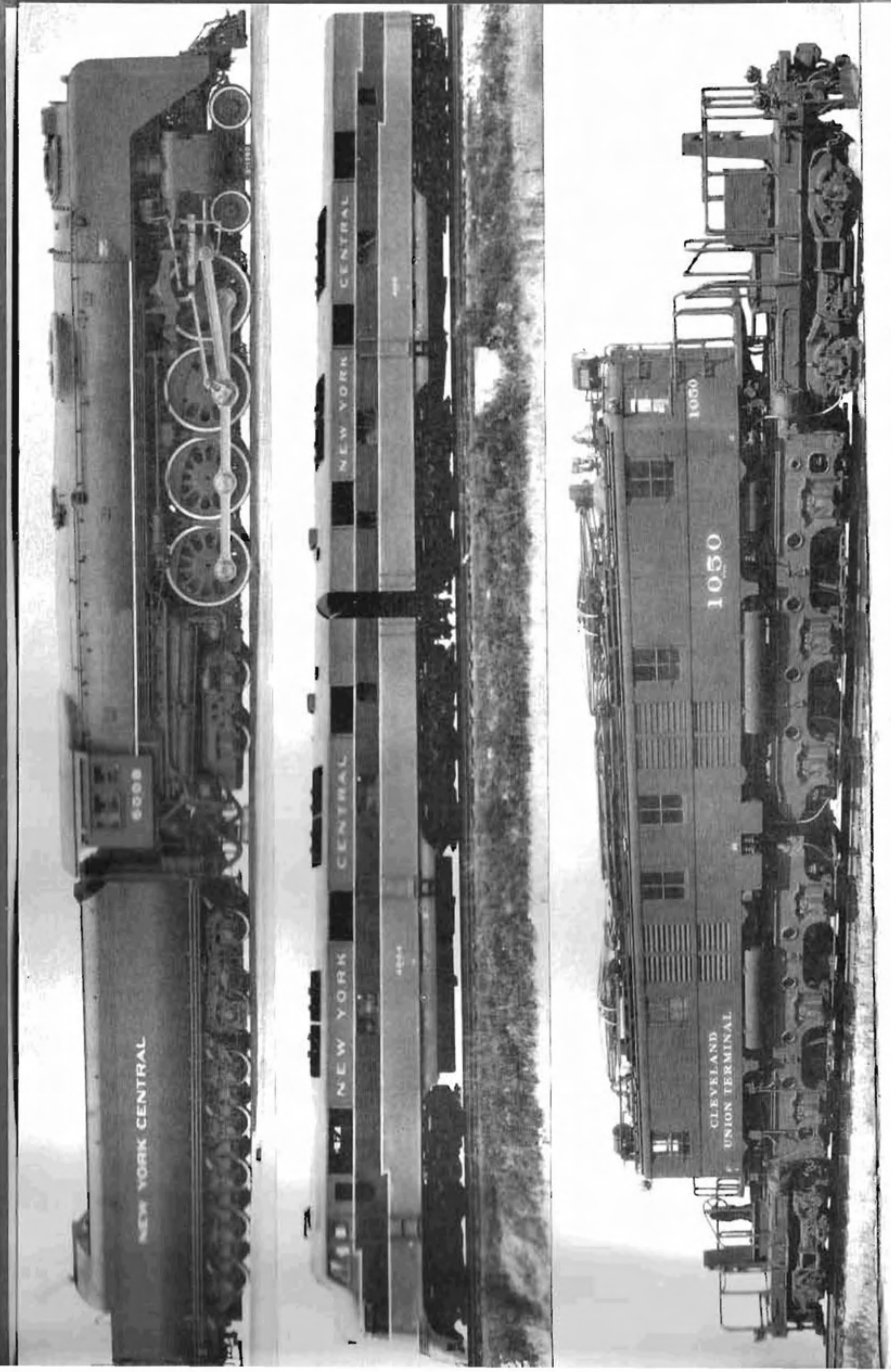
A Practical Evaluation of
RAILROAD MOTIVE POWER



A Practical Evaluation of
RAILROAD MOTIVE POWER

by

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FOREWORD

THE story of motive power for American railroads has been written many times during the past 100 years. Through most of that period only one form of prime mover was available and steam reigned supreme.

At about the turn of the present century the electric locomotive was introduced and after a few successful experimental installations were made several short main line divisions were electrified, followed later by some extended use of this form of motive power. Still the steam locomotive continued to handle the great bulk of railroad traffic and remained as a main source of power on the railroads of the Country.

The Diesel locomotive was introduced in 1924 and proved to be a successful motive power unit—a self-contained electric locomotive using oil fuel. Again, the steam locomotive was challenged and as more and more Diesels were utilized in all classes of service it was soon found that in certain assignments there were substantial economies in operation as compared with the steam power then in service. Higher availability and somewhat lower fuel cost were generally in favor of the Diesel.

Much data have been published during the past ten years on comparative operation of Diesel and steam locomotives, but very little factual information has been given based on modern designs in both cases.

Mr. Kiefer, in this study, has furnished what I consider the best evaluation of railroad motive power that has yet been presented. Modern steam and Diesel locomotives were used in the same service, both given equal care in maintenance; both running over the same divisions.

The results are worth the careful study of everyone interested in railroad operation. Not only does he give the advantages and disadvantages of each, but looking to the future he gives us the story of other developments now under way that may have a decided influence on motive power designs during the next decade.

JOSEPH B. ENNIS

AUTHOR'S FOREWORD

THE contents of this book, founded on experience derived from active contacts and direct responsibilities in the field of railroad motive power and rolling stock development, design and construction over the past two decades, and with detailed material included as necessarily collected and analyzed for the support of the results presented, were originally used to form the basis of a lecture of limited length which the author was invited to present before the Institution of Mechanical Engineers, London, England, during the Centenary Celebrations of that Institution held June 8 to 13, inclusive, 1947.

The Centenary program consisted of thirty-six lectures on various engineering and related subjects, three of which pertained to the Railroad Industry. These three addresses, all under the assigned general title of "Railway Power Plant," were divided British Isles, France—Western Continental Europe, and the United States, and were for the purpose of setting forth the respective viewpoints thereon and the status in the countries indicated. The specific title assigned to this author by the Council of the Institution then was "Railway Power Plant From The United States' Point of View."

Because of the present period of intensive transition in railroad motive power development, design and usage, the complete original document under the title "*A Practical Evaluation of Railroad Motive Power*" is now presented as of possible value in the advancement of this art.

The author acknowledges with appreciation and thanks the valuable help of James Edward Ennis, Engineering Assistant of his personal staff, in the development and analyses of much of the supporting information required for the preparation of this book.

P. W. KIEFER

New York, June, 1947.

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I

INTRODUCTION

The purpose of this presentation is to set forth and discuss objectively what the author regards as the *fundamentals* of this subject.

To eliminate complications and avoid generalities which might serve only to obscure what it is desired to portray, the discussion is developed largely from our own studies and results, particularly those of the past decade, and our relatively near term plans and objectives for the further evolution of road-service motive power. However, it is believed that, basically, the *fundamentals* herein analyzed have the same significance to the American railroads as a whole as to a System such as the author represents, with their import and applicability differing only in degree. Moreover, some of the more important plans are being progressed cooperatively with other railroads.

It is here the deliberate intention and purpose to dispense with lengthy repetitional and statistical comparisons of detailed operating and cost data from different sources because, unless all essential information is available and included for strictly comparable conditions, the results may be confusing and misleading, and recourse to the use of assumed conditions is of little avail in reaching reliable conclusions.

From present experience, it appears logical that judgment of the possible economic value, utility and attractiveness of new forms of motive power, either now in use or under development, may best be predicated largely on certain basic considerations and dealt with most effectively when presented in the form of the aforementioned *fundamentals*.

The Fundamentals of the Problem

It should be understood that these *fundamentals* are not here set forth in absolute order of importance because, while not inseparable, they are closely related and, to a greater or lesser extent, the influence of one may affect the value of one or more of the others.

(1) Availability and Its Dependent Counterpart, Utilization

Availability is here defined as the percentage of total time a locomotive is available for service, with utilization representing the percentage of total time it is actually in operation and dependent in large part on the arrangement of schedules. As herein applied, availability means also, and even more importantly, continuity of operation on the road in terms of reduced delays chargeable to the locomotive, expeditious handling of passengers and freight on established schedules and the resulting possibilities of progressively shortening such schedules without incurring, unless fully justified, the high and burdensome expenditures necessary for the improvement of trackage installations, including signals and related facilities to permit substantial increases in permissible operating speeds. Improved rights of way

and operating practices are essential, but the final results depend also on the locomotive's ability to support the more intensive utilization demands.

The term availability does *not* here mean the percentage of time available for a given *assigned* or *selected* run which daily may require only a portion of each twenty-four hour period, with ample time remaining for necessary current maintenance attention. This is accented because not infrequently claims for availability up to 100 per cent are predicated on such operations.

Today on the railroads of the United States, constantly increased availability of motive power, with opportunity of correspondingly improved utilization, is an absolute necessity to keep traffic on the rails in the face of the ever-mounting competition of other forms of transportation, usually subsidized, and to build up such traffic. This is true even though strictly modern reciprocating steam now is giving a performance in this respect never before approached or equaled. Despite the many factors involved and the numerous important considerations, such as those relating to the sources and kinds of fuel used, this trend and need cannot be interrupted and must be faced resolutely and realistically as its progressive achievement is of the utmost importance.

(2) Over-All Costs of Ownership and Usage

It is a self-evident fact that under the incentive system of free enterprise, assuming that an understanding of the value of this system in the advancement of the human race again is re-established on a sound basis, costs which prevent a fair return on the investment are destructive and self-defeating. Obviously, this *fundamental* requires careful attention and must be retained in this discussion.

Although the alternative to the system of competitive and progressive enterprise is a subject beyond the scope of this book, it is believed essential for the record to say that engineering and technological progress alone is not enough. Without sound economic and social enlightenment and a renewed and unreservedly accepted revival of the age-old truth that "something for nothing" cannot be obtained, the potential and productive results of such gains, regardless of how carefully plans are developed or however conscientiously efforts are applied to carry them out, can quickly be nullified and the intended purpose defeated. For technology to bestow upon mankind the great and lasting benefits which it is capable of producing, the challenge of the future must be faced. This is a challenge principally to statesmanship, labor leadership and business to formulate, adopt and carry out policies known from the lessons of history down through the centuries to be necessary for the continuation of human progress.

Net earnings of the railroads or other legitimate undertakings, if destroyed or unduly restricted, either directly or indirectly, will definitely limit or conceivably completely eliminate the advantages of engineering and related accomplishments which otherwise would be made available to all, and it must be said in concluding the remarks on this pertinent and all-important subject that during the past decade or more in the United States, where some improvement may now be hoped for, and

elsewhere, the science of economic statesmanship has unquestionably fallen behind that of technology and a reversal of this trend must be founded on the sincere co-operation of all individuals within the limits and under the guidance of well-conceived and established law for the protection and proper functioning of the entire society.

(3) Capacity for Work

Obviously, a motive-power unit, present or future, for efficient and satisfactory operation in the movement of trains, must possess a reasonable margin of capacity over that necessary to perform the appointed task if such a unit is to contribute to the betterment of rail transportation. Today, rapid acceleration from rest or back to permissible running speed following slowdowns is a much-desired characteristic in addition to the established capacity of the machine for straight-away running.

(4) Performance Efficiency

In all of its implications, this remains as a definitely important economic consideration. With other essential requirements fulfilled, there is no question but that a major improvement with respect to motive-power fuel economy would be of great and far-reaching importance to the railroads and to the Country, as well as representing a measure of the skill and knowledge of the designers and a worthy mark of achievement in the advancement of the art.

Following this outline of viewpoint and approach to the subject, it will now be the endeavor first to describe briefly the characteristics of the more important present kinds of motive-power units and those proposed for service in the United States, and then, in the light of the *fundamentals* as above enumerated and defined, to scrutinize their potentialities.

To avoid an undesired digression from the main thesis, the questions of improved appurtenances and details of design, materials and construction, which contribute so importantly to the success of the complete locomotive, have been excluded.

II

THE RECIPROCATING-TYPE STEAM LOCOMOTIVE

Over the years, it has been our unceasing determination and practice to advance the design of this kind of locomotive, not only to achieve progressively better results therewith, but also to enforce constantly elevated standards for new and competing forms of motive power, which in turn has accelerated the development and improvement of reciprocating steam. As a self-contained power plant, it provides horsepower at the lowest initial cost of any type of locomotive now used or under consideration. Much should be done, however, to increase its usefulness by providing greater freedom from failures and detentions en route and reducing time now used for maintenance, servicing and inspection. Otherwise, it may not be able to compete on its merits with other forms of motive power and will be faced with a restricted use and market.

With these major objectives constantly in view, it has been our endeavor for succeeding reciprocating steam designs steadily to decrease weight per horsepower developed and to increase the steam generating plant and drawbar pull capacities and over-all thermal efficiencies. The mechanical efficiencies have also been increased through the application of roller bearings and by other means. Improved distribution of wheel loads and progressively bettered counterbalancing for reduction in the effects on rail and road-bed under high-speed operation also have been sought. Long experience has shown that this practice is of great assistance in the maintenance of rail line and surface for good train riding qualities, even though the road-bed and track structure used has been second to none. As an illustration of the fact that with good designing the effects of reciprocating over-balance can be well controlled, it may be said that in the year 1938 a series of slipping tests were conducted on the New York Central over a short stretch of main-line track with 127-lb. rail section on rock ballast.

Test runs were made at train speeds varying from 61 to 82 mph and with maximum slipping speeds of 123 to 164 mph while working steam. In the tests at the lower speeds, no wheel lifting occurred, but in the final run at a revolving speed of 164 mph the main drivers only lifted slightly, and later examination disclosed a number of very slight markings on the rails which, however, were without significance and had no effect on the rails or track structure requiring attention by maintenance forces. No damage to the locomotive occurred in any of these tests.

At the same time, in the advancement of reciprocating steam, tender design and capacity have gone forward apace for the lengthening of runs between fuelings and the taking of other supplies. The use of one-piece cast-steel locomotive frames with integral cylinders, cast-steel trucks, leading, trailing and tender, and integral cast-steel tender frames, the later installations being of water bottom type design, for definitely reduced maintenance attention, shopping time and some weight saving, has been in effect for years on all System steam locomotives built and more recently for the trucks of switch and road Diesels. The underframes and trucks on electric locomotives also have been of this design.

These various features and practices have led to higher availability and serviceability with corresponding increases in miles run per year and mileages between classified repairs.

We have no sacred traditional standards, nor preconceived ideas or preferences, with respect to the kinds of motive power used, but have striven to the limits of our collective abilities to provide units best suited to meet the changing necessities of transportation by rail in which numerous and varied problems are involved.

It is not the intention here to trace the development of reciprocating steam on our System, but as a condensed and convenient means of illustrating its evolution during the last two decades, Table 1 and Chart "A" are presented.

Examination of Table 1 will reveal the progressive increase in capacity and size as necessitated by the demands for higher speeds and heavier trains, and the concurrent reduction in engine weight per indicated horsepower, which has been over thirty per cent in the period. Chart "A" shows the coincident growth of drawbar pull and horsepower of over one hundred per cent and the ascending speeds at which maximum capacities have been attained.

The culmination of this work to date is represented by the "Niagara" 4-8-4 type as illustrated and described in detail elsewhere in the technical press. How-

TABLE 1

SUMMARY OF PRINCIPAL CHARACTERISTICS OF RECIPROCATING TYPE LOCOMOTIVE DESIGNS DISCUSSED

Line No.	Column (a)		(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)
1	Class		K-5	J-1	J-3	L-3	L-4	S-1	S-2	T-1
2	Railroad		NYC	NYC	NYC	NYC	NYC	NYC	NYC	PRR
3	Type		4-6-2	4-6-4	4-6-4	4-8-2	4-8-2	4-8-4	4-8-4	4-4-4-4
4	Service		Passgr.	Passgr.	Passgr.	Freight	Freight	Passgr. or Frt.	Passgr. or Frt.	Passgr.
5	Year first built		1924	1927	1937	1940	1942	1945	1946	1942
6	Year last built		1926	1931	1938	1942	1943	1946	1946	1946
7	Cylinders	Number	2	2	2	2	2	2	2	4
8		Diameter—In.	25	25	22½	25½	26	25½	25½	19-¾
9		Stroke—In.	28	28	29	30	30	32	32	26
10	Valves	Type	Piston	Piston	Piston	Piston	Piston	Piston	Poppet	Poppet
11									Int. Exh.	Int. Exh.
12		Number	2	2	2	2	2	2	8 12	16 16
13		Diameter—In.	14	14	14	14	14	14	6½ 6	5 6
14	Working steam pressure—PSI		200	225	275	250	250	275	275	300
15	Driving wheels—diameter—In.		79	79	79	69	72	79	79	80
16	Rated starting tractive force—pounds		37650	42360	43440	60100	59850	61570	61570	65000
17	Weight Pounds	Drivers-Working Order	187100	190700	201500	262000	265800	275000	275000	268200
18		Total engine-Working Order	308000	358600	360000	388500	397300	471000	485000	497200
19		Tender-Fully loaded	282500	305600	314300	374200	379700	420000	406700	433000
20	Factor of adhesion		4.97	4.50	4.64	4.36	4.44	4.47	4.47	4.13
21	Grate area—sq. ft.		67.8	81.5	82.0	75.3	75.3	101.0	101.0	91.3
22	Tender Capacity	Tons—(2000 pounds)	20	28	30	43	42	46	47	41
23		Gallons—(U.S.)	15000	14000	14000	15500	15200	18000	16000	19500
24	Maximum cylinder horsepower and speed at which attained—MPH		3000 54	3900 66	4700 77	5200 72	5400 76	6600 85	Not yet determined	6552 86
25	Maximum drawbar horsepower and speed at which attained—MPH		2500 45	3100 57	3700 59	4100 55	4300 60	5050 63	"	? ?
26	Engine weight per Cyl.H.P.—Pounds		103	92	77	75	74	71	"	76
27	Engine weight per D.B.H.P.—Pounds		123	115	97	95	93	93	"	?
28	Piston thrust—maximum—Pounds		98200	110400	109300	127700	132700	140000	140000	91500
29	Effective piston thrust load on main crank pin—Pounds		98200	110400	109300	127700	132700	70000	70000	91500
30	Wheel base—Engine & Tender—Ft., In.		80-2½	83-7½	83-7½	95-11½	95-11½	97-2½	97-2½	107-0

ever, as this machine represents a modern concept of its kind, the more-important features and characteristics embodied therein are outlined.

A basic principle in this development was the incorporation of capacity in excess of that required for current work to be performed, in order to obtain the greatest possible continuity of operation, reduced time and expense for maintenance, and possible shortening of schedules. That this principle was correct has already been demonstrated by the performance obtained since the engines were placed in regular service beginning in October, 1945.

Mileage between tire turnings has averaged about 190,000 with individual engines running as high as 235,000 compared with about 100,000 miles heretofore. This high mileage is attributed to the high factor of adhesion, together with the design of spring equalization system which uses coil springs at the connection with the frame, the lower initial resistance in trucks and the use of lateral-motion devices on front and intermediate driving axles, all of which increase the flexibility of the driving machinery and permit automatic adjustment against variations due to accumulative wear.

While of an entirely new design, the conventional fire-tube boiler has been retained, but elimination of the steam dome permitted increased barrel diameter with corresponding increase in furnace volume and gas areas. The present working pressure is 275 psi, but the boiler is designed at a minimum factor of safety of 4.5 with 290 psi pressure, whereas the minimum factor under Interstate Commerce Commission regulations is 4.00.

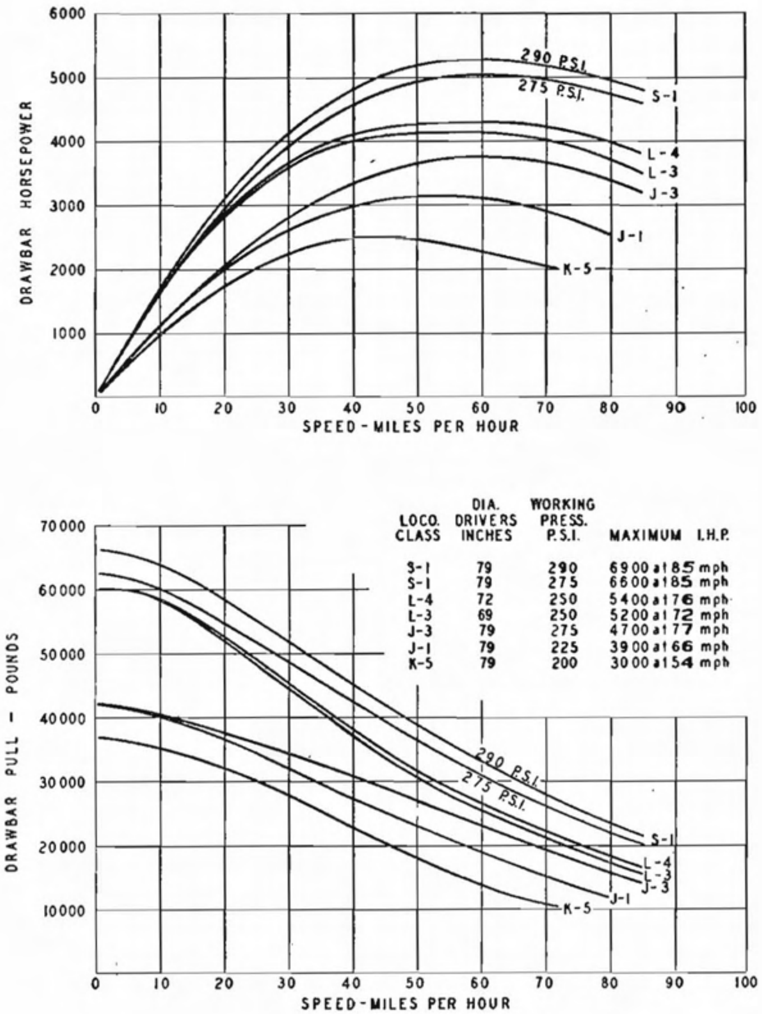


CHART A: POWER CHARACTERISTIC CURVES
RECIPROCATING STEAM LOCOMOTIVES

The front-end arrangement, similar to that on all modern System power, was proportioned from principles developed in a comprehensive series of stationary boiler tests of a kind first undertaken on Class J-1 locomotives in 1937. With the proper relation of exhaust nozzle and stack, and the other essential features and dimensions established, this arrangement results in increasing the flow of the gases with no corresponding increase in the quantity of steam, and effects a reduction in back pressure which is reflected in increased cylinder horsepower and over-all thermal efficiency. Another advantage is that no change in stack dimensions or reduction in exhaust nozzle diameter is necessary for winter operation.

While all power developed is delivered through a single pair of main crank pins, the bending strains on these pins are reduced about fifty per cent as compared with the conventional drive by means of an advanced design of roller bearing rod in which the piston thrust is transmitted in a straight line through the main, intermediate and rear side rods. With the conventional rod arrangement, it would not have been practicable or prudent to attempt delivering the high horsepower of this locomotive through one pair of main crank pins.

Lightened alloy steel revolving and reciprocating parts have been used with cross counterbalance to reduce dynamic augment and resulting stresses in rail and road-bed. The reciprocating parts weigh 1,649 lb. per side and 22.4 per cent are balanced.

Through the use of a new-design four-wheel trailing truck, the ash hopper is enlarged to the extent of providing one cubic foot of volume for each square foot of grate area, which is the largest ratio thus far obtained in System locomotives.

Driving wheels are 79-in. diameter, but the frame is arranged so that wheels ranging from 79-in. to 75-in. diameter may be used, depending on future requirements for passenger or freight service. With 79-in. diameter wheels and the present working pressure of 275 psi, Table 1 shows that a maximum cylinder horsepower of 6600 was obtained at 85 mph, with corresponding maximum drawbar horsepower of 5050 at 63 mph.

With a working pressure of 290 psi, for which the boiler is designed, these figures become, respectively, 6900 and 5300, and with 75-in. diameter wheels, when operating with 275 psi boiler pressure, the maximum cylinder horsepower is 6600 at 77 mph, and the drawbar horsepower is 5200 at 61 mph.

One-piece integral cast-steel frames and cylinders with cast-steel trucks and integral cast-steel water-bottom tender frame previously developed and used on other modern power were applied to these engines.

Open-type feed-water heater and extra-large superheater are installed, both contributing to the over-all steam generating capacity and efficiency.

To save weight, aluminum is used for cabs and running boards. Axles are made of carbon-vanadium steel, and crank pins of Timken high-dynamic steel, while main and side rods are manganese vanadium.

Shields were applied at the smoke box sides to neutralize the vacuum effects ahead of the cab, and due to the arrangement of deck and seat boxes, the degree of visibility from the cab is superior to that of other modern System locomotives having fully satisfactory conditions, regardless of the large-diameter shell courses.

Cast-steel pilots and drop couplers, first applied in 1927 to the J-1 Class 4–6–4 type and since continued on all modern passenger power for increased safety of movement, were used also on these "Niagara" type engines.

For increased availability and continuity of operation, an extra-large capacity tender of bed-type design, now also installed back of the fifty Class J-3 and fifteen Class J-1 "Hudson" type engines, carrying 46 short tons of coal and 18,000 gallons (U.S.) of water, was provided, the water capacity being ample for that necessary when scooping from track pans. The running gear, forming a part of this design tender, originated on the Union Pacific Railroad but was introduced for the first time on our System as a part of the S–1 development to permit the use of the 4–8–4 wheel arrangement for the locomotive, necessary for high power capacity without exceeding a total wheel-base which would allow convenient turning on the 100–foot tables still in use at several of the important main-line terminal points. Meanwhile, alternate designs of swivel truck equipped tenders, to accomplish the same purpose, are now being developed for possible future use.

A specially important feature of these tenders, worked out and perfected on our System, is the tank venting arrangement which allows scooping water at maximum operating speeds and is so designed as to protect from breakage the windows of trains passing on

track pans in the opposite direction and at the same time prevent harmful effects to the track ballast due to overflow.

Capacity tests with 79– and 75–in. driving wheels have been made, from which the horsepower characteristics cited have been derived. These tests were conducted under regular road conditions of operation and indicate what can be obtained daily in actual service.

Another recent and significant reciprocating type steam locomotive for use on American Railroads is the four-cylinder, simple-expansion, non-articulated type for the movement of passenger and freight trains at relatively high speeds in territory where the character of the traffic and the topography of the railroad have imposed particularly heavy demands on the motive power, involving in some cases the use of helper locomotives over grades.

The first unit of this type was built by The Pennsylvania Railroad in 1939 and exhibited at the World's Fair in New York. It was of the 6–4–4–6 wheel arrangement with 84–in. drivers, designed for heavy main-line passenger service. This was followed by 27 freight and 52 passenger locomotives, the latter having 4–4–4–4 wheel arrangement with 80–in. drivers, designated as Railroad Class T–1.

The Class T–1 four-cylinder passenger locomotive is comparable in capacity with the two-cylinder "Niagara" type Class S–1 of the New York Central, described above. Some of the principal characteristics of both types are shown in Table 1.

The four-cylinder type has an advantage over the conventional two-cylinder design of equal capacity through reduction of the piston thrust and the load on main crank pins and connecting rods where the conventional rod drive is used on the latter, together with a reduction in weight of revolving and reciprocating parts per cylinder with correspondingly lighter counterbalance, but introduces the complication of maintaining two additional complete sets of cylinders and machinery, besides necessitating increased over-all length and wheel-base with the attendant complications in handling at terminals and the disadvantages of increased total weight and cost.

A number of reciprocating steam locomotives have recently been built with poppet valves, notably the 52 Class T–1 of The Pennsylvania Railroad, which received the arrangement known as the Franklin System of steam distribution. As these engines were of a completely new design, a direct comparison of the performance characteristics with the same design equipped with conventional piston valves and gear could not be made.

An earlier application of poppet valves was made to one of the P.R.R. Class K–4 "Pacific" type, of which there are a large number, and it is understood the results obtained led to the use of this type valve gear on the T–1 class.

When the New York Central "Niagara" engines were ordered, it was decided to equip the last one of the lot with the Franklin poppet-valve arrangement having four intake valves of 6½-in. diameter and six exhaust valves of 6–in. diameter per cylinder. With this single exception, the engine is identical with the others, all

of which have large-size piston valves actuated by modern-design valve gear.

Thus, a means for making an exact comparison of capacity, acceleration and performance for these two kinds of steam distribution was made available, and comprehensive road tests with a dynamometer car are now being conducted with the poppet-valve engine, which, with the tests already made of the piston valve equipped S–1, will give this exact information.

No predictions of the results of these tests are at present being attempted, but when worked up and analyzed later during the present year, they should provide a basis for definite conclusions.

III

OTHER COAL-FIRED STEAM LOCOMOTIVES

In the constant search for better motive power, the railroads of the United States have not been content to confine their endeavors and anticipations to the reciprocating steam or the present oil-burning Diesel-electric, even though the former has made an enviable record over the years and is still being improved, and the latter has become an established and consistent performer under the most exacting conditions in the movement of trains.

The advantages stemming from the continued large-scale use of bituminous coal as a basic motive-power fuel in the United States are numerous and far reaching, and for the retention and expansion of these benefits several important steps already have been taken and plans for new designs of motive power are under development.

Stoker-Fired Steam-Turbine Locomotive

In 1944, The Pennsylvania Railroad acquired and introduced a coal-burning stoker-fired non-condensing steam-turbine locomotive of 6–8–6 wheel arrangement, with mechanical transmission and geared for passenger service up to maximum speeds of 100 mph.

The boiler is of the conventional fire-tube type with a working steam pressure of 310 psi and a working capacity of about 95,000 lb. steam per hour. Separate turbines are provided for forward and reverse motion, both mounted on the bed casting between the second and third pair of driving wheels, to which they are connected through double-reduction gearing.

The forward turbine delivers a maximum of about 6900 shaft horsepower, while the capacity of the smaller reverse turbine is 1500 horsepower, and both are controlled by a single lever.

This unit was built primarily to try out the turbine principle with mechanical drive in regular operation, and to study the possibilities of developing higher operating speeds and increased efficiency in the use of steam, together with reduced weight and cost as compared with electrical transmission.

After intermittent periods of operation, it was given complete plant tests at Altoona, during which a maximum of 7245 horsepower at the turbine shaft was obtained at 66 mph speed. The steam rate when delivering this horsepower was 14.86 lb. per horsepower hour, and the back pressure was 19.5 lb. Maximum evaporation secured from the boiler during these plant tests was 111,293 lb. per hour.

Examination of the turbine disclosed only very slight erosion of the blades, and the geared transmission was in practically perfect condition, showing no measurable wear.

Future locomotives of this capacity, if constructed, probably could be designed for a 4–8–4 wheel arrangement, which would reduce weight and length, and result in improved mechanical efficiency.

Compared with the reciprocating type, it provides more power from a given boiler, lower center of gravity, uniform torque and absence of reciprocating parts and dynamic augment.

Disadvantages are the high steam rate required at low speed and the resulting effect on the stayed type boiler due to the extremely heavy steam demand, with related variations in temperatures and pressures, and the excessive turbine back pressure caused by the high draft required under the conditions of maximum boiler demand.

Three additional steam-turbine units are under construction for the Chesapeake & Ohio Railway, scheduled for delivery in the early summer of this year. Designed for passenger service, they are expected to develop about 6000 horsepower at the turbine shaft, which should provide approximately 5000 horsepower for traction. The boiler is of the conventional fire-tube type with stoker firing and maximum evaporation rate of about 90,000 lb. steam per hour at a working pressure of 310 psi. Electric transmission is used, with motors geared for a maximum speed of 100 mph, and running gear similar to that used on electric and Diesel-electric engines. Thirty tons (2000 lb.) of coal are to be provided at the head end as in the case of the Pennsylvania steam-turbine units, with separate tender carrying 25,000 gallons (U.S.) of water. The wheel arrangement is of the 4–8–0–4–8–4 type, with eight motors, each connected with one of the driving axles.

Pulverized Coal Fired Steam-Turbine Locomotive

A group of nine of the principal coal-carrying railroads, the P.R.R., B.&O., C.&O., I.C., L.&N., N.&W., Reading, Virginian and N.Y.C. System, have been cooperating with the General Electric Company in the design of a double-unit steam-turbine-electric locomotive to burn pulverized coal in a high-pressure water-tube boiler and develop about 6700 horsepower at the turbine shaft.

Exhaustive study has been given this project and an experimental boiler of full size was constructed and given a series of tests during the fall of 1946. No difficulty was encountered in maintaining the required evaporation up to the maximum design capacity of 78,000 lb. steam per hour, but some problems developed in connection with slag formation and disposal which would necessitate certain changes if decision should be made to proceed with construction of the locomotive.

Because of the apparent high cost as compared with other forms of motive power, the matter is now held in abeyance.

IV

THE GAS-TURBINE LOCOMOTIVE

Coal Fired

EARLY IN 1945, six of the nine railroads previously mentioned (The Pennsylvania, Baltimore & Ohio, Chesapeake & Ohio, Norfolk & Western, Louisville & Nashville, and New York Central System), in conjunction with three large coal companies and Bituminous Coal Research, Inc., formed the Locomotive Development Committee having a distinctive personnel consisting of the Presidents or other ranking executives of the cooperating companies. The objective of the Committee is the development of a coal-fired gas-turbine locomotive, and a full-time director with necessary working staff was immediately engaged to carry out this project.

Subsequently, much experimental work has been progressed with encouraging results, and in August, 1946, orders were placed for two complete open-cycle gas-turbine power plants which will be installed in locomotives of two units each, one carrying the power plant and the other the coal and water supply and auxiliary equipment. Preliminary general arrangements have been prepared, and delivery of both locomotives is expected during 1949, to be followed by comprehensive tests.

The respective turbines are being designed to develop approximately 3750 and 4250 shaft horsepower,

which will be equivalent to approximately 3000 and 3400 horsepower at the rail. It has been decided to use a gas temperature of 1300° F. at the turbine inlet, since metals currently being produced have been found to operate successfully at this temperature. Under these operating conditions, a cycle efficiency of approximately 24 per cent is expected, with full load coal consumption about 1.00 lb. per rail horsepower hour.

Several unique features have been developed during the course of the experimental work on coal pulverization, combustion and disposal of fly ash.

Coal of regular locomotive size is to be dried in the stoker and fed from the bunker into a hammer mill where it will be crushed to about 16–mesh maximum size. The crushed coal is then conveyed to a coal pump, where it is pressurized and fed under pressure to the atomizer nozzle, in which pulverization takes place.

The removal of fly ash is of the utmost importance, as tests have shown that if this function is not properly accomplished, serious abrasion of the turbine blades will result. It is anticipated that if approximately 90 to 95 per cent of the original dust loading can be eliminated, including all of the particles above 10 microns (.0004 in.), abrasiveness should be reduced to a point that will not prove harmful to the turbine blades.

Experiments made with small cyclone separators, known as Aerotec tubes, have led to the belief that a battery of these tubes should fulfill the requirement of removing 90 to 95 per cent of the fly ash which will be present in the hot air coming from the combustion chamber under pressure at about 1300° F. temperature.

Further experimental work is being conducted with Aerotec tubes and other type separators as part of full-scale tests of coal-handling and combustion equipment. When these tests are completed, definite decisions are expected on this important part of the program.

If the two proposed locomotives operate successfully, study probably will be made of the feasibility of mechanical instead of electrical transmission, in view of the possibilities of increased efficiency and appreciable savings in weight and cost.

Oil Fired

An oil-fired gas-turbine locomotive has been ordered by the Atchison, Topeka & Santa Fe Railway from The Baldwin Locomotive Works which is now scheduled for delivery during 1949. Designed for passenger service and geared for a speed of 100 mph, the power plant, which will be furnished by the Elliott Company, is expected to develop about 3000 horsepower.

This is the first locomotive of the kind to be announced for service in the United States, but it is highly probable that additional units will be offered in the near future, particularly for use on some of the western railroads where oil is plentiful and comparatively cheap, and good-quality coal involves a long haul from the east and is expensive.

Power-Gas Process

The exhaust-gas turbine, supplied from a free piston Diesel oil compressor, acting as a power-gas generator, has been investigated, but because of the multiplicity of

cylinders with connecting cranks which would be required, and the attendant complications in weight, space and cost, does not at present appear to be adaptable for locomotive use.

V

ELECTRIC LOCOMOTIVES

THE first electric locomotive used in road service in the United States was introduced in 1895 on the Baltimore & Ohio for operation through the tunnel at Baltimore. In 1906, electric locomotives powered by third-rail direct current were placed in service on the New York Central for operation into and out of New York, and in 1910, the Pennsylvania electrified their New York terminal, using similar power. The number of such road locomotives now in use is approximately 622, or about two per cent of all road engines operating.

Electric locomotives have many advantages. The power being supplied from an outside source provides capacity to the limit of adhesion for short periods, and the characteristics of design permit maximum utilization, with more rapid acceleration and better and more reliable over-all performance than can be obtained with either steam or Diesel-electric. Length and weight per horsepower of the locomotive itself are less than for any other type of modern motive power used, and cost approximates that of the modern reciprocating steam for equivalent continuous output rating.

Maintenance outlays are lower and, because less labor is required, future costs should not expand as rapidly as for the other forms of motive power, due to further possible increases in unit labor and material rates and prices.

Charges for power should not increase in the future to the same extent as those derived directly from either coal or fuel oil, and rates may become less due to bettered efficiency in generation more than offsetting possible growth in other related expenses.

Because it is a converter of energy and not a prime mover, output is not appreciably affected by mechanical condition nor by manual handling. Running times may more readily be maintained because of the surplus power normally available, which, in turn, provides ability to handle heavier trains and a greater volume of traffic than can be done with locomotives whose outputs are confined to the capacities of their self-contained power plants. Faster acceleration reduces traffic congestion more quickly.

The possibility of the electric power supply causing delay and engine failures on the road is relatively remote, due to the size and capacity of transmission lines and the arrangement of substations and feeders used.

Among the disadvantages of electric motive power are inflexibility and the higher first cost and fixed charges for plant and equipment necessary to generate and deliver this form of energy to the locomotive. With steam or Diesel-electric operation, it is practicable to make use of alternate routes for detouring trains, while the electric is confined to its own tracks, but because of the limited number of occasions that such detouring has been necessary, this is not considered very serious.

Although restrictions on the use of coal-burning steam imposed by municipalities have in some cases resulted in the establishment of electric operation for relatively short distances, which for the most part are uneconomical, first cost and resulting fixed charges are the limiting factors for any contemplated electrification of consequence, and unless the density of traffic, or other conditions such as line topography, are such that an over-all return on the investment can be obtained, such operation is not justified.

VI

DIESEL-ELECTRIC LOCOMOTIVES

As EARLY AS 1924, a 60–ton 300–bhp Diesel-electric was assigned to switching and puller service on the New York Central in New York City territory with favorable results. The switchers as of June 1, 1947, totaled 257, of which 157 are of 600-bhp size, 52 of 1000 and 48 of 300 bhp. An additional 15 units of 1000-bhp capacity are now under construction, making a total of 272 for straight switching service on the System. A few of these are operated in hump service with motorized power trailers. Furthermore, there are now under construction 13 of the road switcher type, 9 of 1000 bhp and 4 of 1500 bhp, which can be used in passenger or freight service on branch lines and for switching as required.

As of June 1, 1947, there were a total of 2730 Diesel-electric units in switching work on railroads throughout the country, largely of the 600– and 1000–bhp sizes.

Diesel-electrics have firmly established their place in switching operations, and have proven economically so successful that very few steam switchers have been constructed in recent years.

The first successful Diesel-electric for road operation was introduced in regular passenger service on the C.B.&Q. Railroad in 1934. Subsequently, a large number have been installed on our railroads until, as of June

1, 1947, the total had reached 2,339 units, forming approximately 1,086 locomotives having 1000, 1350, 1500, 2000 or 3000 bhp per "cab" and operated singly or in combinations of two to four to comprise locomotives of capacities from 1000 to 8000 bhp, which provides a large degree of flexibility to suit the various and changing traffic requirements.

In the year 1928, the New York Central purchased a Diesel-electric for freight haulage, followed in 1929 by another for passenger-train use. Neither was successful, but from 1944 on, including those now under construction, the following cab units will have been acquired and used in different combinations:

No. of Cabs	*Size*	*Service*	*In Service 7-1-47*	*Under Construction 7-1-47*
10	1350 bhp	freight	10	..
73	1500 bhp	freight	22	51
2	2000 bhp	freight	..	2
12	1500 bhp	freight or passenger	..	12
48	2000 bhp	passenger	32	16
Total 145			64	81

To obtain a direct comparison of the performance of Diesel versus the best available steam power in road freight movements, a comprehensive program of test operations was prepared which provided for typical trains and schedules on various divisions, and which included the handling of both tonnage and fast freight over some of the heaviest grades on the New York Central System.

Train tonnages were predetermined through the use of actual drawbar pull versus speed curves for the classes of power involved and the profiles of the territory, and

all locomotives were operated at capacity or as closely thereto as was practical or required under regular conditions of train movements. Equivalent tonnage and number of cars were used with both types, although differing on the several divisions because of varying characteristics with respect to grades, speeds, train loading and related conditions.

These tests were carried out in the fall of 1944 and the spring of 1945 under direct supervision of Equipment Engineering Department representatives, and an evaluation of the results revealed, among other basic conclusions, that a three-unit Diesel of 4500 bhp would handle the scheduled symbol main-line freight trains equally as well as the four-unit 5400 bhp or the latest modern freight steam of the same power rating as the latter. This work led to the acquirement and installation of the 34 additional units of 1500 bhp previously mentioned, which, combined with the 10 units previously introduced, are being used largely in through service as three-unit 4500 bhp locomotives.

For passenger use, the System total will consist of 48 cabs of 2000 bhp each, geared for a maximum speed of 98 mph, which will be assembled and used as two-unit 4000 bhp and three-unit 6000 bhp, hauling the most important main-line trains, and in addition there are twelve units of 1500 bhp capacity, suitable for either freight or passenger work as required.

In the handling of main-line passenger trains, the Diesels have shown a high degree of availability and utilization. For the entire year 1946, the average monthly mileage each for the six double units operated was 29,021. As more locomotives are introduced, and their use is extended to trains of lesser importance and shorter runs, the availability and the utilization as expressed in miles per month will of necessity decrease somewhat, but it is believed that a considerably greater number can be justified, depending on volume of traffic and character of trains operated.

While the Diesels are definitely established in the motive-power field, and possess certain important inherent advantages over modern steam, much still remains to be done if they are to continue to meet successfully competition with other forms of motive power.

First cost, weight per horsepower, number of units for a given power output and over-all length must be reduced, and improvements made in power plant and transmission, and long-range repair costs must be kept under control.

Future developments may include mechanical or hydraulic transmission, with a saving in weight and cost, more dependable valve and piston construction, additional fuel and water capacity, and progressive decrease in weight, length and relative cost per horsepower. As higher speed engines, having overload capacity for short periods, are designed and used, with accompanying larger generators and motors for an approach to the performance of the straight electric in the handling of trains, care must be taken that the cost of the higher quality fuel which may be required does not offset the savings realized through weight reduction.

A 6000 bhp triple-unit combination suitable for either freight or passenger movements, delivered last

year to The Atchison, Topeka & Santa Fe, has some outstanding new features. The total weight, fully loaded with fuel and supplies, is 912,000 lb., equivalent to 152 lb. per horsepower, compared with approximately 165 lb. per horsepower for other recently constructed Diesel passenger power. Total wheel-base of the three units has been reduced to 176 ft. 8 in., and the over-all length is 195 ft. 4 in., which increases to nearly 31 the horsepower per foot of length.

The Diesel engine is a new high-speed type design with sixteen cylinders, arranged for application of modified aircraft type supercharger which operates from an exhaust manifold and weighs only 1400 lb. The high output produced by supercharging has made possible a considerable reduction in engine weight. The main generator is also of new light-weight design, delivering 2000 horsepower at 1000 rpm. Weighing only 10,000 lb., it develops much more power per pound of weight than previous models.

The control system has been so arranged as to simplify the wiring and provide easy accessibility and identification, and clear space around the Diesel engines permits easy removal of entire assemblies for repair.

Another important development is the single-cab 3000 bhp unit placed in service not long ago on the Seaboard Air Line. This engine represents the largest capacity yet built in a single unit. The wheel arrangement is of the 4-8-8-4 type, which has permitted moderate axle loading, and with total wheel-base kept to 77 ft. 10 in., considerably less than other two-unit locomotives of equal capacity. Rated horsepower per foot of total length is 33, compared with about 28 for two-unit 4000 and three-unit 6000 bhp locomotives previously built.

Other recent designs for road service include a 1500 bhp unit, with a two-stroke cycle engine, which can be directly coupled in combinations of two to four, and geared for speeds varying between 45 and 100 mph for either freight or passenger use. All belt drives have been eliminated from the power-plant accessories, and a number of the auxiliaries are driven by A.C. motors. The fully loaded weight per horsepower is about 153 lb. with horsepower per foot of total length at 30.

A distinctly new type of unit, which can be combined in multiple to provide up to 8000 horsepower when required, for all classes of service, is characterized by an opposed piston engine, operating on two strokes per cycle.

VII

MOTIVE-POWER POTENTIALITIES

Versus

THE FUNDAMENTALS OF THE PROBLEM AS ALREADY SET FORTH AND DEFINED

Before proceeding further, it is well here to restate these *fundamentals:*

(1) Availability and its dependent counterpart, utilization.

(2) Over-all costs of ownership and usage.

(3) Capacity for work.

(4) Performance efficiency.

(1) *Availability and Its Dependent Counterpart, Utilization*

Passenger Service

As a measure of locomotive potentialities in passenger-train duty, data have been assembled for steam, electric and Diesel-electric operations during 1946 which indicate the comparative degree of availability and utilization for each of these kinds of motive power.

In that year, six 4000 bhp two-unit Diesels were used regularly on three westbound and three eastbound schedules, one in each direction, between Harmon and Chicago, and two between Harmon and Mattoon, Illinois, the assigned train service mileage per day being, respectively, 928 and 1000. The six locomotives accumulated a total of 2,089,563 miles in the twelve months, an average of 29,021 per engine per month, or 954 per day.

Beginning October 1 of the same year, six of the "Niagara" 4–8–4 type steam, including the one equipped with poppet valves, were assigned to three westbound and three eastbound runs between Harmon and Chicago. Up to the end of November, the accumulated mileage was 314,014, representing an average per engine of 26,168 miles monthly, or 858 per day.

The strike in the bituminous coal mines caused a disruption of this arrangement for thirteen days during December, and the engines were assigned to other runs in this period. The total mileage for the three months beginning October 1 was 455,404, or an average of 25,300 miles per month per engine.

An analysis of the records of the two Diesels and six "Niagara" Class "S" for fifteen consecutive days during October indicates the comparative potential performance (page 39) on a yearly basis, Harmon to Chicago, under conditions prevailing during favorable weather when the steam locomotives are less susceptible to delays and failures and relatively better performance can be expected than for the full twelve-month cycle.

The actual average mileage obtained in the entire month of October was 28,954 for the two Diesels and 27,221 for the six steam.

In this operation, both types of power were given the same attention at terminals, but the Diesels were under

Annual Potential Performance Per Locomotive

Line No.		*Diesel*	*Steam*
(1)	Total Hours (365 × 24)	8760	8760
(2)	Hours for Shopping & Periodic Inspections	288	672
(3)	Assigned Hours (1)−(2)	8472	8088
(4)	Hours Used	6292	6080
(5)	Hours Available–Not Used	338	573
(6)	Hours Unavailable	1842	1435
(7)	Per Cent Utilization (4)÷(1)	71.8	69.4
(8)	Per Cent Availability (4)+(5)÷(1)	75.7	75.9
(9)	Mileage Operated	329934	314694
(10)	Average Miles Per Month (9)÷12	27496	26226
(11)	Average Miles Per Day (9)÷365	904	862

repair and inspection daily for 21.74 per cent of the time versus 17.75 per cent for the steam. This accounts for the difference in hours unavailable, Line (6). On the other hand, the time out of service for shopping and periodical required inspections was 3.29 per cent of total hours, Line (1), for Diesels and 7.67 per cent for steam, which produced a lower potential in hours of use for the steam, offset to some extent by the slightly longer steam schedules, and resulting in the total hours used, Line (4), and per cent utilization, Line (7), being less for steam than for Diesel. The availability ratio, Line (8), representing the total of hours used and hours held waiting, involves the three factors and is almost identical for both classes of power.

These comparisons and analyses are informative, and illustrate the potentialities of the two kinds of motive power in strictly comparable service under favorable weather conditions and with the same efficient attention at terminals and en route to maintain assigned schedules.

For year-round operation, such performance cannot be expected of the steam power with its inherent disabilities increased during severe winter weather, and the annual mileage anticipated would be less than given in the tabulation. With a conservatively estimated allowance for additional out-of-service time for steam because of increased inherent disabilities during severe winter weather, the following comparative evaluation for potential utilization and availability was revealed from this study:

Line No.		*Diesel*	*Steam*
(1)	Annual Mileage	324,000	288,000
(2)	Average Miles Per Month	27,000	24,000
(3)	Utilization, Per Cent of Total Annual Hours	70.4	63.0
(4)	Availability, Per Cent of Total Annual Hours	74.2	69.0

To appraise the possibilities of on-time performance of steam and Diesel-electrics in the handling of passenger trains, a study was made of delays en route and at division terminals between Harmon and Buffalo, 403 miles, for six "Niagara" 4–8–4 type steam and six 4000 bhp Diesel-electrics in through service on the most important trains during the month of October, 1946.

Both types of power received the same preferred attention at terminals, and coal of a somewhat higher grade than normal was provided for the steam units. The records of 356 trains, 179 for the steam and 177 for the Diesels, were examined, with the following average results in minutes:

Line No.		*Diesel*	*Steam*
(1)	Gross Delay	16.1	21.1
(2)	Running Time Made Up	13.9	17.6
(3)	Net Time Late at Final Terminal (1)–(2)	2.2	3.5
(4)	Gross Delay Chargeable to Locomotive	1.3	1.2

Of the total number of trains involved, the number recorded as on time was 134 or 75 per cent for steam and 126 or 71 per cent for Diesels, with average delay

chargeable to the locomotive practically negligible for both classes of power. Running time made up nearly compensated for the delays en route and at terminals and the relatively more stable performance of the Diesel was accomplished with the same size trains as with the steam, although rated horsepower was about one-third less, but full capacity of the steam could not be utilized because of train length and other limitations.

Electric locomotives, having no self-contained prime mover, can be expected to possess inherently greater availability than either steam or Diesel, and experience on electrified portions of the N.Y.C. System and other railroads of the United States confirms this potentiality. Utilization is also higher where the length of runs and the arrangement of train schedules permit. The principal electric operation on our System is between New York and Harmon, and in this short distance of 33 miles, with highly congested traffic and many trains arriving in New York during the morning hours, with late afternoon and evening departure, opportunity for intensive use over the twenty-four hour cycle is limited, and the utilization, as a percentage of total time, is low. For a single revenue run in one direction, an average of about 1.5 total locomotive hours is required and an average of about two round trips is made daily, although this is occasionally exceeded.

Steam locomotives labor under several handicaps not applicable to Diesels or electrics, and severe winter weather accentuates these difficulties. Poor coal and low steam pressure, shortage of coal and water, ash hopper defects and disposal of ashes, heating of friction-type crank pin and other journals, broken machinery parts, failure of piston and valve packing, defective feed-water equipment and water-scooping apparatus all contribute to failures and delays en route and late arrival at terminal points, peculiar to steam only, and in some cases affect power output; while Diesel and electric motive power suffer no diminution of efficiency or capacity under low-temperature conditions.

Considerable progress has been and is currently being made to reduce these difficulties and resulting delays chargeable to modern reciprocating steam.

Roller bearings on axles, crank pins and valve gear, the use of alloy steel for machinery parts, refinements in design and insistence on careful workmanship have been of great help, and the provision of larger ash hoppers has permitted longer runs between servicings.

Ash hopper servicing en route still constitutes a serious bottleneck in the maintenance of fast schedules, particularly during cold weather, when it is often necessary to thaw out the hopper in order to discharge the ashes and clinkers, and the necessity of refueling at intermediate points and delivering the semi-frozen fuel to the stoker screws, even with the high-capacity steam-operated coal pushers on large-capacity tenders now in use, remains as a serious cause of delay.

Reciprocating steam also is out of service a greater portion of the total time than the Diesel for shopping and regular terminal attention and maintenance, including governmental inspection requirements. A careful study indicates that over a period of one year, for high-mileage locomotives in Harmon-Chicago service, excluding unforeseen contingencies and operating emergencies, the through-service steam is unavailable a minimum of 28 and the Diesel 12 days. This reduces the potential utilization and mileage of steam, but is inherently characteristic, with its high-capacity boiler and relatively complicated reciprocating machinery. Some further improvement can probably be effected in the time required for shopping and for periodic inspection, but it is probable that the Diesel will retain the advantages in this respect.

It is possible that in the future development of reciprocating steam some of the principles and devices proposed for use in the pulverized coal burning gas-turbine and steam-turbine motive power may be adapted, particularly with reference to the use of coal fuel and the disposal of ashes and other solid residue of the combustion process.

The Diesel locomotive is subject to certain maintenance difficulties not encountered on steam. The engine itself contains a multiplicity of reciprocating parts in the form of pistons, valves and related mechanism, with which there is a continuing possibility of failure, and while not necessarily resulting in locomotive cut-out, sufficient reduction in capacity may take place for delay en route, particularly with the one- or two-unit locomotive. The water and cooling systems occasionally give trouble and the motors are subject to overheating, but this is relatively rare. Heating of long trains in extremely cold weather has always presented difficulties, and the inadequate equipment heretofore furnished on the Diesels has been a constant source of trouble.

The electric locomotive offers to date the best possibilities for eliminating delays en route due to motive power, largely because it does not include a self-contained power plant and related apparatus, and with its greater power input during accelerations, it can readily make up more time following train detentions for various reasons.

Troubles with the electric consist principally of motor flashover, hot motor bearings, and failure of auxiliary equipment. Power supply failure may occur, but experience has shown that little interruption of service is encountered on this account and that this kind of motive power is the best available or even as now contemplated for minimum delays and maximum utilization. Because it has fewer moving parts, failures on the road are negligible, and terminal time for inspection, servicing and repairs is less than for other forms of power.

Freight Service

The eight Diesel cabs of 1350 bhp capacity which were acquired in 1944 have been in service continuously since their delivery, most of the time as two-unit 2700 bhp combinations. In the year 1945, when they were thus used, the total mileage for the four locomotives was 506,608, equal to an average of 10,554 miles each per month.

In July, 1946, two additional cabs were added and since that time the twelve units have been operated as four locomotives, two comprised of three units each, and two of two units each. The average miles per locomotive per month in 1946 was about 10,000.

Analysis of the performances of two 5400 bhp Diesels versus two modern steam freight locomotives of about the same ihp capacity, in comparable service, for a check period of seventeen days in October, 1944, indicated the following maximum potential yearly performance:

Annual Potential Performance Per Locomotive

Line No.		*Diesel*	*Steam*
(1)	Total Hours (365 × 24)	8760	8760
(2)	Hours for Shopping and Periodic Inspections	216	696
(3)	Assigned Hours (1)−(2)	8544	8064
(4)	Hours Used	7219	7023
(5)	Hours Available—Not Used	349	252
(6)	Hours Unavailable	976	789
(7)	Per Cent Utilization (4)÷(1)	82.4	80.2
(8)	Per Cent Availability (4)+(5)÷(1)	86.4	83.0
(9)	Mileage Operated	137450	118237
(10)	Average Miles Per Month (9)÷12	11454	9853
(11)	Average Miles Per Day (9)÷365	377	324

During the period studied, every effort was made to keep the engines in service and avoid delays at terminals. Favorable weather conditions also contributed to the excellent performance.

Records of actual usage over extended periods of time indicate that for year-round operation an approximate average monthly mileage of 10,000 for Diesels and 8,500 for steam can reasonably be expected and should be obtained when receiving equivalent attention. With these mileages, the percentages utilization and availability are evaluated as follows:

Line No.		*Diesel*	*Steam*
(1)	Annual Mileage	120,000	102,000
(2)	Average Miles Per Month	10,000	8,500
(3)	Utilization—Per Cent of Total Hours	70.1	63.5
(4)	Availability—Per Cent of Total Hours	73.5	65.7

New Designs and Kinds of Locomotives

The most attractive present development is the gas-turbine, promising all the advantages of the Diesel plus the rotating prime mover and low fuel consumption when produced for the successful use of pulverized coal.

For constructive contribution to the possibilities of the pulverized coal fired steam-turbine-electric, the high-pressure water-tube boiler offers the advantages of higher steam temperatures and improvement in ash disposal and if harmful slag deposits can be eliminated therefrom, this kind of locomotive should become a competitor of the Diesel unless total cost is found to be excessive.

The stoker-fired coal-burning steam-turbine will have, as well, the advantages of rotatively applied power and the complete absence of cylinders and valves with related reciprocating parts for greater continuity of operation, although with the conventional boiler and ash pan, it is not expected to equal the Diesel.

(2) *Over-All Costs of Ownership and Usage*

For analysis, this important fundamental is here divided into its two chief component parts, i.e.,

(a) First costs and resulting annual fixed charges, and

(b) Operating costs, consisting principally of fuel, repairs and crew wages.

First Costs

Prices as of December, 1946, indicate the following approximate relationships among reciprocating steam

(taken as 100), the Diesel-electric and the straight electric:

4-8-4 Type—Steam		*Diesel-Electric*				*Straight Electric*	
6000 Nominal ihp		*6000 bhp*		*4000 bhp*		*5000 Cont. Rated hp*	
Complete Locomotive & High-Capacity Tender	*Per hp*	*Complete Loco.*	*Per hp*	*Complete Loco.*	*Per hp*	*Complete Loco.*	*Per hp*
100	100	214	214	147	221	114	137

Annual Operating Costs

For steam, Diesel and electric, these costs per mile in daily, fast, heavy passenger-train movements, through without engine change, Harmon-Chicago, are shown in Table 2, the result of detailed study for comparison of locomotives of equivalent power. It should be definitely understood, however, that for constructive comparative purposes, *repairs*, Item 3, have been projected to represent such costs averaged over the full anticipated useful service lives of the motive-power units tabulated in accordance with the best information now available.

These data apply only to one representative railroad and the class of service indicated, and it follows that, of necessity, each railroad should establish its own figures to determine the economic advisability, insofar as these costs are concerned, of using the different types of power shown. It is especially noteworthy that an increase of as little as one cent per mile added to 1946 costs for the item of either repairs or fuel amounts to some $3,000.00 per year per engine for the annual mileages given.

For the pulverized or stoker-fired coal-burning steam-turbine-electrics, and the gas-turbine-electric, determination of construction, operating and over-all costs of ownership must await actual experience.

TABLE 2

ANNUAL COSTS

	Steam "Niagara" 4-8-4	Diesel 4000 bhp 2 Unit	*Estimated* Diesel 6000 bhp 3 Unit	*Estimated* Electric 5000 Cont. hp
(1) Approx. Relative First Cost Per Loco. (As of Dec. 1946)	100	147	214	144
(2) Total Annual Mileage	288,000	324,000	324,000	324,000
COST PER MILE				
(3) Repairs	$.356	$.352	$.500	$.170
(4) Fuel	.410	.280	.420	.400 (0.006 per kwh)
(5) (3) + (4)	.766	.632	.920	.570
(6) Water	.031	.004	.005	.005
(7) Lubrication	.011	.030	.045	.011
(8) Other Supplies	.005	.002	.002	.002
(9) Engine House Expense	.100	.100	.100	.020
(10) Crew Wages (two men)	.1944	.1979	.2046	.1927
(11) Vacation Allowance (3%)	.0058	.0059	.0061	.0058
(12) Social Security and Unemployment Tax (8.75%)	.0175	.0178	.0184	.0174
(13) Total Per Mile (Operating)	$1.1307	$ .9896	$1.3011	$ .8239
(14) Total Annual Operating Cost	$325,642	$320,630	$421,556	$226,944
(15) Fixed Charges (Interest, Depreciation and Insurance)	24,453	38,841	56,640	24,635
(16) Total Annual Cost	$350,095	$359,471	$478,196	$291,579
(17) Total Annual Cost Per Mile	$1.22	$1.11	$1.48	$ .90 (See Note No. 1 below)

NOTE No. 1: Fixed charges for substations and overhead contact system, which represent an important increment of cost per power delivered to the locomotive, are not included in this figure, but for comparison in the service indicated would average about 25 cents per mile, making the comparative total $1.15. This total, however, makes no provision for the cost of maintenance of substations and overhead contact system, which would amount to a substantial charge against the electric locomotive.

These steam-turbine locomotives, because of the absence of all reciprocating machinery, but with the added electrical and coal-handling equipment and use of steam generating plant, probably would approximate or exceed the reciprocating steam power in maintenance costs; but with some saving in fuel, the over-all operating cost might be about equal or less. The gas-turbine, if successful, will provide equal power at a large saving in fuel over either steam or Diesel, and having no boiler and little machinery other than for coal processing and handling, maintenance costs should be lowest except for the straight electric.

For both types, the over-all economic results will be importantly affected by the first cost which, if it is found may be brought to a figure comparable with the Diesel-electric of equivalent horsepower, should provide substantial competition for that form of motive power.

(3) *Capacity for Work*

Chart "A" shows the progressive increase in drawbar capacity for reciprocating steam built during the last two decades, from the Class K-5 type 4-6-2 to the S-1 "Niagara" 4-8-4. These curves, from which the detailed cut-off information has been omitted to simplify the composite chart, were developed during road tests using the dynamometer car and made under the direct supervision of qualified Equipment Engineering Department personnel, using suitable length trains and a second engine back of the test car for close regulation of trailing load resistance so as to insure the elimination of practically all acceleration effects during separate runs made to produce the required increments of the complete curve as here illustrated.

With approximately rated boiler pressure and the locomotive, as a whole, in reasonably good condition, there is a cut-off for each incidental speed at which maximum power output is made available from a given design, regardless of whether the capacity of the steam generating plant or the engine cylinders is the limiting factor. Any longer cut-off not only reduces the power output at that speed but also is wasteful of steam and fuel. At a shorter cut-off, the power output becomes less and it follows that there is a corresponding reduction in steam consumption.

By developing each increment of the pull speed curve, the succession of cut-off points throughout the range of operating speed to produce maximum power is definitely established and consequently each portion of any such curve can be reproduced at any time in regular train service by using the proper cut-off in relation to speed. This type of operation is utilized for all System reciprocating steam road locomotives, freight and passenger, and is based on the principle of cut-off selection which can be applied directly and conveniently through the guidance of a device known as the "Valve Pilot" which by means of a duplex gauge indicates the incidental speed and position of the cut-off at all times. Thus, full available capacity may currently be produced while accelerating to running speed and, thereafter, the cut-off may be shortened consistent with load, profile and speed conditions.

As illustrated by the chart, there has been a gradual increase during the twenty-year period from 2500 dbhp at speed of 45 mph obtained with a K-5 class to 5050 dbhp for the S-1, with 275 psi, an increase of 102 per cent. The curve for the S-1 with 290 psi, derived from the test with 275 psi, shows a maximum of 5300 dbhp, an increase of 113 per cent over the K-5.

Charts "B" and "C" show, respectively, the power characteristic curves for steam and Diesel-electric freight and also for steam, Diesel-electric and electric passenger power. The relatively constant horsepower of the Diesel engine is shown with the extremely high starting drawbar pull, but rapidly decreasing as the locomotive speed is advanced, until at the range of about 30 to 40 mph the Diesel and steam of equivalent maximum capacity have approximately the same drawbar pull and horsepower. Thereafter, the steam has the advantage.

The electric locomotive, Chart "C," because power for short time rating is limited only by the adhesion of the wheels on the rails and the traction motor characteristics, has higher capacity throughout the entire speed range than reciprocating steam and in excess of the Diesel at speeds over 30 mph.

Chart "C" also includes curves representing the pounds resistance and equivalent horsepower of a fifteen-car air-conditioned train of 1005-ton (2000-lb.) weight on level tangent track, which indicate the balancing speeds for the motive power shown.

Chart "D" illustrates the comparative acceleration characteristics of the three forms of power, with time plotted against speed and distance, in handling a fifteen-

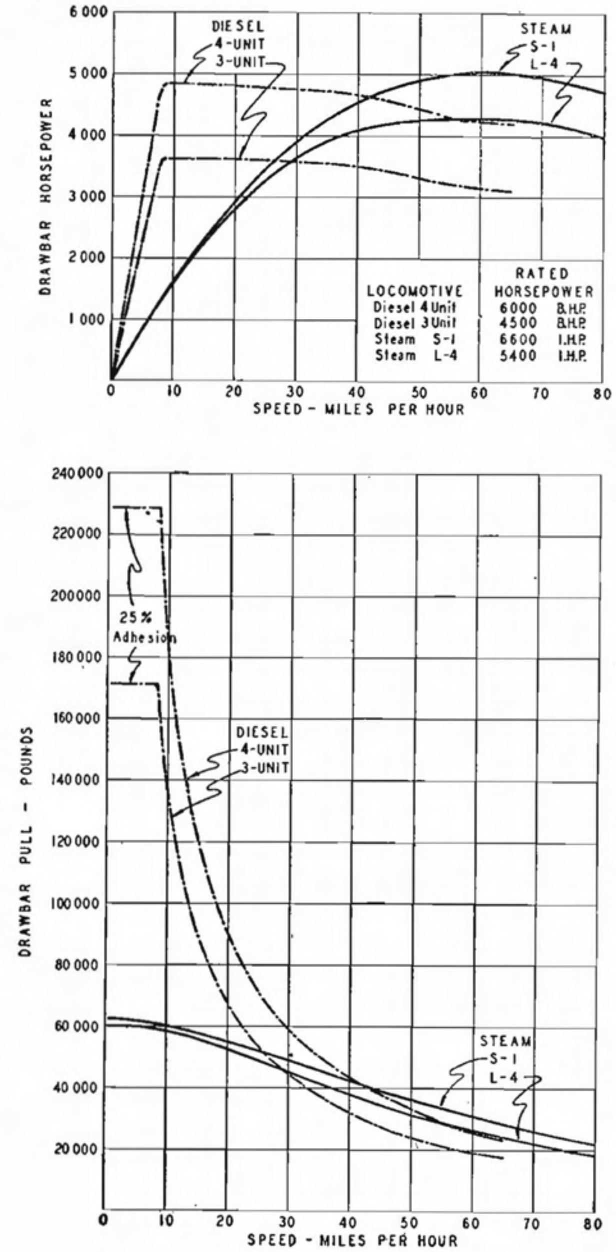


CHART B: POWER CHARACTERISTIC CURVES
FREIGHT LOCOMOTIVES
RECIPROCATING STEAM—DIESEL ELECTRIC

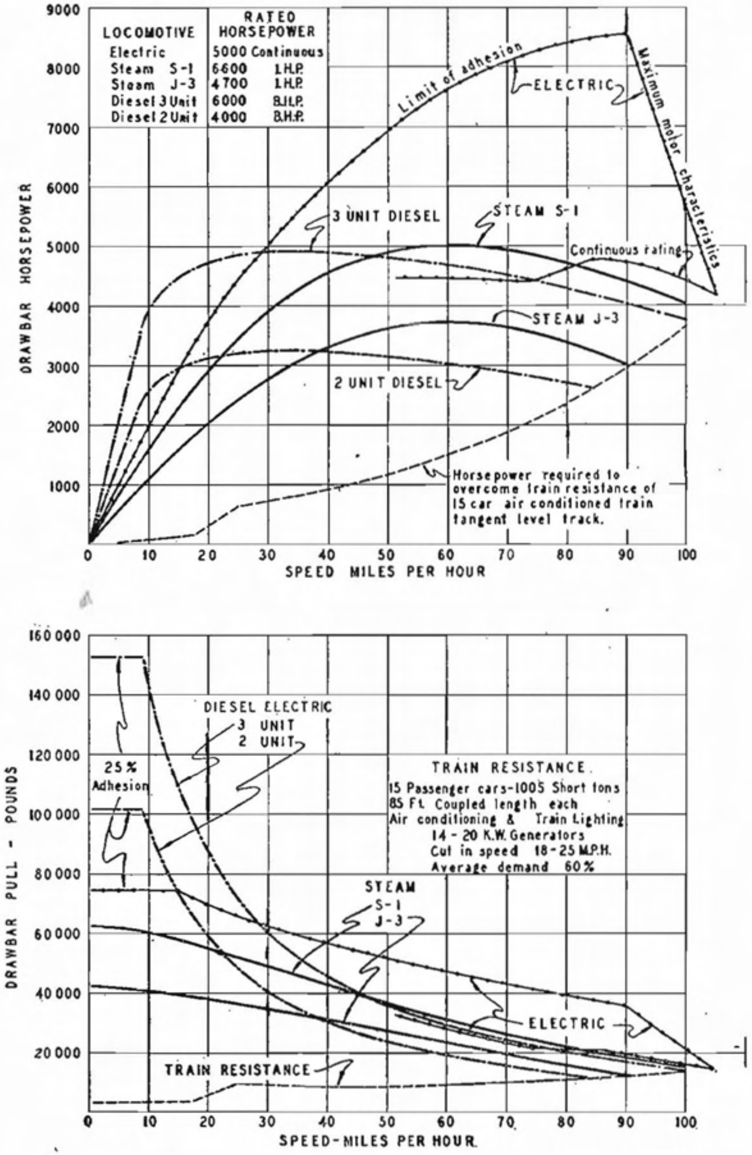


CHART C: POWER CHARACTERISTIC CURVES
PASSENGER LOCOMOTIVES
RECIPROCATING STEAM—ELECTRIC—DIESEL ELECTRIC

(Tabulated Results on Table No. 3)

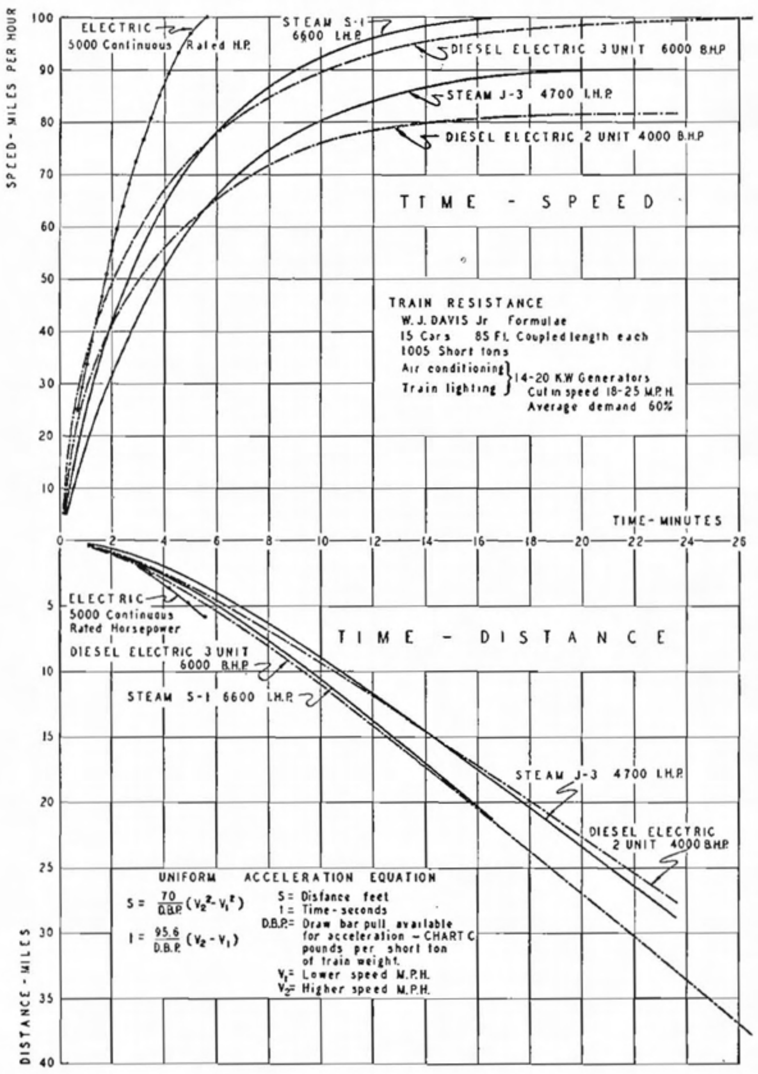
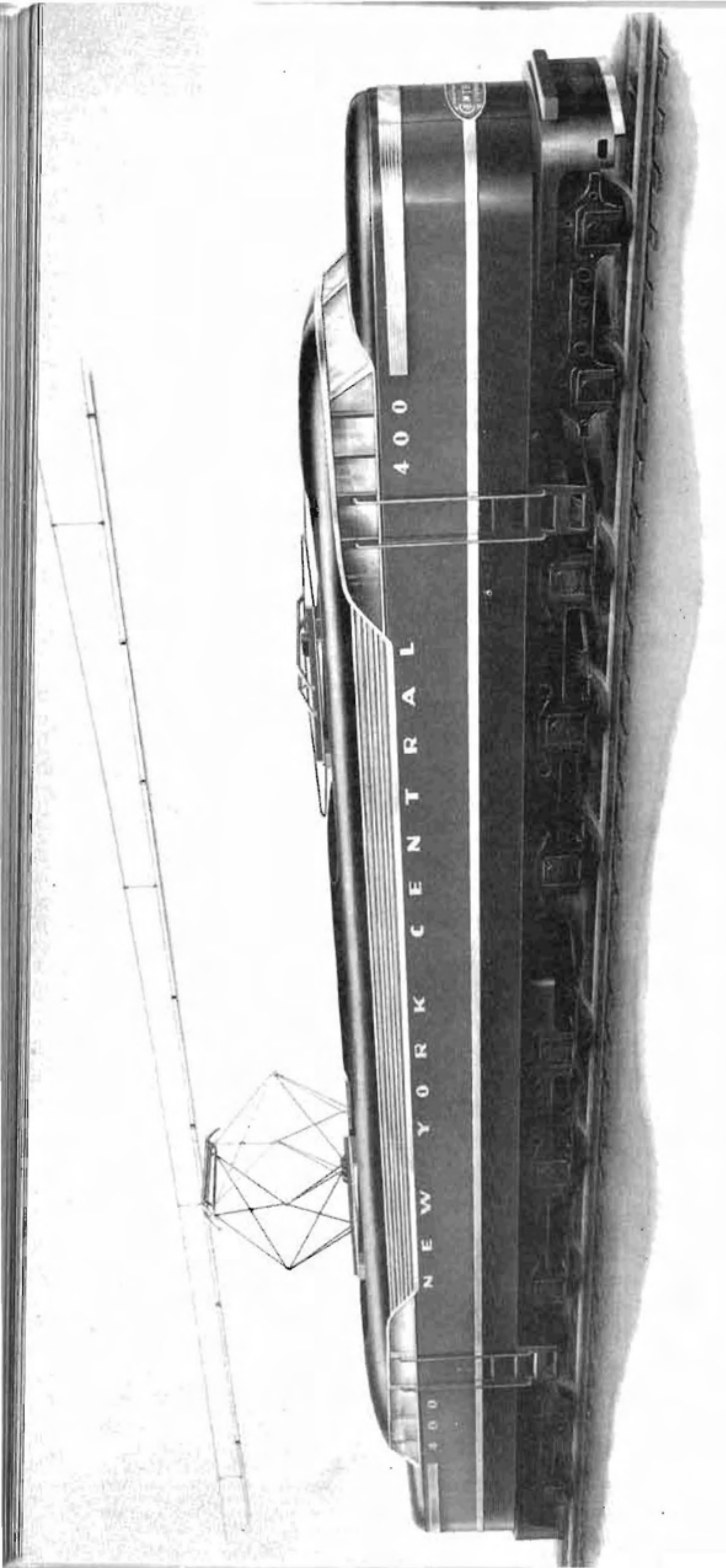


CHART D: MAXIMUM ACCELERATION CHARACTERISTIC CURVES
PASSENGER LOCOMOTIVES
RECIPROCATING STEAM—ELECTRIC—DIESEL ELECTRIC
TANGENT LEVEL TRACK—FIFTEEN CAR PASSENGER TRAIN



5000 H.P. CONTINUOUS RATING ELECTRIC LOCOMOTIVE.
Proposed for Service on the New York Central Lines. See Tables 2 and 3.

car passenger train on level tangent track. For convenient reading, Table 3 is given to show these characteristics to speeds of 35, 60, 80 and 100 mph, and from 35 and 60 to running speeds of 60 and 80 mph.

TABLE 3

MAXIMUM ACCELERATION CHARACTERISTICS
PASSENGER LOCOMOTIVES—LEVEL TANGENT TRACK
RECIPROCATING STEAM—ELECTRIC—DIESEL ELECTRIC
15 AIR CONDITIONED PASSENGER CARS—1005 SHORT TONS
(TAKEN FROM CHART D)

1	Locomotive Type		*Steam*		*Diesel-Electric*		*Electric*
2 3a b	Locomotive Class Wheel Arrangement Driving Axles		J-3 4-6-4 3	S-1 4-8-4 4	2 Units 2(0-6-6-0) 8	3 Units 3(0-6-6-0) 12	 4-6+6-4 6
4	Horsepower Rating		4700 I.H.P.	6600 I.H.P.	4000 B.H.P.	6000 B.H.P.	5000 Continuous Rated H.P.
5 6	Working Pressure Driver Diameter	PSI Inches	275 79	275 79			
7	Balancing Speed	MPH	91	102	84	100.5	105
	Acceleration						
8a b	0 to 35 MPH	Time Minutes Distance Miles	2.28 0.7	1.58 0.5	1.42 0.5	1.00 0.3	1.08 0.3
9a b	0 to 60 MPH	Time Minutes Distance Miles	5.00 2.9	3.50 2.1	4.73 3.2	3.06 2.0	2.19 1.2
10a b	0 to 80 MPH	Time Minutes Distance Miles	9.76 8.6	6.36 5.1	14.17 14.8	6.51 6.1	3.38 2.5
11a b	0 to 100 MPH	Time Minutes Distance Miles		16.50 21.3		26.50 37.8	5.54 5.9
12a b	35 to 60 MPH	Time Minutes Distance Miles	2.72 2.2	1.92 1.6	3.31 2.7	2.06 1.7	1.11 0.9
13a b	35 to 80 MPH	Time Minutes Distance Miles	7.49 7.9	4.78 4.6	12.75 14.3	5.51 5.8	2.30 2.2
14a b	60 to 80 MPH	Time Minutes Distance Miles	4.76 5.7	2.86 3.0	9.44 11.5	3.45 4.1	1.19 1.3

While from the charts, the 4000 bhp Diesel might not be expected to equal the performance of the J-3 steam with its somewhat higher maximum horsepower, even though the Diesel accelerates more rapidly up to 60 mph, actually with trains of fifteen or sixteen modern cars, it has proven more effective in maintaining the fastest schedules between Harmon and Chicago.

Diesels of brake horsepower rating the same as the indicated horsepower of reciprocating steam have much higher drawbar pull at the lower speeds, and train acceleration is more rapid up to about 60 mph, but thereafter the steam with its rising power characteristics will outperform the Diesel up to the desired running speed.

Electric power has the advantage over both steam and Diesel in regaining speed from stops or slowdowns because its excess reserve capacity permits accelerating the train at a much faster rate. As a train-handling unit only, the straight electric is the most satisfactory motive power available, and in this respect it is not expected that new forms herein described, either under development or in use, will exceed it.

Both Diesels and electrics sometimes are run at higher speeds on curves and tangents than reciprocating steam in view of the lower center of gravity, generally lighter wheel loads and complete absence of dynamic augment. However, the chief reason for moderate speed restriction of the reciprocating steam is to avoid increased maintenance costs as, if well designed, it is inherently capable of safe and suitable operation at present maximum speeds of the other types.

For heavy grade work, Diesels and electrics have a distinct advantage over reciprocating steam. With the former, the drawbar pull increases rapidly as the speed is reduced, and this is true to a lesser degree of the latter. Consequently, slow-speed heavy pulls will not cause stalling when motor capacities are not exceeded,

whereas, under similar conditions, the reciprocating engine may slip and stall. The constant torque and the adhesion characteristics of the Diesels and electrics are also of assistance in this respect and, with heavy trains, some double heading or helper service may be eliminated.

Any shortening of passenger-train schedules through elevated speeds will require greater power output and higher cost, even though during recent years a definitely downward trend in passenger-train weights has been effected with light-weight modern-design streamlined equipment. Regardless of this, more rather than less power is needed, especially for acceleration, if faster schedules are to be provided.

The advantages of Diesel-electrics over reciprocating steam may be summed up as follows:

(1) Little affected by cold weather.
(2) Lower center of gravity.
(3) Reduction in track stresses because of lighter wheel loading and absence of dynamic augment, but with this advantage partially offset because of the small-diameter wheels used throughout and the effects of lowered center of gravity.
(4) Somewhat better riding qualities.
(5) Less time required for servicing en route.
(6) Faster acceleration at lower speeds.
(7) Cleaner operation.
(8) Higher availability and utilization.

With respect to practically all of the items enumerated, the straight electric is superior to the Diesel.

The Diesel capacity is bound to that of a self-contained power plant, whereas the straight electric is limited by adhesion, and surplus power normally is available at practically negligible additional costs.

The fundamental problem in shortening passenger-train schedules is primarily that of maintaining high average speed, which may most effectively be accomplished through reduction in the number of stops and slowdowns, and by reducing the time unnecessarily used with the train at rest. An increase in maximum permissible speed reduces the over-all time to some extent, but much more can be gained by raising the over-all average speed to the extent found practicable. An analysis of a typical schedule, Harmon-Chicago, showed that the additional time required over the total scheduled running time at permissible speeds amount to 210 minutes of a total schedule time of 16 hrs. 45 mins., or about 21 per cent divided as follows:

(1)	Decelerating and accelerating to and from slowdowns	52
(2)	Decelerating and accelerating to and from stops	74
(3)	Time-table allowance for station stops	62
(4)	Additional time required for station stops	22
	Total time lost	210

The number of stops and local speed restrictions and the time thus sacrificed have an important effect on the maintenance of fast competitive schedules and obviously should be kept to the minimum practicable.

Certain of the delays, peculiar to steam only, may be eliminated by changing to Diesel or electric power, but most of the time lost is independent of the type of motive power as indicated elsewhere in this discussion.

(4) *Performance Efficiency*

Over-All Thermal Efficiency at Drawbar Referred to Fuel

Any reference to this important factor in the performance efficiency equation usually affords an opportunity for considerable argument. The fact is not questioned that it is highly desirable to improve this characteristic, but it is believed prudent first to review some of the reasons for its relatively low value at the tender drawbar of reciprocating steam. All such units in the United States are non-condensing, self-contained and self-propelled power plants, with over-all dimensions confined within close and definite limits of weight, height, width, and in many cases length, because of operating clearances and load restrictions. Naturally, these dimensional limitations pertain also to other forms of motive power now in use or under development.

For reciprocating steam in heavy through service, the necessarily high horsepower requirement is accompanied by elevated combustion rates, and this complete power plant, including all auxiliary equipment and its own fuel and water supply, is handled successively by different engine crews on fast schedules, under widely fluctuating load requirements and, not infrequently, in dense traffic. While the same conditions pertaining to train handling are present also with other forms of motive power, none contains the variables inherent in the production of power from the coal-burning reciprocating steam.

The efficiency at the drawbar is affected by the loads on the non-power-producing wheels and those of the tender, which for the latest designs are the equivalent of two fully loaded freight cars having rail weights of 210,000 lb. each.

The retention of simplified design, particularly with respect to cylinders and valve gear, penalizes the thermal efficiency, but repayment is secured and augmented in terms of higher serviceability and reasonable freedom from excessive maintenance troubles and related delays on the road.

Although the over-all thermal efficiency of the Diesel locomotive may be four to five times that of reciprocating steam, it should be recognized that without this advantage the cost of Diesel fuel oil would be prohibitive. As a practical fact, the margin in favor of the road Diesel on a fuel basis is of relatively little consequence for equivalent power at current costs for fuel.

Predicated on practical performance of the Diesel-electric, straight electric and reciprocating steam, and thermal analyses of power plants now under development, comparative over-all efficiencies may be cited approximately as follows under conditions of full load in train service at a speed of about 65 mph, with fuel of the average quality currently furnished:

Diesel-Electric	22.0
Straight Electric	17.0
Pulverized Coal Burning Gas-Turbine-Electric (Estimated)	16.0
Pulverized Coal Burning Steam-Turbine-Electric (Estimated)	10.0
Modern Reciprocating Steam	6.0

Over-All Performance Efficiency

The primary measure of the value of a locomotive is its use. Motive power when idle because of mechanical defects or other causes represents, during such periods, total loss of investment and constant expense and it is continually demonstrated in all service that maximum over-all performance efficiency must be sought and secured through the use of units capable of providing consistently high mileage throughout their useful lives.

VIII

CONCLUSION

Progress of any kind must necessarily be geared to change, and the creative mind in the realms of science, invention and engineering is ever seeking newer and better ways of procedure in its efforts to overcome the effects of obsolescence due to constantly changing conditions.

No all-inclusive formula can be presented which would provide, per se, a conclusive answer to the question of motive-power selection and, because the field of speculation is strewn with pitfalls, there is no substitute for the salutary lessons of experience. It seems logical, therefore, that when to Railroad Management anywhere the need for better performance is manifest in any of the *fundamental* aspects which it has been the author's endeavor to analyze and, it is hoped, illuminate in some degree, with the results now summarized in Table 4, the acquisition of new forms of motive power giving fair promise of improved results should be authorized as they are developed and made available, and introduced for intensive trial use and direct comparison in competitive service with locomotives presently employed; and that from this experience a course of future action best suited to meet the specific needs should be developed and gradually expanded.

Where introduction of the straight electric may ap-

pear desirable or warranted, the problem faced by management is of an entirely different character than that imposed by new types of self-contained motive power, with decision depending upon careful and comprehensive study of all factors involved, which, if engineered and supervised by the railroad company, should provide a valid guide to proper conclusion.

This is the procedure on the New York Central System and generally on the railroads of the United States.

Summary of Motive-Power Evaluations

The relative evaluations given in Table 4 are predicated upon:

(a) Locomotives of equivalent power and representing the latest state of the design art.

(b) Equivalent through-line passenger schedules and freight operations and efficient use of potential availability.

(c) Equivalent maintenance and servicing attention at all times.

(d) Presently accumulated knowledge and experience.

(e) The exclusion of fixed charges and maintenance expense for motive-power operating, servicing and repair facilities. Where the use of steam may gradually decrease, some reduction in the facilities required therefor should take place, but as a partial offset to the resulting savings, moderately increasing investment is required in suitable facilities for other forms of motive power as their number becomes greater.

TABLE 4

RELATIVE EVALUATIONS OF VARIOUS MOTIVE-POWER TYPES

It is admitted and emphasized that the following ratings for the gas- and steam-turbine locomotives are speculative and at the present stage are based on design characteristics and possibilities only.

For the straight electric, Diesel and reciprocating steam, the evaluations given are founded on substantial experience and may be considered independently of the others without alterations in the respective sequences of ratings given.

(1) *Availability*	(3) *Capacity for Work*
1st –Straight Electric	1st–Straight Electric
2nd–Gas-Turbine (Estimated)	2nd–Gas-Turbine (Estimated)
3rd–Diesel-Electric	3rd– Diesel-Electric
4th –Steam-Turbine (Estimated)	3rd– Steam-Turbine (Estimated)
5th –Reciprocating Steam	3rd– Reciprocating Steam

(2) *Over-All Costs of Ownership and Usage*

1st – Diesel-Electric
1st – Reciprocating Steam
2nd–Straight Electric (See Note No. 1, Table 2)
–Gas-Turbine and Steam Turbine
Determination of this value must await actual construction, operation and maintenance expense.

(4) *Performance Efficiency*

Over-All Performance	*Thermal Efficiency at Drawbar*
1st –Straight Electric	1st –Diesel-Electric
2nd–Gas-Turbine (Estimated)	2nd–Straight Electric
3rd–Diesel-Electric	3rd–Gas-Turbine (Estimated)
4th –Steam-Turbine (Estimated)	4th –Steam-Turbine (Estimated)
5th –Reciprocating Steam	5th –Reciprocating Steam

Finally, it follows that to maintain the supremacy of rail transportation, so far as this may be accomplished through the selection and introduction of modern locomotives and cars, properly balanced quantities and kinds of rolling stock, both passenger and freight, must currently be acquired and, as conditions permit, this is being done on the railroads of the United States.

For passenger service alone, the New York Central System is now taking deliveries of a total of 720 new day-service and sleeping cars of most modern construction and of 31 different types, fitted with the latest auxiliary equipment and furnishings, which are to be made up into 52 additional streamlined passenger trains for operation on improved schedules throughout the System.