record.

Mr McClean apparently had read into the paper in too many places, ideas that he had *not* said, written, thought, or 'implied'. Every statement had been given careful thought, because the paper was contrary to a number of prevailing opinions. Further on in his discussion under the heading '*Traffic*', he had again made similar charges, associating with the word 'campaign', his own words 'improper sales promotion' and 'claims justifying the purchase of diesels were inaccurately presented'.

Since Mr McClean had introduced all those pointed statements to the attention of the readers, he believed that they should be correctly informed *from the record* (part of which had been published only recently) as to just what the 'locomotive manufacturing industry' did tell the railway industry about dieselization in those early days. It now became a vital part of his reply to Mr McClean's entire discussion, and threw entirely new light on the subject of the paper. It placed him on much firmer ground, and Mr McClean very much on the defensive.

He had already shown in his reply to Lt-Col. Fell's remarks, exactly what the Vice-President of the Baldwin Locomotive Works, speaking 'on behalf of the three recognized locomotive builders in this country', had told the railway industry in 1935. The performance records, as shown in the paper, seemed to show that the ideas expressed by Mr Binkerd at that time were not only sound, but prophetic.

At that same meeting in 1935 he had also made the additional statement:

> 'Therefore, the field of probable profitable application of the Diesel locomotive is pretty generally indicated at work speeds not exceeding 10 miles an hour.'

That forecast to the railways was also confirmed by the statistical record which the paper presented.

In those statements the managements of the (then) leading locomotive manufacturers, who, with the collaboration of the leading electrical manufacturers, had been making diesel locomotives for yard service since 1925, electric locomotives since 1905 and steam locomotives since the earliest days of their production in the United States, gave the railways their best advice concerning the *economies* to be expected from the diesel, in comparison with steam power. Why should they have tried to expand the sales of a product they honestly believed would not be as economic as steam? Its first costs and its maintenance costs would be much higher. No one could say that the railways were 'deliberately misled' by 'erroneous claims' made by any one of the steam locomotive manufacturers. The fact that some of them were no longer in the locomotive manufacturing business in no way invalidated the advice given. It had been confirmed as sound advice by the subsequent performance.

Quite recently, and quite timely for the present discussion, he had received a booklet* sent out to all the shareholders of the automotive and diesel manufacturing corporation with which Mr McClean was associated. In that, there was a short chapter entitled 'Steam *versus* Diesel', which was so germane to the discussion that he wished to quote two consecutive paragraphs from it verbatim. They showed the sales approach of that manufacturer, *by its own acknowledgement*, with the railways relative to its sales promotion of diesels:

> 'Looking back after the many years Diesel locomotives have been in service, the advantages of Diesel power as compared to steam power, for locomotives, are obvious. The record speaks for itself. But in the early years of the Diesel locomotive industry, it was necessary to dramatize these advantages even to prospective customers who were not steam-engine minded.
>
> 'Among other sales tools, a method of selling was developed, and is in use today, called an economic study. Based on the performance record of Diesel electric locomotives of all types that were in service, it was possible to project the economies and return on investment of replacing all steam power with Diesel electric equipment. These studies became the standard method of selling in 1946, because a return on the investment of upwards of thirty per cent per year could be shown in comparison with steam operations.'

There was disclosed for the first time to himself, and he now shared it with the reader, the source of the claim, made all those years, for the 'thirty per cent per year return on investment'. It really *was* made by that manufacturer in 1946 to *dramatize* the product they wanted to sell. To call an economic study a 'sales tool' developed in 1945 to promote the sales of diesel locomotives, was akin to saying the mariner's compass was developed by the Cunard Line to promote trans-Atlantic travel.

It should be noted that the 'thirty per cent savings per year' in no case had been the *actual* savings made by the diesels installed, but in every case were the *estimated* savings which could be made, if *all* the railways were dieselized. That was *estimated* to be $550,000,000 in 1946 in the booklet referred to above.

It should also be noted in his reply to Mr Cantlie relative to the number of diesels in service, that about 58 per cent of the diesels were in yard service in 1945 (on which year any *estimate* of diesel performance would have had to be based in 1946). No doubt those had made notable savings.

Also should be noted, from Figs. 31 and 32, the quite small percentage of total diesel operation which must be 'magnified' to become the total, in 1945–46.

It was curious to note also that in 1957, with but 69 per

* G.M. CORPORATION 1961, p. 8, 'The Electro Motive Story'.

cent of the motive power, and the corresponding reduction in train performance, those *estimated* savings over steam operation had grown to $1,000,000,000 (Mr McGee now stated that in 1959 they were $1·5 billion).

There was no longer any wonder in his own mind why, in his search through all the statistical records of actual operating performance, he could find no substantiation of those 'dramatized' *estimates.*

No railway electrical engineer, with any knowledge at all of economics, would ever suggest that *all* the railways of the United States be electrified. That would be nonsense. Neither should have any locomotive manufacturer ever suggested that *all* the railways be dieselized, except for their own profit motives. There were many places in the United States where it would have been far more economic to electrify. There were many places where diesel operation was without doubt the proper and economic method to use, just as in every other country in the world. There was a proper and economic place for steam operation, as demonstrated by a number of railways, until steam could no longer be obtained or maintained. The place for each type could still be found by economic studies that were *not* dramatized sales tools.

Not content with the elimination of steam, one diesel manufacturer had continued its dramatic 'sales-tool' studies of existing electric operation in comparison with substitute diesel operation, with the script written in red ink for the electric, and in what appeared to be letters of glittering gold for the diesel.

The Interstate Commerce Commission, reporting recently on the wretched state of affairs of one railroad, which had received and *acted* on such a dramatized 'sales-tool' study, described it quite aptly as 'a mirage'.

*Locomotive repair costs*

Under that subject, Mr McClean had presented Fig. 28 as evidence that repair costs shown in the paper were not typical.

Those had the appearance of 'cumulative' repair costs. That was a method of keeping repair costs, devised by the manufacturer, to disguise the true rise. Cumulative costs had one-half the actual rate of rise with age.

He had then stated that those 'would be equally misleading' (as those shown in Fig. 21), 'since the values were most likely well below the average for most railroads'. (As indeed they were.) Why then should such figures be presented as evidence? Why not show just what the 'typical costs' were, if he had them. The costs shown in Fig. 28 were as far below graph A in Fig. 21, as the graphs B, F, G, and H were above graph A. Graph A was calculated for a 15-year life (used in the comparison with steam power). The slope of graphs B, F, G, and H indicated economic lives of from 12 to 14 years, and were confirmed by retirements shown in Fig. 30.

He had then cited a statement from a railway president to the effect that diesel repair costs on his road 'levelled off'. That was even contrary to Fig. 28. It was of interest to note that on that president's railway, 87 diesel units had been retired up to the end of 1959. That was exactly the number in service on that railway at the end of 1946, 13 years before, thus again confirming Fig. 30 which, *per se*, confirmed Fig. 21.

One interesting point was noted in Fig. 28: the graph for the latest unit (or group) starting in 1950–51 had a steeper rate of rise than the graph for the earliest unit (or group) starting in 1945. That was to be expected, if the engine had been given a higher rating. The materials would be working harder, and the repair costs would rise at a greater rate. Since all costs in any one year were comparable, adjustments for price levels would have no effect on that relationship. That was poor evidence of lower repair costs due to 'product improvement'.

*Fuel costs*

To Mr McClean Fig. 22 was 'unfortunate' and misleading because it presented fuel costs on a B.t.u. basis so that they might be equitably compared. That figure was simple and factual and would mislead no intelligent person when considered with the text it was designed to illustrate.

He had referred to the actual fuel cost in 1957 of $367,000,000, as being 'suggested' in the text. That cost was shown in Table 1*a*. He thought that the method of calculation, shown fully in the text, of $408,000,000 for equivalent coal 'might be questioned as unfavourable to diesel', but he had failed to submit any evidence to support his statement, or even to outline his ideas of a method more favourable to the diesel.

*Depreciation and obsolescence*

No one, in the period 1942–50, had any reason to question the 20-year life that had been agreed upon jointly by representatives of the railways and the manufacturers with the I.C.C., for accounting purposes. The line-haul units in service at that time were too new. By 1953 there were a few scattering indications that some might have a shorter life, possibly 15 years. As late as 1954 he had used the 20-year life in a technical paper*.

He agreed with Mr McClean that 'there was ample evidence to indicate that the locomotive . . . was going to be a satisfactory piece of operating equipment *at that time*'. There was no 'implication' in the paper otherwise.

Mr McClean had then attributed to him statements not made in the paper: (The author) . . . 'was critical because the manufacturers, by an active programme of continuous product improvement, with the encouragement of the railways, had made it possible to establish economic justification for replacement or remanufacture of the locomotive before it had reached its 20-year life.' By that phraseology he was stating that the railways had figuratively said to the manufacturer(s), 'we know our locomotives are only 12 years old, and we can use them just as they are for another 8 years, but we know they are obsolete from what you have

* Brown, H. F. and Kimball, R. L. 1954 *Amer. Inst. elect. Engrs*, Paper No. 54–29, 'A Reappraisal of the Economics of Railway Electrification: How, When, and Where Can it Compete with the Diesel-Electric Locomotive'.

told us. Please take them back and rebuild them to be like the two you sold us this year. They are bigger, and we will only have to use three instead of four.'

If Mr McClean, or his company, believed *any* railroad in the United States was in a financial position to do that with their motive power, unless it had become inoperable or too expensive to continue to repair, they had become self-deluded by their own philosophy. Railway traffic had declined, and was continuing to decline. On most railroads three old units could do the work of four formerly required, in general, if they were at all operable and could still be maintained.

That 'continuous product improvement' mentioned was simply the continuous effort of the manufacturer to improve a design of engine, possibly obsolete, in order to produce a part of greater capacity per unit that the railways had been continuously requiring. It was also highly significant and unfortunate that most of that 'product improvement' was not made until the railways were more or less completely dieselized, after 1953.

The fact was still clear, that diesel motive power had not been retired or 'rebuilt' (i.e. replaced) until it had become badly worn out and incapable of further use. The diesel locomotives as presently manufactured in the United States, simply and factually, did not have a long life.

The railway industry, in spite of Mr McClean's fantastic statement about long life involving 'technical stagnation' was still entitled to the long life equipment it formerly had, in *any* type—steam, electric, or diesel—and must have it if it expected to survive under present-day competition.

'Technical stagnation a great demerit of electrification'! That statement would surely raise the eyebrows of every railway electrical engineer in every country in Europe, if not all over the world! Mr McClean was viewing technical progress through the wrong end of the opera glasses supplied with every one of his 'dramatized sales tools'. Possibly one of the best examples of 'technical stagnation' was the diesel locomotive as manufactured in the United States today.

Why otherwise would two of the progressive railways in the United States be importing from Europe a number of 4000-h.p. diesel units having hydraulic drive? Why otherwise would one American manufacturer have recently developed a high horsepower unit with every detail newly designed toward reduced maintenance? (The fact that that manufacturer had been unable to sell any was another part of the story.)

### *Traffic*

If Mr McClean were an experienced railway man instead of a diesel sales executive, he would recognize that Fig. 1 (which he thought misleading) was a fair representation of traffic on the American railways in so far as its relation to the subject of the paper was concerned; which was *not railroad revenue*, but diesel motive power economics.

Traffic must be hauled, as offered or as scheduled, regardless of type of service. Revenue had little bearing on type of railway motive power. Passenger traffic must be provided with motive power the same as freight, in accordance with the train milage to be performed. Train-miles were the units for which the motive power operating officers must provide. In fact, diesel motive power was used in passenger service for several years before it was used in freight service. Mr McClean had possibly forgotten that.

The most casual glance at Fig. 7 would show that for the past 30 years, in spite of losses to the automotive traffic on the highways, the American railways had continued to operate considerable passenger train milage. As late as 1957, it was 60 per cent of the freight train milage. That had required its fair share of diesel motive power. With that in mind, Fig. 1 would mislead no one who understood railway operations in the United States.

His introduction of 'sales promotion of diesel locomotives' at that point had already received sufficient commentary. The relationship of that subject to *traffic* seemed to be significant to Mr McClean.

Next, for some reason not made clear, he had stated,

> 'For the benefit of the uninformed, perhaps it would have been desirable that the author should have made it plain that the reference to the automotive industry should not be taken to imply that automotive manufacturing facilities were converted to locomotive manufacture.'

Again nothing was stated or implied concerning that in the paper, nor did he himself see any bearing it had on diesel economics. However, since Mr McClean had introduced the subject, he wished to quote another statement made by Dr Th. Thelander, on p. 29 of his paper already referred to under his reply to Mr Warder. That had a pertinent bearing on the entire discussion and on the subject:

> 'It should be observed that the extensive use of diesel-electric traction in the United States is in a not inconsiderable degree to be attributed to the topography of that country. In the inland, the trains perform daylong runs extending over broad tracts of flat, open country, which are practically free from difficult upgrades. In the mountainous regions of the East and the West, on the other hand, the character of railway traffic is different. In these regions, the railway men make a virtue of necessity. They utilize the ability of diesel-electric locomotives to develop a great draw-bar pull at a low speed as the trains are slowly hauled up the steep grades. This causes great losses of time, but they are of little importance since they are largely made up for on the wide-stretching plains.
>
> 'In spite of the circumstance that the train schedules are thus adapted to the topography, the unproductive locomotive weight in the United States often amounts to such a substantial part of the total train weight that the economic aspect of American diesel-electric traction appears to be debatable. Contrary to what one is sometimes led to believe, this statement holds true regardless of the structure of the train service, which is characterized by a large proportion of very heavy trains in the United

States. In fact, the draw-bar pull required at the draw-bar of the locomotive per ton of weight of cars remains unchanged irrespective of whether the trains are heavy or light, and is dependent only on the speed and on the lay of the land. Therefore, it seems as if the widespread use of diesel-electric traction in the United States were determined by financial factors rather than by engineering and economic considerations.

'If we take this broader view of American diesel-electric traction, then we discover several noteworthy circumstances. We find that very large industrial resources which had been tied up in the manufacture of diesel-electric generating sets for submarines during the Second World War were turned to account by using such sets in railway traction. Furthermore, we realize that diesel-electric traction has enabled the railways to make full use of the production and the distribution of fuel oil, which are well developed in the United States. Moreover, it is possible that some commercial banks which are interested both in railways and in industries tend to favour diesel-electric traction as a business link which induces the former to become important customers of the latter. Finally, it may be presumed that those engaged in high finance prefer to keep their capital in the form of liquid or floating assets, which are readily available for speculation, rather than convert a large part of the capital into permanent or fixed assets. The whole constitutes an intricate and peculiar pattern, which might deserve a detailed analysis.'

That was a most concise and accurate summarization of diesel-electric traction on the railways of the United States. It was as accurate today as when written in 1956.

He had already outlined, at the outset of the closing remarks and in his reply to the discussion of Lt-Col. Fell, just where and by whom the original development of the diesel-electric locomotive in the United States was started; Mr McClean's remarks to the contrary notwithstanding.

*Assumed steam locomotive costs*

His assumption of $45 per h.p. and the average size of assumed equivalent steam locomotives, had already been discussed in his reply to Mr Cock, Mr Lambe, and Sir Ralf Emerson and as shown in Table 6. The average horsepower of steam units was shown to be 3650 and not 5000. Mr McClean had asked him to 'indicate the weight, wheel arrangement, boiler and grate area of a typical locomotive of the class that he had in mind'. There would be about as many types as there were at present of diesels. If Mr McClean would avail himself of a copy of 'Steam's Finest Hour'*, he would find all those details of the several types of steam locomotives that doubtless would have been continued.

No single diesel unit now operating in the United States would ever be able to equal the life and performance during its life of a classic steam locomotive built by Alco for Timken in 1930, originally called 'The Four Aces'. Purchased, shortly after being demonstrated on all the major railways of the country, by the Northern Pacific and renumbered 2626, it was finally retired and scrapped in 1957 after 27 years of service in which it was operated 2 225 000 miles—an average annual milage of 84 000.

In so far as regular day-to-day performance of motive power was concerned, diesels could be just as erratic as steam, even after skilled technicians took over, as Mr Fuller had already pointed out. To inject just a bit of humour, he understood that in England during the past winter, owing to a diesel failure on one important train (which could happen to most any type of motive power), an old popular song was reworded, '*Pop Goes the Diesel*!'

*Large horsepower single locomotive units*

The paper was misquoted by the omission of the final clause—'delivered to the rim of the driving wheels'. If Mr McClean wished to presume that the wording of the paper 'have not been able to build' signified *that they do not know how to build*, it was his and not the author's presumption. If the American manufacturer(s) really did know how to build more horsepower into a single unit, to meet the demand for such, *which had existed from the start of their use*, they had limited that ability to the statement which had appeared unvaried, except for model number, in their advertising for the past five years: 'Added capacity enables three VP–60's to replace four older units!' Meanwhile the traffic on the railways was declining so that three of the older units, had their useful life been longer, could have handled the traffic anyway.

The fact that one manufacturer did make larger capacity diesel units was connected by Mr McClean to the fact that he was no longer in the United States railroad locomotive business. That seemed to have a sinister portent, when considered with his prior statement that 'most of those manufacturers had held the belief that the retention of the multiple unit concept of smaller units was a better *policy for both operator and manufacturer*'. That had a familiar ring to many Americans—'What's good for the (Automotive Industry) is good for the Country!'

A final bit of evidence of what the railroads desired in motive power capacity was shown by the approaching acquisition of the European-made 4000-h.p. units with hydraulic drive (to which reference had been made). In connection with that, a statement was recently made to him by a well-informed railway motive power expert of long years of experience: 'This is the first time locomotives have been purchased by *the motive power department* of any United States railroad in twenty years'. That would seem to agree with Dr Thelander's opinions expressed at the end of his second paragraph quoted above.

*Economic results of dieselization*

Nowhere had he stated that dieselization had been a mistake. The first paragraph in the paper under the heading 'Total Railway Operating Expense', made simple statements

* Morgan, D. P., editor, 1959 'Steam's Finest Hour' (Kalmbach Publishing Co., Milwaukee).

of fact which when intelligently read would mislead no one. Expenses and revenues had gone up as traffic had increased, and had declined as traffic had declined. Expenses had increased at a greater ratio than revenue, so the operating ratio, in general since the war, was higher than before the war. It would be nonsensical to relate an increase in revenue, so obviously related to traffic, to a change in type of motive power. But if there had been any relationship in that direction and since expenses had continued to rise in a greater ratio, then that bearing of motive power on the operating ratio would be unfavourable. It was definitely stated, however, that the change in type of motive power had had little bearing on either of those items. Indeed the final study made as a check, and shown in Table 4, confirmed that statement. There was very little difference between the actual cost with diesel and the calculated cost with steam in the overall picture with yard service and line service combined—both of which were in the operating ratio.

The present study had been based on the performance of motive power on *all* the class I railways of the United States *as a whole*. The statistics of *no one specific railway* had been selected and applied as representing the whole.

There was no question in his own mind that the diesel had been highly successful and economic on a number of railways. By the same token it had been unsuccessful and uneconomically applied on others, since the *average*, for all the railroads, by the study, had been about an even break. Why should any railway president be called upon to endorse or reject any opinions on that subject? Dieselization was not only a *fait accompli*, but there was no other type of motive power he could buy, unless he looked overseas.

Britain had more than a dozen locomotive manufacturers, most of which would make any type called for. She was fortunate in having so many to choose from for her railway motive power needs. Among all the pros and cons of Government operation there was a definite advantage to the Nation's economy in having a solid national organization of trained engineers and specialists in every branch of railway operation, engineering and motive power, who neither presented nor accepted an economic study as a 'sales-tool'.

Mr McClean had cited the 'action of the Norfolk and Western Railway as the best refutation of his (the author's) statements'. That was quite agreeable to him, who had been a small shareholder in that well-managed railway for many years, and was quite familiar with its operations. It was one of the few financially sound railways in the United States because its principal traffic, coal, could not be diverted to automotive vehicles on the highways. The experience of that railway with its motive power, steam, electric and diesel, was an excellent epitome of the whole subject under discussion.

For years that railway had built its own steam motive power which was outstanding in its performance. But there was a short, difficult section of single-track line, having a 2·2 per cent grade against their prevailing heavy traffic in the mountains. That was further complicated by a long tunnel, creating a serious 'bottleneck' on their otherwise two-track line. Electric operation of that section was installed in 1914 for helper service of the through traffic. Also for complete electric operation of the heavy coal trains from the various gathering yards over the summit of the grade to the main departure yard. From thence heavy steam power could take the trains down grade to the seaport terminal. That electrification was paid for out of earnings; created no additional debt; satisfactorily solved the operating problems; and was just another part of smooth, economic railway operation.

Like all railway electrification installed in the United States in those early days, it had been necessary to install its own power plant for its operation. Railway loads were far too heavy to be assumed by the small isolated industrial and lighting plants then existing. By 1950, after 35 years of exceptionally severe operation, including the 1941–45 war traffic requirements, the power plant and the electric motive power had reached the end of their economic life. Both required replacement.

The diesel manufacturers were immediately on their doorstep, dramatic sales-tools in hand, to convert them to the 'modern way' of operating their railway. Their motive power officials, being excellent steam locomotive manufacturers as well as operators and maintainers, had been quietly collecting the facts concerning diesel operation from their associates on the connecting lines—of which there were many. They compared the 'dramatized version' with the facts collected and saw further that their own steam costs were below either version of diesel costs.

That railway being principally engaged in coal haulage, and having excellent steam locomotives, had elected to retain their steam operation. They spent a considerable sum out of earnings to construct an entirely new double-track line over a new route through the mountains. That had much more favourable grades and a larger, shorter, double-track tunnel, all of which replaced the former single-track section that had required the electric operation. They had then returned to complete through operation with steam at speeds that were higher than the fixed-speed induction-motor type of electric locomotives had been capable of performing. All that was accomplished with no increase in debt and at about the same cost as new electric motive power and power supply.

In 1955 there was a sharp increase in the coal export business to Europe. Additional motive power was required —and soon. Their steam motive power had increased in age and was becoming more expensive to maintain. More especially since all other steam locomotive manufacturing had ceased, even the various small replacement details, formerly easily obtained from suppliers, were no longer available. The Norfolk and Western Railway had *no decision to make* by comparing motive power costs. *They had no choice.* They could no longer build, maintain or purchase steam. They had no time to study and develop the new commercial frequency electrification for 60-cycle operation which would be required. They purchased diesels from the two manufacturing companies and it cost them approximately $86,000,000. That was more than they wished to divert from the unappropriated earned surplus. So, like all the other railways, these were purchased by means of 'equipment trust certificates'.

He had a copy of the speech made by the President of that railway, referred to by Mr McClean, relative to dieselization. Of course he had to explain the expenditure of that large sum in the best light to the shareholders. He could not be criticized by anyone for what he had to do, nor were his statements incorrect. New diesels had saved materially in maintenance costs, compared with the much older steam power now retired. Also, diesel oil was much cheaper at the present time than the very high grade, high B.t.u. content Pocahontas coal, formerly used. The N. & W. was enjoying the palmy days of initial diesel operation, as other railways were doing in 1950–53.

But all costs do not appear in operating costs or operating ratios. And that was the part censored in all the 'dramatized versions'. The N. & W., which for years had been free from debt except for a very small mortgage bond issue, largely covered by a sinking fund accumulation, was now *for the first time in its history*, burdened with a large debt represented by equipment obligations. It was paying off that debt at the rate of $5,662,000 per year on the principal, plus annual interest charges of $1,700,000, a total of $7,362,000. (Those sums were all taken from the 1960 record before its merger with the Virginian.)

The main point to note was that by the time that debt was paid, the equipment would be worn out and that, or a larger debt, would have to be renewed for replacement motive power. There was no denying that the financial burden on that railway had been increased by more than $7,000,000 annually, because of its *necessity* of adopting diesel motive power. That financial burden must be carried until a type of motive power having a much longer life took its place. The fact that that particular railway could, at the present time, assume that debt without too much drain on earnings had no bearing on the thesis.

The statement made in the paper that 'diesel motive power has added to the financial burden of the railways' was not disproved by the evidence of the N. & W., submitted by Mr McClean.

He submitted that Mr McClean had not produced *any* evidence at all to show that any statements in the paper were 'highly misleading'.

Mr McGee thought that he had made some serious omission 'of important operating and cost indices' and had substituted unsupported personal opinions 'largely refuted by available data and the substantial operating railroad records'. He also, for some reason, thought that he had used 'a mysterious hypothetical steam locomotive for a comparative cost study with diesel power', and was 'mildly unconvinced'.

For the benefit of the reader, it should be stated that Mr McGee was a valued friend of his, regardless of opinions, and had been almost from the start of their respective careers. Their occupational paths had diverged in or about 1937 when Mr McGee had became associated with the automotive-diesel manufacturing industry.

Mr McGee had submitted, to correct the errors and omissions in the paper, Table 5, which really was a valuable addition to the whole subject. There was displayed, for the reader's benefit, the manufacturers' concept of an economic study, dramatized as it should be as a sales-tool. That would be discussed item by item, so that the reader might decide for himself the comparative value of the evidence presented by himself and by Mr McGee's Table 5 and his analysis.

Table 5 started with the year 1941 and gave values for every fifth year thereafter, including 1959. He himself had started originally with the year 1940 but had soon found that it was essential to obtain a longer 'backsight' because other factors besides the mere change in type of motive power were involved. He had not the advantage of 1959 figures in the paper, for it was completed in that year and he could not give firm figures much later than 1957. The tables and figures in the paper were self-explanatory as to the period reviewed.

*Item 1. Freight gross ton-miles*

He had indeed omitted to show that item—the pattern was so nearly identical with the revenue ton-miles shown in Fig. 1*b*, it was considered unnecessary. It was shown graphically, however, in the discussion in Fig. 34.

There was no mention whatever in Table 5 of passenger train operating statistics. Evidently Mr McGee and Mr McClean were in agreement that the costs of that service were unimportant because the revenues were so small. He, in spite of his former connection with a large passenger-carrying railroad (as Mr McClean had pointed out), thought from his study that the related statistics and costs of diesel motive power in that service should also be included. The passenger ton-miles were therefore included in Fig. 34.

*Item 2. Freight gross ton-miles per train-hour*

That, according to Mr McGee, and to many railroad statisticians, was held to be 'the most significant of operating indices of freight movement'. He himself had also been impressed by that 'statistical average' until he 'broke it down' as shown in Fig. 31, to show whether the rise was due to any particular type of motive power or to some other cause. Particular attention was directed to the group of graphs in Fig. 31 enclosed in the bracket labelled 'gross ton-miles per train-hour'. The statistics shown in Table 5 could be located on the graph composed of the fine dots marked AVG. The rise in that graph was the 'tempo of freight movement' that Mr McGee and the statisticians extolled. What had caused that rise, the change to diesel motive power ? If so, why should graph S, for steam, rise; or graph E, for electric, rise ? And why should both rise with the drop in train-miles ? The performance of the diesels, graph D, were much lower in 1958 than in the period 1945–50, and even slightly below the AVG. line. Electric had out-performed the diesel since 1951 and even steam had out-performed the diesel after 1957.

He submitted that all that rendered item 2 valueless for the use Mr McGee intended to make of it in item 5. The

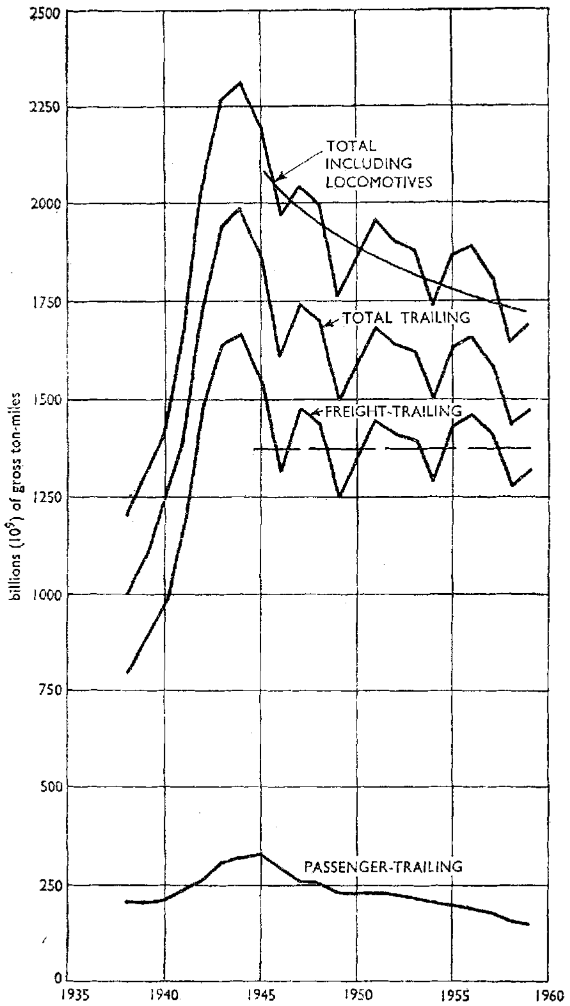



*Fig. 34. Gross ton-miles, all class I railways*
Source: I.C.C. statistics.

importance of the rise in that 'statistical average', shown along the line AVG. which had been held for a number of years to be due to the change in type of motive power, and which had been given a leading role in the 'dramatized version', had been 'miscast' to say the least. Change in type of motive power had had no important effect.

His analysis of that group of statistical graphs, which was also applicable to the two other groups of graphs in Fig. 31, was:

As diesels were acquired for freight service, soon after 1949, they lost their position in special or preferred service and began to assume more of the everyday work of steam motive power. Gross ton-miles per train-hour dropped because many of those trains were lighter and many were slower. Meanwhile the character of freight traffic was slowly changing. Branch-line traffic slowly disappeared. Local short-haul traffic on the main lines also slowly declined, both being taken over by the automotive traffic on the highways. Those slower steam trains with lighter tonnage slowly dropped out of the aggregate ton-miles and train-hours, and steam gross ton-miles per train-hour rose. The older, lighter steam motive power was retired leaving only the newer, heavier steam power. As the shorter trains disappeared more diesel power was released, or acquired, to equal the capacity of the heavier steam power then growing old. So that beginning about 1955, the diesel unit-miles, per locomotive-mile and per train-mile, began to rise as indicated by the two short graphs in Fig. 31. Then the gross ton-miles per train-hour again began to show in the diesel performance. Finally, by 1957 only the heaviest steam power and the electric power was left undieselized because the diesel could not equal their performance while they remained in service. Much of that steam power was, without doubt, that remaining on the Norfolk & Western.

That analysis was offered as evidence because it seemed to fit all the facts. It was probably embarrassing to Mr McGee because it invalidated the use of items 2 and 5 as he intended. And, as would be shown, some of the other items would be affected if that analysis was sound. It rendered the 'index improvement of nearly 90 per cent' somewhat without value in so far as being related to motive power.

*Items 3 and 4. Percentage operated by steam and percentage operated by diesels*

That was given in Table 5 in gross ton-miles. He had shown similar percentages graphically in Figs. 31 and 32, expressed in train-miles. There was very little difference between the two units used, as might be seen from plotting the values given in Table 5 on Fig. 31.

*Item 5. Operating expenses, in millions of dollars*

That was shown more completely in Tables 1a and 2a; also graphically in Fig. 10. If, as Mr McGee claimed, the rise after 1945 was controlled at all by item 2, it certainly *was not due to any change in type of motive power*, as Fig. 31 would show. The major factor involved in rise or fall in total operating expense was traffic. That was one thing that all railroad presidents did know—if traffic volume was good, operating expenses must be increased to handle it. If it was poor, expenses must be cut.

The effect of each item of motive power expense on total operating expense was shown in the ratio costs in Tables 1b and 2b. The effect of fuel cost (item 13) was given in those tables and shown graphicallly in Figs. 12*a* and 13*b*.

*Item 6. Taxes*

That was of general interest but had no real bearing on the subject of the paper.

*Items 7 and 8. Average compensation per employee, and its index on basis of 1941 as unity*

Those items were also of interest, but not too relevant to his presentation where *index costs had been purposely avoided to prevent distortion*. All labour cost involved in motive power expense had been included for each year since 1940 in such items as repair costs, wages of engine crew, and engine house expenses, in Tables 1a and b and 2a and 2b.

They were also a part of items 15 and 16 in Table 5. Items 7 and 8 could not be used at all with item 2 as Mr McGee had suggested, unless certain parity factors, almost impossible to calculate, be applied. For example, how would Mr McGee apply item 7 to AVG. G.T.M. per train-hour shown in Fig. 31, say, for the year 1951? And if an 'influence factor' of item 7 could be found for 1951, would he say that by dividing by two he would get that same 'influence factor' for 1941, or by multiplying by 1·5 he would get that same factor for 1959? (That was apparently the operational use of item 8.)

He did not believe items 7 and 8 had any bearing on, or could be applied to, item 2 in Table 5.

Another point unexplained was the use of the year 1941 as the unity index base year for labour costs in item 8 and material costs in item 9.

*Items 9 and 10. Ratio of cost of rail, cars, signal equipment and basic cost per h.p. Typical 130-ton diesel railroad unit*

Both items 9 and 10 were also of general interest but not too relevant to the subject of the paper except as material costs affected repair costs, which were all included in Tables 1 and 2, a and b.

Examination of the average ratio cost of materials selected, as shown in item 9, seemed to indicate that materials *had* increased about on the same ratio as labour, in spite of Mr McGee's statement that materials had risen less.

Mr McGee had erred in citing costs of $94 per h.p. for typical 130-ton diesel units in 1959. That cost, according to the 1959 I.C.C. Annual Statistics (p. 29, Table 37), was for a rebuilt unit. On p. 27 of the same volume, in Table 37, 'New Units', there was an entry of 279 multiple-purpose units, type B–B, 1750 h.p. Avg. wgt. per unit of 131 tons, Avg. cost per unit, $196,078. That gave a cost per h.p. of $112. The corrected cost, applied in Table 5, item 10, indicated that diesels, like everything else, had been increasing in cost.

*Item 11. Fuel unit costs*

That information was shown in a different way in the paper in Fig. 22. It would be discussed further under item 12.

*Item 12. Fuel and power total, road and yard*

The total costs of fuel consumed had been shown in Tables 1 and 2. He agreed that for that discussion the amount of each type of fuel consumed was important and submitted Fig. 35 to show in graphical form the total fuel used on the class I railways from 1939–59. Mr McGee called worldwide attention to the fact that diesel oil consumption in 1956–59 with close to 100 per cent diesel operation was less than the fuel oil consumption used in 1946 for only 18·5 per cent of the total freight movement and, therefore, enormous sums, which he roundly estimated at one-half billion dollars, had been saved. Even Fig. 35 would seem to indicate that the entire amount of coal had been saved.

Once more, *parity* of performance must be observed,

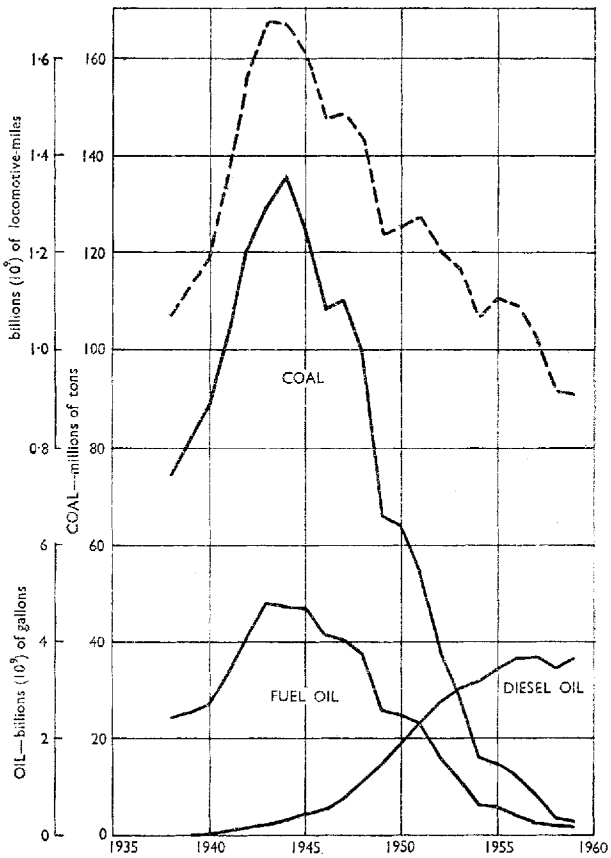



*Fig. 35. Fuel consumed on all class I railways and its performance*

Source: I.C.C. Annual Statistics.

— — — — Performance: total locomotive miles, freight, passenger and shunting.

before such savings could be claimed. He or the reader might say that since the total freight gross ton-miles shown in item 1 and in Fig. 34 seemed to be about the same over the ten-year period, approximate parity of performance had been observed. When the total tonnage moved was considered with passenger trains and locomotives themselves included, Fig. 34 showed a drop of at least 10 per cent over that period. That was not all. The tonnage shown in Fig. 34 for passenger trains could not be compared with the tonnage for freight movements, in considering fuel consumption. Because of being higher speed, the fuel consumption per ton-mile would be much greater. Immediately, 'gross ton-miles' became a poor yardstick for measuring fuel consumption. (It became more obvious why neither Mr McClean nor Mr McGee liked to include passenger service.) Train-miles or even locomotive-miles might be a better measure, *provided* the character of train-miles had remained the same over the years. But even that had been changing, as might be seen from Figs. 8, 31, and 32; and he still held that very little in the change in character of the trains from year to year had been due to change in *type* of motive power. As stated in the paper, the increase in train weight had demanded increased *capacity* in the motive power and that was all.

It became apparent that parity of performance was affected by too many factors to be blithely converted from one year to another by the simple application of index factors, as had been done, not only by Mr McGee but by all believers in the 'dramatized version'.

In so far as fuel cost savings were concerned, he had arrived at the conclusion that savings could be determined only by taking the actual fuel consumption in any one year and determining as closely as possible the actual work performed by that fuel. On the general assumption that 6 per cent of the B.t.u. content of all the coal and fuel oil consumed in that year represented the work done by the steam locomotives, and that 26 per cent of the B.t.u. content of all the diesel fuel consumed represented comparable work done by the diesel locomotives, and adding those amounts of what might be called 'useful B.t.u.'s' for each year, the diagram shown in Fig. 36 was obtained. That was for line-service motive power only, as yard power would require different thermal efficiency factors. The statistics did not permit going back further than 1921. The similarity of Fig. 36 to Fig. 1, and more especially, Fig. 7 (train-miles) was to be noted.

From Fig. 36 (or from the tabulated figures from which it was plotted) might be calculated *in any one year* the fuel savings made by the substitution of one type of motive power for another type.

For example, in 1959, the fuel used was nearly all diesel fuel. Had the *same line-haul train services* been performed by steam locomotives, the cost of the steam fuel would be calculated thus:

> By construction, Fig. 36 showed 26 per cent of the actual diesel fuel consumed, in B.t.u. Then the actual B.t.u. consumption was 100/26 or 3·84 times that amount, which at the cost per million B.t.u. shown in Fig. 22 for 1959 was *M* dollars. If the fuel consumption shown in Fig. 36 for 1959 had been from coal it would have been, by assumption (and by construction if any coal had been used), 6 per cent of the total amount of coal consumed, which would be 100/6 or 16·7 times that amount of B.t.u. shown for the year. That multiplied by the cost per million B.t.u. for coal shown in Fig. 22 for 1959 would be *C* dollars. Then *C* dollars minus *M* dollars was the saving in fuel cost made by diesel operation in comparison with steam, using coal as a fuel, and *for that year only*. The same method of calculations could be applied for any year, but the calculations made for 1959, or for 1956, or for 1946, could not be multiplied by any cost index, or other factor, to obtain the savings in another year, because *all* the performance parity factors were not known.

That method was used by himself in calculating the fuel savings shown in Table 4 for the year 1957.

The soundness of that reasoning was left with the reader to decide for himself. Since he believed that reasoning was sound, then item 13 was shown to have little meaning of value, and the second line of item 14 was shown to be completely wrong, both in logic and in values shown.

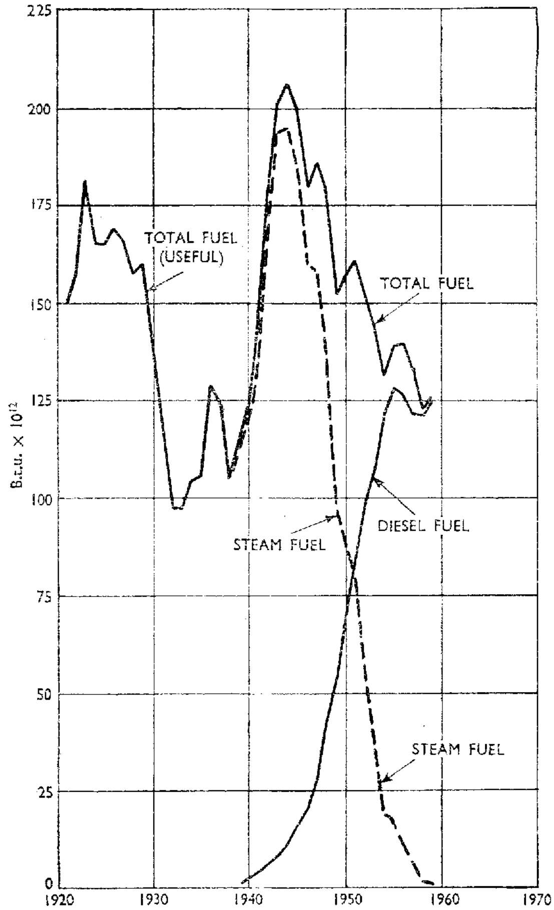



*Fig. 36. Calculated useful portion of all fuel consumed in moving all freight and passenger trains on all class I railways*

The graph is virtually fuel required independent of motive power type.
Basis of calculation: all fuel consumed taken from I.C.C. annual statistics.
Assumed B.t.u. content: coal, 25 000 000 per net ton; fuel oil, 149 000 per U.S. gal; diesel oil, 138 000 per U.S. gal.
Assumed thermal efficiencies: steam locomotives, 6 per cent; diesel locomotives, 26 per cent of total fuel consumed.
Six per cent of all steam fuel in line-haul service is added to 26 per cent of diesel fuel. All switching fuel excluded.

*Item 13*

Those 'Statistical Averages', as mentioned above, had little real value because not only was the purchasing value of the dollar changing from year to year, but the fuel cost of producing 'ton-miles' was changing each year, due to entirely different factors, and would not be equally comparable for different types of motive power in any year. That highly 'dramatic' index was so completely meaningless when applied to electric operation that attention must be called to it. The electric power costs from which the '1000 G.T.M. per $1·00 cost' were compiled were from all the railways using electric power for *any* type of traction service, most of which was for commuter passenger service, with poor load factor, with correspondingly high unit costs per kWh. Only three electrified railways were operating any electric freight haulage today—Pennsylvania, 'Milwaukee' and N. & W. (formerly Virginian), all having fairly low electric power costs. Nevertheless, the statisticians included every electrified railway, with the exception of the metropolitan rapid transit lines (and even one of those), in calculating that 'index cost' for hauling freight by electric power. He was in full agreement with those who had mentioned in their discussion the care required in using statistics.

Mr McGee, however, had stated that item 13 confirmed the savings he had shown in items 12 and 14.

*Item 14. Total fuel and power cost of all services*

Those costs in dollars were shown in Tables 1a and 2a. The second line of that item was fully discussed under item 12.

*Item 15. Locomotive maintenance, road and yard*

The cost in dollars had been shown in Tables 1a and 2a. The treatment of those costs as 'ratio costs', shown in Tables 1b and 2b, with their comparison to numbers and age as shown in the paper, took more account of parity than was shown in Mr McGee's 'index' comparison. No explanation was given why 1956 had been selected as the 'base' year. That made three base years in Table 5, for making the desired distortion of the dollar costs.

*Item 16. Engine house and engine men, road and yard*

The dollar costs were all shown separately in Tables 1a and 2a. The application of index costs from one year to another to that item was particularly meaningless. In the example of engine-crew wages, that item should be treated for each year, as fuel costs were. In any one year, the change in type of motive power would have little effect on crew wages. It unfortunately cost as much for engine crews for diesel operation as for steam, except for a small additional amount for helper service, shown in Fig. 8 to be about 5 per cent in 1957 and for which full credit was given in Table 4. Actually, crew wages had increased considerably for diesel operation due to their being based on 'weight on drivers'. That was too difficult to calculate, so it was omitted (as being favourable to diesel) in the paper.

The application of index costs to engine-house expense was also without meaning or value. The number of engine houses had declined principally because of branch-line abandonments. Each line abandoned removed at least one, and often two, engine houses. The number of employees in the remaining houses had possibly declined. The effect of change in type of motive power on engine-house expense had been given more than its proper value in the paper for reasons shown in the calculations.

Relative to savings in maintenance of way and structures expense that Mr McGee estimated to be in excess of $200 million annually: little more could be said than was stated in the paper and the reply to Mr Cantlie.

However, in 1959 with nearly 100 per cent dieselization, the total maintenance expense of roadway, track, tunnels and all supporting structures was approximately $702 million including $120 million for total superintendence. That was 0·0911 of the total railway operating expense. In 1948 with at least 75 per cent of the steam operation still in the picture and with the lingering effects of the heavy war traffic, those costs were approximately $848 million, including $83 million for total superintendence. That was 0·1133 of the total railway operating expense. A drop of $146 million was indicated which was 0·0222 expressed as a ratio cost.

The ratio costs of all expenses charged to 'maintenance of way and structures' had been:

| | |
|---|---|
| 1940 | 16·08 |
| 1945 | 20·01 |
| 1950 | 18·24 |
| 1955 | 18·15 |
| 1959 | 16·05 |

In other words, in so far as maintenance of way costs were concerned, they were right back to what they were before the war and before dieselization.

To allocate all of the $146 million difference between the 1959 and the 1948 cost indicated above to the change in type of motive power, was to entirely overlook:

(1) Reduced track milage.
(2) Longer and heavier rails.
(3) The growing milage of welded rail joints.
(4) The improved track maintenance machines and methods.
(5) Fewer trains.
(6) Reduced maintenance on branch lines pending abandonment.

to mention but a few of the factors which had contributed to the drop of 0·0222 in those ratio costs.

Mr McGee could be assured that maintenance of way engineers had been just as busy, if not far busier, than had the diesel manufacturers in improving their contribution to reduced railway operating expenses. Finally, there was no total of $200 million in the entire picture.

In regard to 'large savings with the extensive closing down of the mandatory tunnel, terminal and grade electrifications' Mr McGee had mentioned, if those had been of sufficient magnitude to be outstanding, they had all been included somewhere in the motive power expenses shown. The major costs of those might be found in reduced engine-house expenses. The electric operation abandoned in the United States appeared impressive when listed, but the kilowatt-hours of energy consumed in railway electric traction had declined very little from 1940 to date. Any savings from the abandonment of those various small installations, if they could be isolated, would be microscopic in the total railway operating expense.

He submitted that Mr McGee had presented in Table 5 little important information not shown in the paper, *except* *that* he had taken the reader behind the scenes, had shown how the 'dramatization' had been staged, the backgrounds shifted, and the principal characters spot-lighted. He had greatly enlightened the author himself who had no real concept, when he had started his search for the *facts*, how or where they turned into *fiction*.

The reader having now seen for himself the 'dramatized version' of the Economic Results of Diesel Electric Motive Power on the Railways of the United States of America, and how they had been calculated in Table 5, could continue to accept that version if it appealed to him. There was certainly 'more money in it'. (But who had received it?) He himself had no mission to make converts to his analysis or thinking.

It was always of interest to uncover the origin of folk-lore and mythology, but no one gained popularity by upsetting old beliefs. He could only say, with the crusaders of old, '*Magna est veritas, et praevalebit!*'

Before closing the discussion, he wished to add one or two final thoughts. If his analysis was sound, and he believed it was, otherwise he would not have spent all that effort on the study—he was not implying, nor was it to be inferred, in any way, that those who had made other analyses, or who held other views, had not been just as sincere and convinced that their views and convictions were sound and correct. No one could go out and do missionary work against his own beliefs, nor try to sell a product against his own convictions.

Without question, the diesel was *sold* to the railways of the United States. Those who sold it *believed* in it, and did an excellent sales job of *convincing* the railways that it *was* all that it appeared to be during those early years. They still believed in it, and neither he nor anyone else could convince them they were wrong. That was as it should be, for the diesel had its merits as a fine type of railway motive power and there were many places throughout the world yet awaiting its economic application.

One thing was quite apparent. Sooner or later, the railways of the United States must wake up to the fact that they must do a little thinking for themselves about more economic motive power. The manufacturers had no incentive or *obligation* to do that thinking for them. They were in business to make profits, and they had been far more clever than the railways had been in that effort during the past quarter century. (Actually some of their profits had been at the railways' expense.) For every million ton-miles the railways lost to the automotive traffic on the highways (and that was where most of it had gone and was still going), the automotive industry made possibly fewer diesel locomotives, but a great many more automotive highway vehicles. They could not lose—nor was it really necessary for them to change the *status quo*—unless some of the railways started to wake up and decide they really did require some more economic, longer life, single-units with higher capacity at all speeds, that cost much less to maintain and much less in first cost.

Motive power was not *sold* to the railways in Europe. They studied their needs, specified their desires, and *bought* their motive power. There was a large difference. The same was true in the United States until there was no further demand for steam. The American railways could, if they really wanted to, put themselves back into that position again. And they must, if they wished to continue in business as free enterprises. Possibly a move in that direction had already been started by the acquisition of some foreign-made diesels.

He could not refrain from stating that as a result of the study, he was more than ever convinced that the diesel had been misapplied to a considerable amount of milage of the American railways. It was well known that 50 per cent of the traffic was handled on about 10 per cent of the American railway milage. That required also about 50 per cent of the motive power capacity. That traffic could be handled, just as it was in Europe, far more economically with electric operation. *Fifty per cent of the traffic, handled more economically,* was really something to think about and to look for. But the railroads would not be able to get any American locomotive manufacturer to help them in their search for that. There was no real incentive in that for any such manufacturer, and for some, it could be to their disadvantage. The railways must make that search for themselves, as they had in every country in Europe, and as England was doing today.

If the paper stimulated any serious thinking along those lines at home, it would have served a further, unexpected purpose.

He could not feel otherwise than honoured, and not a little complimented, by the discussion, both pro and con, the paper had elicited. He had felt that the results of the research he had made on the subject over a number of years might be of sufficient interest to others to be made a matter of record. He had no concept when the paper was completed in September 1959, that he would have the honour of presenting it to the Institution, or that it would arouse the interest that had been shown.