THE INSTITUTION OF MECHANICAL ENGINEERS

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

By H. F. BROWN, Ph.B., Fellow A.I.E.E.

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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.

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* *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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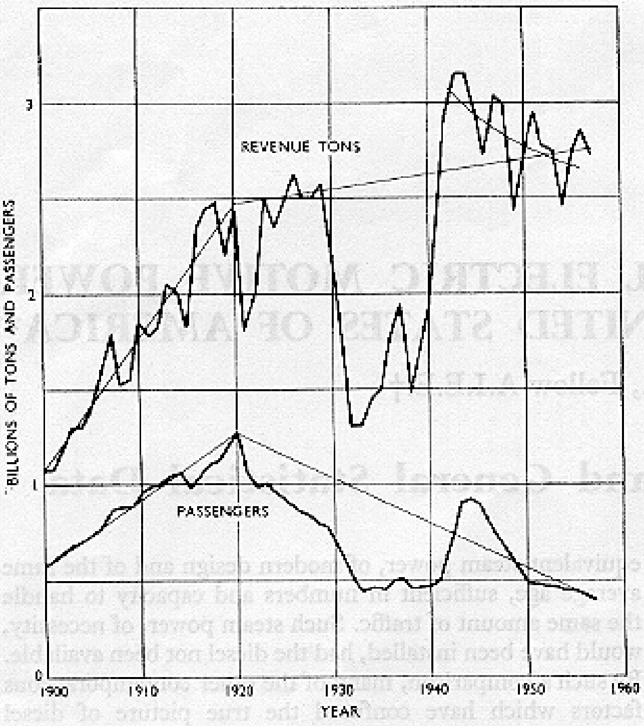
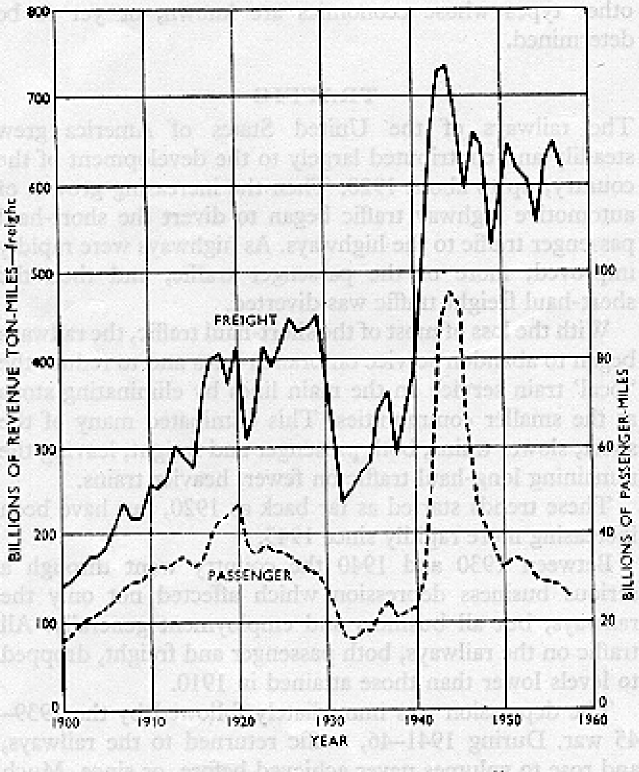


a Revenue tons and passengers carried.



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.

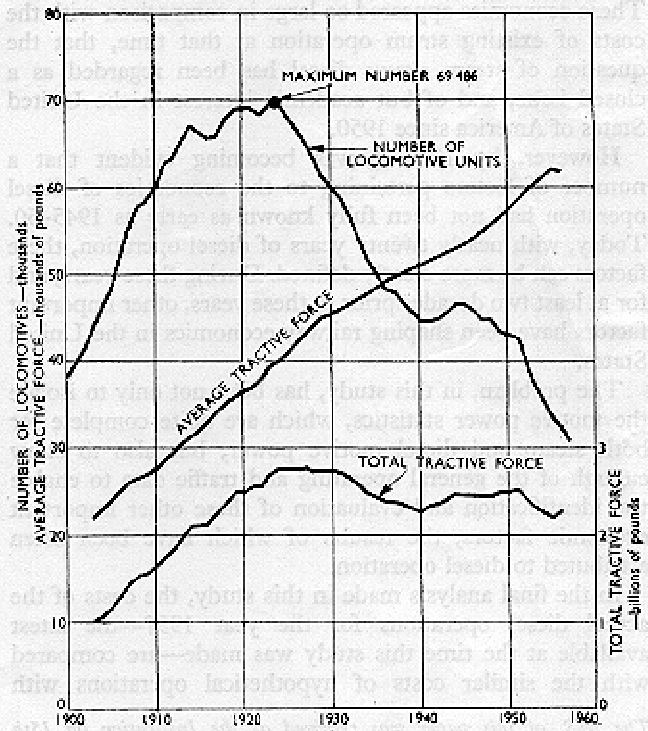


Fig. 2. Motive power in service on all railways in the United States of America

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

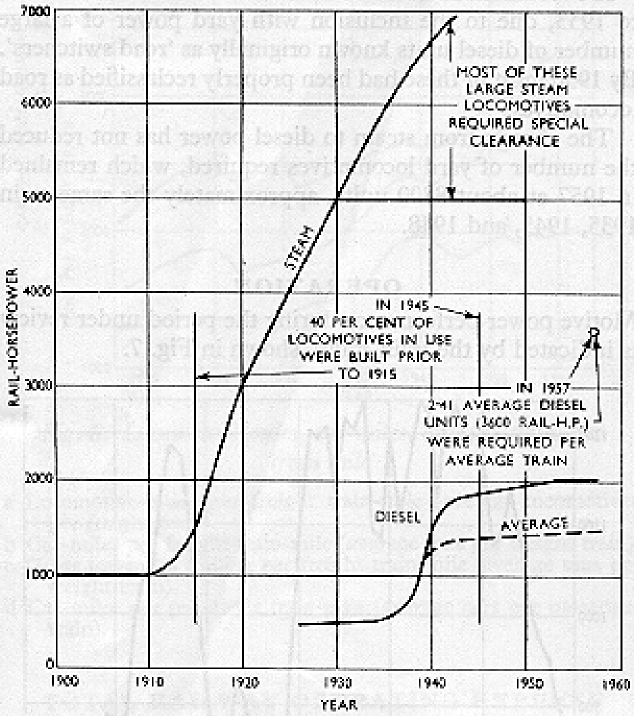


Fig. 3. Development of maximum locomotive rail horsepower

Available at rim of driving wheels.

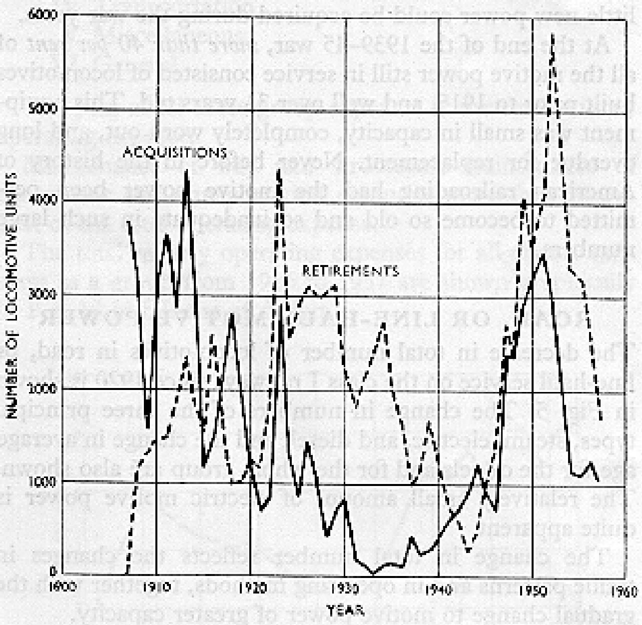


Fig. 4. Locomotive acquisitions and retirements on all class I railways from 1907 to 1957

All types, steam, electric, diesel and other.

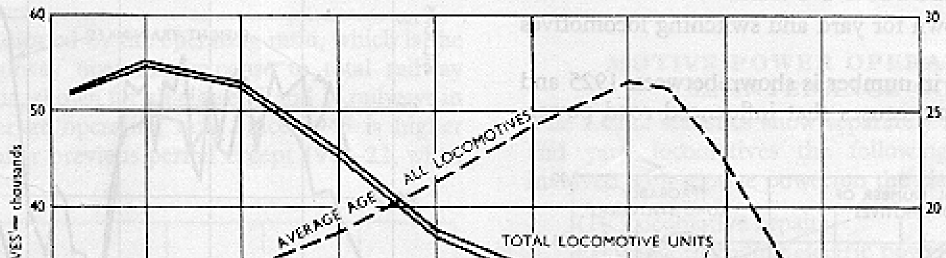


Fig. 5. Road locomotives on all class I railways

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.

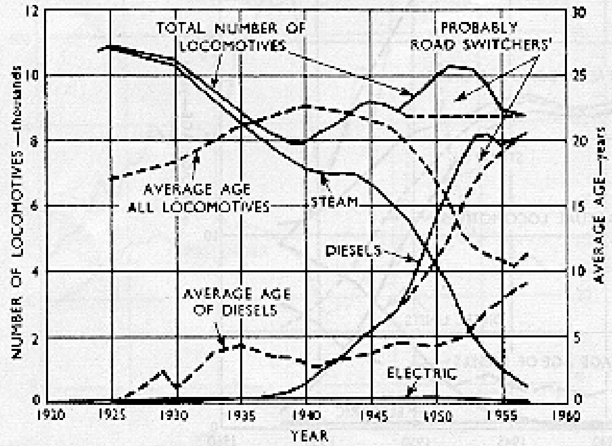


Fig. 6. Yard and switching (shunting) locomotives on all class I railways

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.

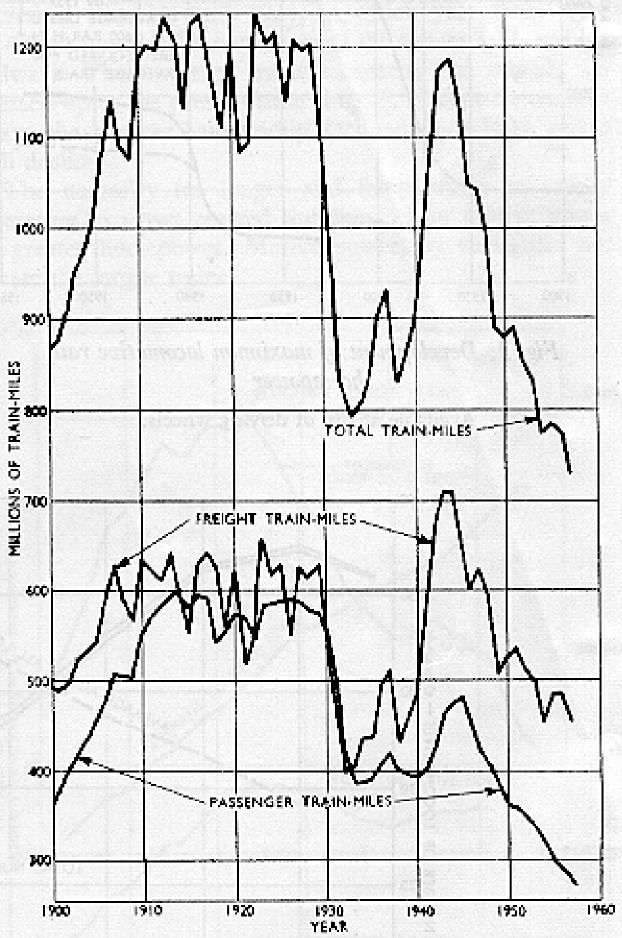


Fig. 7. Train-miles

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.

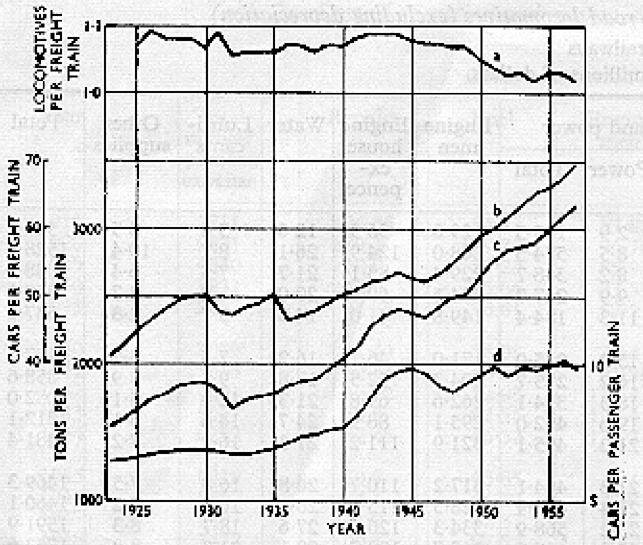


Fig. 8. Locomotive-miles, car-miles, and ton-miles per train mile

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

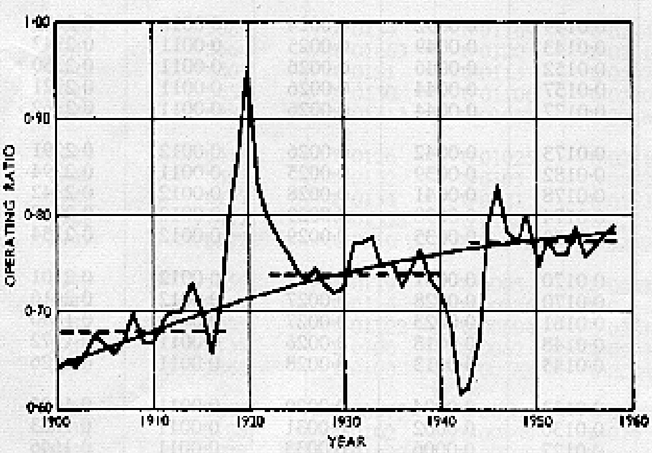


Fig. 9. Operating ratio, all classes I and II railways

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.

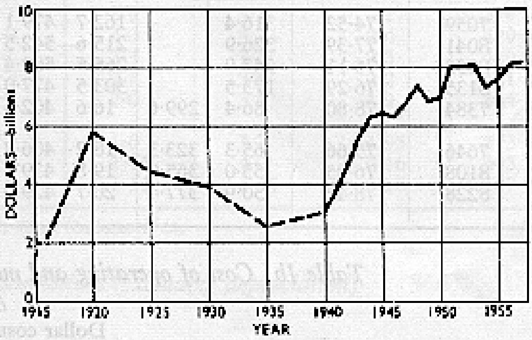


Fig. 10. Total railway operating expense, all class I railways

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-pence	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'

(Per cent 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'

(Per cent 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*,

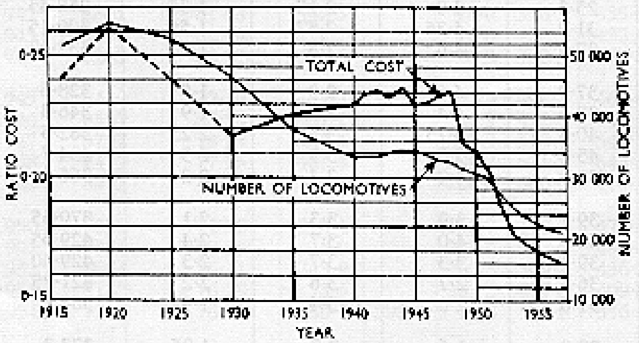
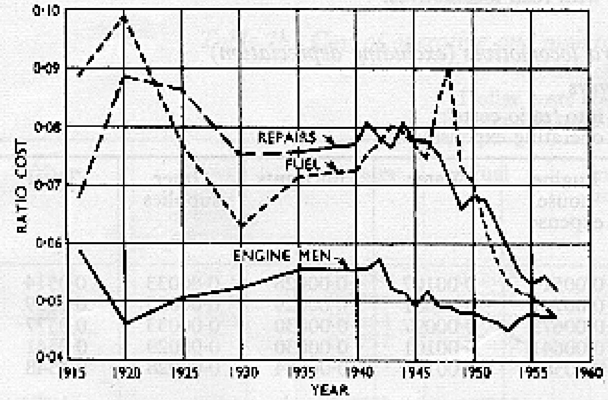
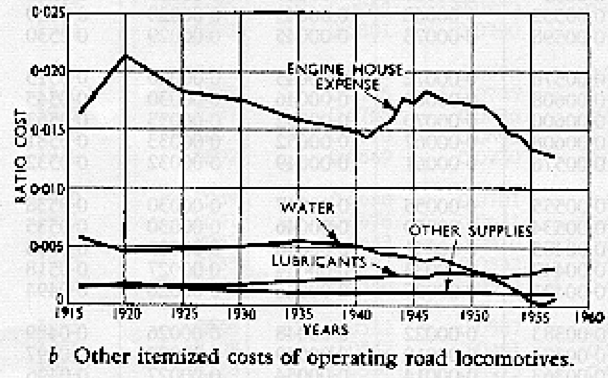


Fig. 11. Total cost of operating and maintaining road locomotives on all class I railways

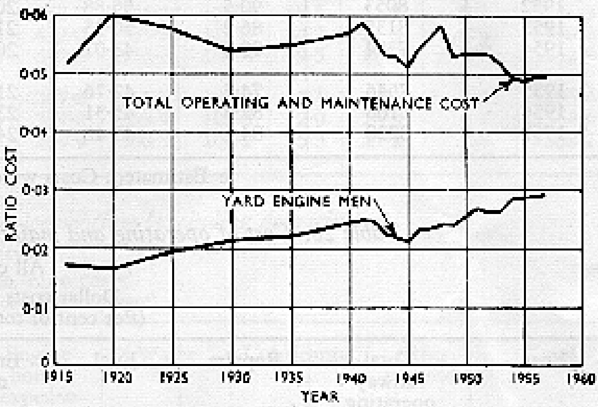


a Repairs, fuel, and engine men for road locomotives.

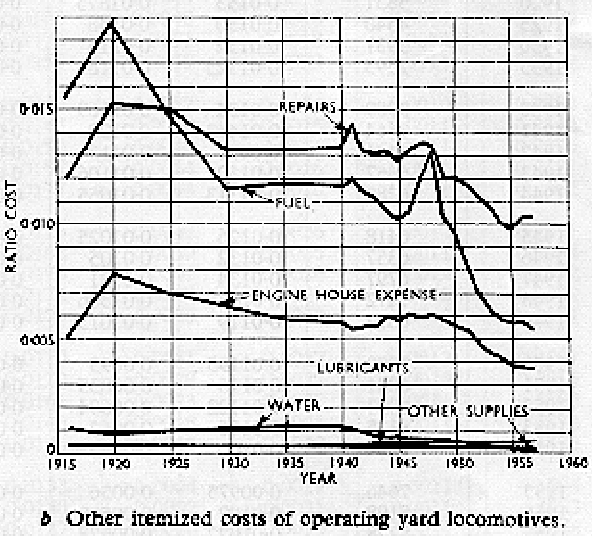


b Other itemized costs of operating road locomotives.

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.

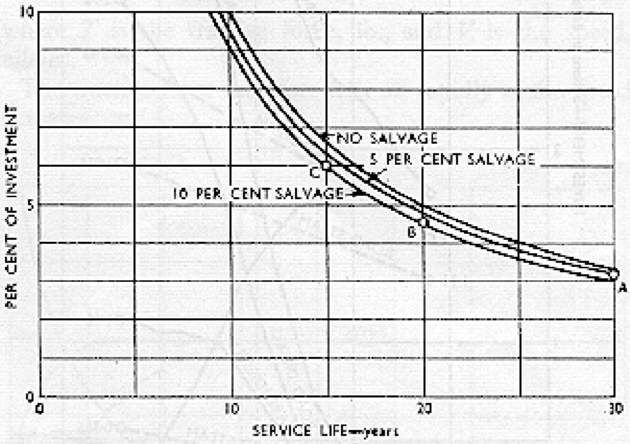


Fig. 14. Annual depreciation charge in per cent of investment

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 dis-

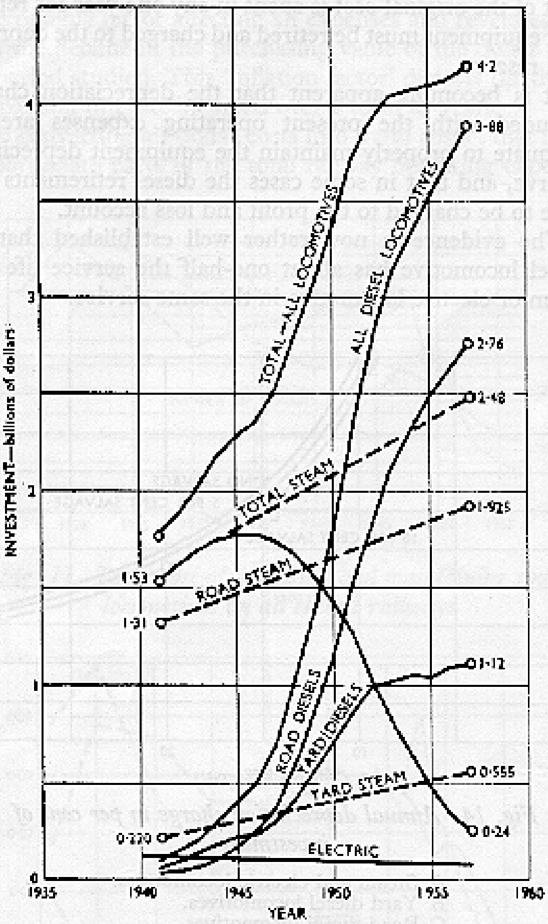


Fig. 15. Investment in locomotives, all class I railways

tinguished 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.

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

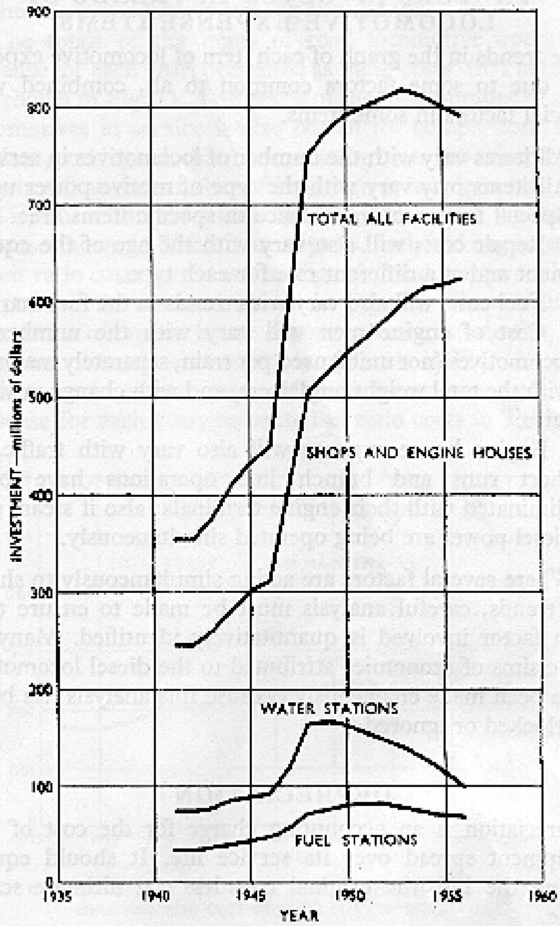


Fig. 16. Investment in motive power facilities

light broken lines in Fig. 15 as $1925 million for road locomotives, and $555 million for yard locomotives*.

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 1952. One of the largest manufacturers stopped building steam locomotives in 1948.

The class I railways are all operating today with most of its 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.

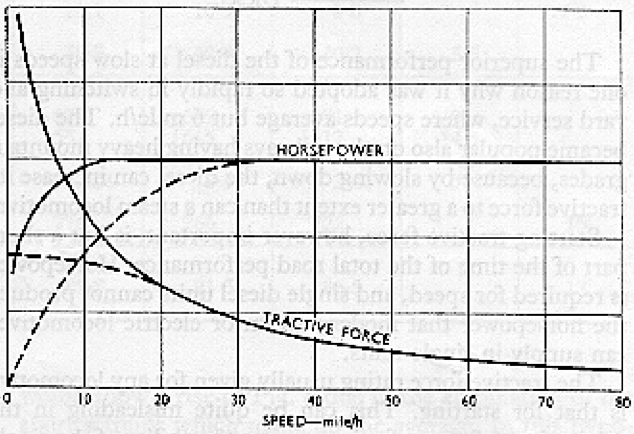


Fig. 17. Comparative horsepower and tractive force, steam and diesel locomotives of same maximum horsepower

— — — 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.

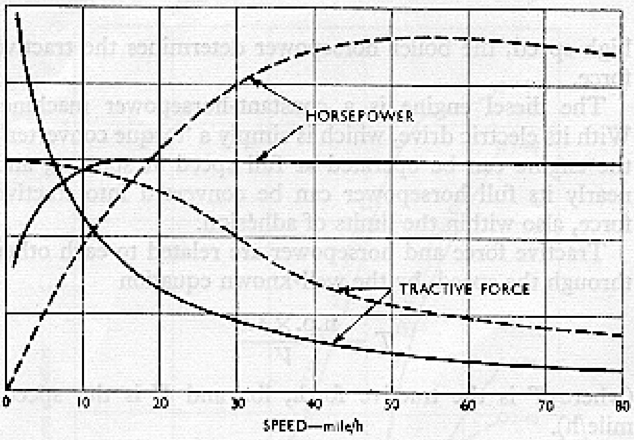


Fig. 18. Comparative horsepower and tractive force, steam and diesel locomotives of same weight on drivers

– – – – 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

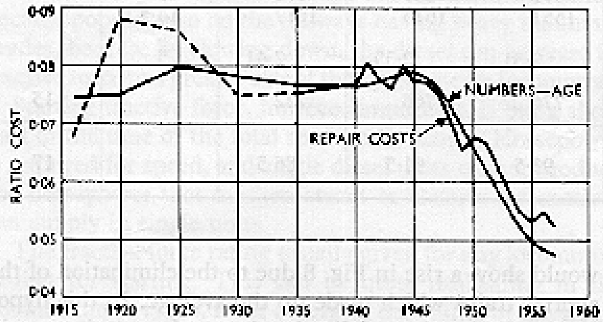


Fig. 19. Road locomotive repair costs, all class I railways compared with the numbers–age graph

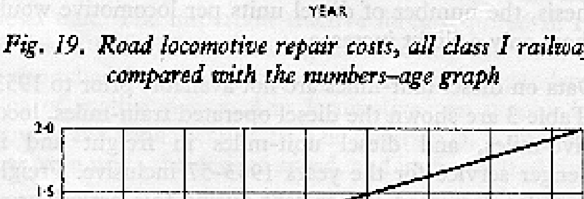


Fig. 20. Cost of steam locomotive repairs in dollars per 10 000 h.p.-mile unit

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

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.

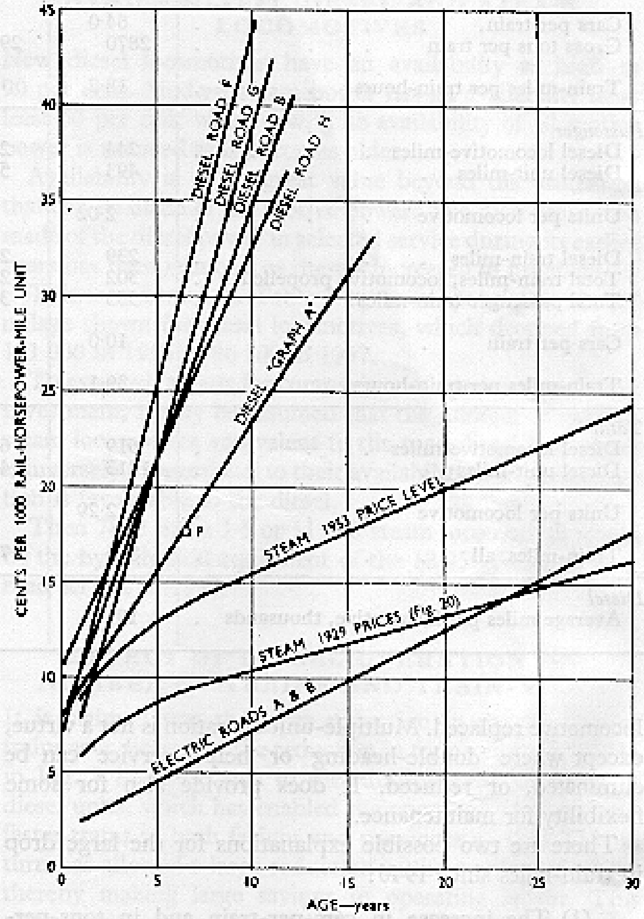


Fig. 21. Comparison of steam, diesel, and electric locomotive repair costs on basis of 1953 price level

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 compositie '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.

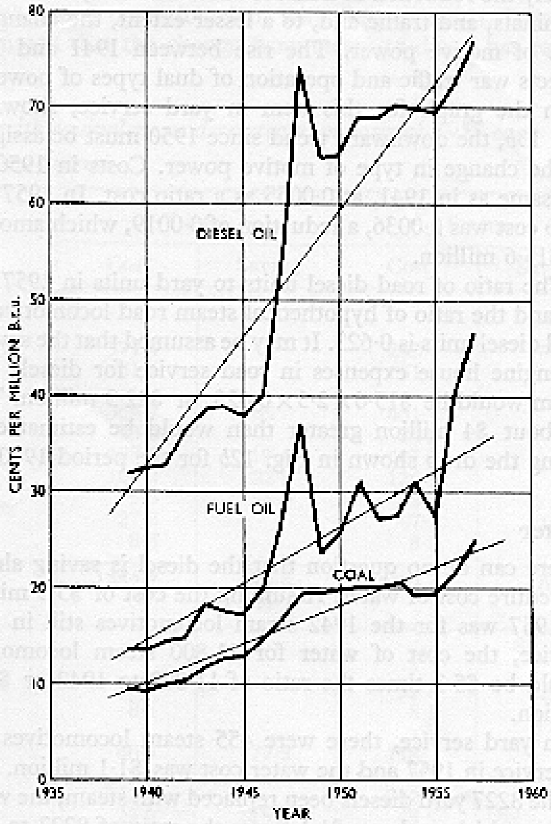


Fig. 22. Comparative cost of fuels used on class I railways, on B.t.u. basis

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 $15·6 × 2·3 × 0·623, 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 $7·5 × 2·4 × 0·425 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		2036·1	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.

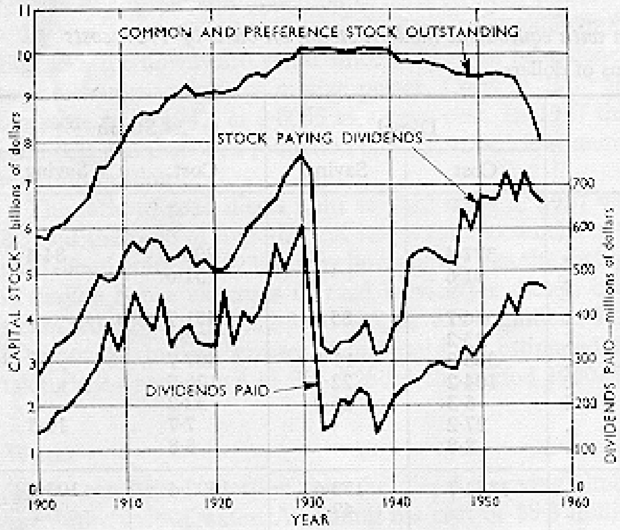


Fig. 23. Capital stock and dividends paid, all classes I and II railways

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 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

The author gratefully acknowledges the valuable editorial assistance of Mr. Alfred G. Oehler, Consulting Editor of *Railway Age*, and Jacob Stair, jun., consulting engineer with Gibbs and Hill, Inc., in the preparation of the text.

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

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