Motive Power for High Speed Service*

By R. P. Johnson

Due to the fact that many lightweight high speed passenger trains are powered by internal combustion engines, it is assumed by some that the realization of speeds around 100 m.p.h. is dependent on this type of power. This, of course, is not true. The only factor that allows a 600 h.p. internal combustion engine to compete with a 1000 to 4000 h.p. steam locomotive, is that of the tons handled. Steam locomotives of the 1890's could produce more speed than the high speed internal combustion units of today, if given the same load to haul. Thus, for instance, locomotive No. 999, which pulled the *Empire State* express of the New York Central more than 40 years ago, made a speed of 112 m.p.h., and high speed locomotives used by the Reading Railroad for its service to Atlantic City made speeds of 115 m.p.h. There is nothing inherent in a steam locomotive to limit its speed. That the railroads have not availed themselves of this speed is due to other practical considerations as detailed previously. The fundamental problem in raising passenger service speeds is to decrease the dead weight of the cars which constitute the train.

The effect of streamlining is not confined to internal-combustion powered trains and can be used to advantage and is as readily applicable to steam trains.

To compete with the steam locomotive economically, the Diesel-powered unit should become a separate unit and not an integral part of a train. When part of a train, it is not flexible, as the units are not interchangeable with any other passenger equipment. If any portion of the unit is out of commission, the entire investment in the unit is out of service. These units are rigid in their capacity and can neither be increased nor diminished to meet the changing requirements of travel from day to day and from season to season. The same rigid limitation exists upon the motive power unit as upon the train as a unit and even if it were possible to expand the size of these trains at periods of peak demand, the rapid decline at speed of the tractive force of Diesel power would soon exhaust the ability of the Diesel unit to perform its schedule.

The internal combustion engine, which has the highest thermal efficiency of any type of prime mover, is unable to run at low speeds and has a low starting torque. A clutch gear arrangement is difficult to adapt to outputs of over 300 h.p. and consequently electrical transmission is generally used between the engine and the driving wheels. This is expensive and accounts for the high cost of internal combustion powered trains.

All the high speed, lightweight, Diesel-powered trains to date are used for light passenger service. Due to the rapid fall in tractive force with increase in speed of the internal combustion engine, it seems improbable that it will ever be used for high speed freight service. The same limitation applies where traffic requires a number of passenger cars on each train. If only 75 to 125 passengers are to be handled on a specific run, the problem from the viewpoint of power required, is simplified, as the weight in two or three coaches can be reduced to the point where the internal combustion locomotive can handle it at high speeds. Where density of traffic requires trains carrying six and eight cars with 400 to 500 passengers per train, the limitations in tractive force at high speeds of the internal combustion locomotive becomes very prominent.

A modern steam locomotive with high wheels, high boiler pressure and high superheat can haul eight or ten modern steel coaches of conventional design at any speed required. If the engine and train are streamlined, as are the internal-combustion-powered trains, the power required at high speeds is decreased and a smaller locomotive can be used. The modern

* *This is the second of two articles on this subject, the first having appeared in the April-July, 1934, issue of* Baldwin Locomotives.—*Editor.*

steam locomotive, due to its better boiler design, is capable of maintaining its effective drawbar horse-power up to higher speeds than older designs and, therefore, in considering the relative merits of internal combustion and steam only modern types of steam power should be used.

Very little attention has been paid to decreasing the weight of the steam locomotive, but for maximum economy this matter should be given consideration, while at the same time retaining as far as possible the well proved components of ordinary locomotive practice, such as low first cost, low maintenance, reliability, safety, high horse-power at speed, and capability of being operated and maintained with present railroad facilities and organization.

The main advantage of the internal combustion powered train is in its initial acceleration, which is at the rate of 3 to 4 m.p.h. per second against .2 to .5 m.p.h. per second for steam locomotives. These acceleration rates may be calculated from the formula:

$$A = 0.733 \frac{(V_2^2 - V_1^2)}{S}$$

Where A = Acceleration in miles per hour per second.
S = Distance of interval between V_2 and V_1 in feet.
V_1 = Lower speed in miles per hour.
V_2 = Higher speed in miles per hour.

Acceleration in ft. per second per second = 1.466A.

The steam locomotive by refinements in design, which would decrease the weight, could be built to provide a starting acceleration of one mile per hour per second. However, in comparing the "get-away" of steam and Diesel locomotives, the relative capacities at higher speeds must also be compared. The steam locomotive will pass all Diesel powered units at higher speeds, due to its ability to maintain a high power output.

To make this point clear we will calculate the performance of several internal combustion powered trains and a tentative high speed streamlined steam train. The trains considered are as follows:

Internal Combustion Train A

Consists of 3 cars with one 4-wheeled truck between each car—8 axles.
Built of aluminum alloys.
One 12-cylinder, 600 h.p. distillate-burning, internal-combustion engine and generator.
Two motors on the axles of the first truck.
202 ft. long, 11 ft. high, 9 ft. wide.
80 tons total weight.
116 passengers.
Fully streamlined.

Internal Combustion Train B

Consists of 2 cars with one 4-wheeled truck between each car—6 axles.
Two 410 h.p. Diesel engines with electric drive.
137½ ft. long, 9 ft. 3 in. wide, 12 ft. 2 in. high.
85 tons total weight.
100 passengers.
Fully streamlined.

Internal Combustion Train C

Consists of 3 cars with one 4-wheeled truck between each car—8 axles.
Built of stainless steel, "shot" welded.
One 600 h.p. Diesel-electric power plant.
Two motors on the axles of the first truck.
197 ft. long, 12 ft. high, 9 ft. 9 in. wide.
100 tons total weight.
72 passengers.
Fully streamlined.

Internal Combustion Train D

Consists of 2 separate cars, the first on two 4-wheeled trucks and the second on two 8-wheeled trucks.
Built of stainless steel, "shot" welded.
Two 240 h.p., 12-cylinder gasoline engines—electric drive—4 motors.
70 ft. long, 10 ft. wide, 13 ft. high.
Total weight 52 tons—first car 40 tons—trailer 12 tons.
76 passengers.
Partially streamlined.

4-6-2 Type Steam Locomotive—Streamlined Design

Weight on drivers, tons	100
Weight on front truck, tons	25
Weight on trailing truck, tons	30
Weight of tender (2/3 loaded), tons	80
Weight of engine and tender, tons	235
Cylinders, inches	25 x 26
Rated tractive force, lbs.	43,000
Steam pressure, lb. per sq. in.	250
Diameter drivers, inches	80
Potential horse-power	3180
Grate area, sq. ft.	80

Type E superheater
Feedwater heater
Hauling three 45-ton streamlined passenger cars.
Total weight of train .... 370 tons
200 passengers.

In figuring resistance for a train such as those designated "A," "B" and "C," the first question that arises is whether it is one car or three. If considered as three cars, the number of axles per car is abnormal, and if considered as one, the weight distribution per axle is unequal. However, as they are fully streamlined, with a common truck between units, we will consider them as one car.

The next question is what coefficient of air resistance to use. As we are considering the train as one car, we must use the coefficient for motor cars, 0.0024 less a reduction for streamlining. On the basis of information available, a proper reduction for streamlining (for leading cars) is 50%. The air resistance coefficient for the trains under discussion will therefore be 50% of 0.0024, or 0.0012.

Flange friction on light electric motor cars for interurban service (which are equivalent to the trains under discussion) has been found to be materially higher than for electric or steam locomotives, due to short wheel base of the trucks. Davis gives it as 0.09V while for electric locomotives it is 0.03V. However, we will use 0.03V in these calculations.

In order to bring out the relative abilities of these several trains to attain high speeds, and illustrate the method, we will compute the resistances and acceleration rates for each of them.

Method of Calculation

Three of the internal combustion trains are considered as one unit, with an air resistance coefficient of 0.0012. Resistance is calculated from the formula:

$$R = 1.3 + \frac{29}{w} + 0.03V + \frac{.0012\,AV^2}{wn.} \quad \text{(lbs. per ton)}$$

in which:—n = number of axles
w = weight per axle
A = frontal area in sq. ft.

The tractive force of these trains is derived from the following:

$$\text{H.P.} = \frac{\text{Pull x Distance}}{33{,}000}, \text{ therefore, } \text{T.F.} = \frac{\text{H.P. x } 33{,}000}{\text{feet per minute}}$$

Giving efficiencies of 90, 95, 95 and 80% respectively to the engine, generator, motors and transmission we have an overall efficiency of 65%. The efficiencies of the power transmission units will vary with the speed and their characteristics when new may be higher than the above figures, but with dirty commutators, worn gears, etc., these figures are average. Also, no deduction has been made for power used for auxiliaries which varies from 4 to 8% of the rated horse-power.

Substituting in the above formula we have:

$$\text{T.F.} = \frac{\text{rated h.p. of engine x .65 x } 33{,}000}{\text{ft. per minute}}$$

For distance and time required for acceleration, we use the formulas:

$$S = \frac{70}{\text{D.B.P.}}(V_2^2 - V_1^2) \text{ and } t = \frac{95.6}{\text{D.B.P.}}(V_2 - V_1)$$

$$\text{Where D.B.P.} = \frac{\text{T.F. available for accel.}}{\text{wt. of train}} = \text{lbs. per ton available for acceleration}$$

V_2 = higher speed.
V_1 = lower speed.

The mean speed over the interval is used in calculating flange resistance, air resistance and tractive force.

Table 1 gives the constants used in the calculations, based on the above.

Train	D. B. P.	n	w	Resistance: Journal	Resistance: Flange	Resistance: Air	H. P. at Wheel	Tractive Force
A	99	8	10	336	2.4V	$0.12V^2$	390	$\frac{12{,}870{,}000}{\text{Ft. per Min.}}$
B	112.6	6	14.2	285	2.55V	$0.135V^2$	533	$\frac{17{,}589{,}000}{\text{Ft. per Min.}}$
C	117	8	12.5	232	3V	$0.1404V^2$	390	$\frac{12{,}870{,}000}{\text{Ft. per Min.}}$
D (First Car)	130	4	10	168	1.2V	$0.208V^2$	312	$\frac{10{,}398{,}896}{\text{Ft. per Min.}}$
D (Trailer)	130	8	1.5	247	0.54V	$0.065V^2$		

Train D is two separate units, neither completely streamlined, therefore, the resistance formulas are:

For power car $= R = 1.3 + \frac{29}{w} + 0.03\ V + \frac{0.0016AV^2}{wn}$ in pounds per ton.

For trailer car $= R = 1.3 + \frac{29}{w} + 0.045V + \frac{0.0005AV^2}{wn}$ in pounds per ton.

Table 1. Constants Used in Calculations.

Speed M.P.H.	Train A		Train B		Train C		Train D		Steam Train	
	Distance Feet	Time Min.	Distance Feet	Time Min.	Distance Feet	Time Min.	Distance Feet	Time Min.	Distance Feet	Time Min.
0–10	19	.04	20	.05	24	.05	16	.04	66	.15
0–20	118	.12	200	.19	144	.14	163	.15	264	.30
0–30	638	.36	720	.43	779	.43	608	.35	619	.46
0–40	1723	.71	1791	.78	2102	.86	1609	.68	1235	.67
0–50	3694	1.21	3672	1.26	4523	1.47	3706	1.21	2290	.93
0–60	7000	1.87	6763	1.90	8802	2.35	8524	2.21	3920	1.27
0–70	12837	2.89	11768	2.78	16381	3.68	43520	8.33	6442	1.71
0–80	23892	4.57	20033	4.03	31381	5.95	.....	....	10192	2.28
0–90	54407	8.65	35282	6.07	85475	13.18	.....	....	15802	3.03
0–100	.....	....	76854	11.04	.....	....	.....	....	24390	4.06

Train A.........will attain a speed of 90 M.P.H. in 10.3 miles and 8.65 minutes
Train B.........will attain a speed of 90 M.P.H. in 6.7 miles and 6.0 minutes
Train C.........will attain a speed of 90 M.P.H. in 16.2 miles and 13.2 minutes
The Steam Train will attain a speed of 90 M.P.H. in 3.0 miles and 3.03 minutes
Train D cannot exceed a speed of 70 M.P.H.

Table 2. Accumulated distance required and accumulated time consumed in accelerating each train from 0 to 100 m.p.h. by 10 m.p.h. intervals.

Recapitulation

From Table 2 it is seen that all the internal combustion powered trains accelerate to 30 m.p.h. faster than the steam train. The steam train in about 40 seconds attains a speed of 40 m.p.h. in a distance of 1235 feet from the starting point, and passes all the internal combustion trains. It attains a speed of 90 m.p.h. in 3.03 minutes and a distance of 3.00 miles against 6.00 minutes and 6.68 miles for the fastest internal combustion train. It accelerates from 90 to 100 m.p.h. in 1.03 minutes and a distance of 1.63 miles against 4.97 minutes and 7.87 miles for the best internal combustion train. This clearly shows the quicker starting of the internal combustion powered trains and the better performance at speeds of the steam trains.

Operating Costs

Granting that high speed trains are desired by a railroad, and that the relative advantages of steam and internal combustion powered trains from the viewpoint of acceleration and maintenance of speed have been considered, the next item of interest is cost of operation. There are many ways of calculating this and care should be exercised that all items affecting these costs should be included. For instance operating costs are listed by the I. C. C. as fuel, water, lubricants, other supplies, engine house expense and locomotive repairs. These constitute pure operating costs, but in considering the relative merits of two propositions, the statement should also include crews' wages, interest charges on the capital investment, amortization and taxes and insurance. A proper operating cost statement should be constituted as follows:

1. Fuel
2. Water
3. Lubrication
4. Other supplies
5. Engine house expense
6. Crews' wages
7. Locomotive repairs
8. Interest on book value
9. Amortization
10. Taxes and insurance

The first six items in the above list are constant costs, that is, they will be the same regardless of the age of the locomotive. Nearly every railroad has the cost per mile of these items. We will consider them singly:

1. *Fuel*

The cost of coal used over a division can be based on the knowledge of what the present service uses and a comparison of the present and proposed power. Or, the evaporation of the proposed steam engine can be calculated and the pounds of coal per pound of water evaporated assumed, knowing the quality of coal and grate area. An average figure would be 6 pounds of water per pound of coal. It is difficult to ascertain the average percentage of maximum capacity, or load factor, the engine operates under over the run, but as the average speed is high, it is reasonable to assume the engine will operate at high capacity, say 75%.

In determining the relative costs of fuel it should be noted that the steam engine requires fuel between runs unless the fire is dropped. Stand-by coal may be assumed as 500 pounds per hour and terminal coal (dropping and rebuilding fires) as 30 pounds per square foot of grate area.

For calculating purposes 100 pounds of coal per mile may be used, and a cost per ton of $2.00 to $2.50, on the tender.

Internal combustion electric powered high speed trains are not yet sufficiently common to make fuel costs available. Manufacturers claim about .50 pounds of oil per brake horsepower hour. The Burlington Zephyr averaged .502 pounds of oil per rated H.P. at 80% average load factor on its Denver-Chicago run. The maximum performance characteristic of this type of power is high and approximately constant over the speed range. The Diesel unit will operate at a higher average load factor than the steam as it accelerates faster at low speeds and therefore reaches full capacity more quickly. For general purposes a figure of 80% may be used. An average price for Diesel oil is 5 cents per gallon.

2. *Water*

The cost of water varies greatly, depending on whether it is plentiful and of good quality or must be treated to make it usable. A high speed steam locomotive hauling a heavy train will evaporate around 50,000 pounds of water per hour. An average cost of water is 4 cents per 1,000 gallons.

The internal combustion locomotive only uses water for engine cooling purposes which is negligible in a consideration of costs.

3. *Lubrication*

The cost of lubrication per mile of a steam locomotive averages about $0.005, while records of internal combustion locomotives indicate a lubricating cost of $0.02 per mile.

4. *Other Supplies*

This item is small and includes miscellaneous supplies such as tools, waste, sand etc. It approximates $0.003 per mile for both steam and oil electric locomotives. This figure is based on I. C. C. reports for 1932.

5. *Engine House Expense*

On long high speed runs this item will normally be more nearly equal for both steam and internal combustion locomotives than in the case of a switching comparison where the greater availability of the internal combustion locomotive and the necessity to fuel and water the steam locomotive makes this item about five times as great for the steam locomotive. At the end of a run over a 300-mile division both engines would normally have stand-by time and require fueling, sanding, cleaning, inspection, etc. As the steam locomotive would also have its fire cleaned it would appear just to give it twice as much engine house expense as the internal combustion locomotive. No figures are available for oil-electric engine house expense in high speed service but for steam we know this to run from $8.00 to $10.00 per turn-around. The cost of this item per mile will depend on the length of run and arrangement of the schedule. Lacking definite knowledge we can assume a cost of $8.00 per turn-around for the steam locomotive and $4.00 for the internal combustion unit.

6. *Crews' Wages*

In switching work it is often possible to handle an oil-electric locomotive with one man which gives it an advantage over a steam locomotive in the matter of operating wages. In long distance, high speed service a regular crew would be needed for both types of power, for reasons of safety if nothing else.

The manner in which a high speed service would be handled by train crews is subject to various opinions. On a 300 mile run of 4½ hours, one crew would be paid three days wages. Or three crews might be used on one trip. Whatever the system, both types of power will be handled in the same way and the item of crews' wages will come to the same amount.

Engine crews are usually paid on the basis of a "Basic day" which is 100 miles or less, or five hours or less, whichever is the most. The rate of pay per mile or per day is based on the weight on drivers of the locomotive. Thus, on a certain road, for any type of power weighing 100 tons on drivers the engineer gets 6.24 cents per mile or $6.24 per day and the fireman 5.04 cents per mile or $5.04 per day. Therefore the cost of such an engine crew would be 11.68 cents per mile. The I. C. C. reports for 1932 show an average cost for engine crews of 15 cents per mile in the United States.

7. *Locomotive Repairs*

Repair cost studies on 16 United States trunk lines have shown a steadily rising cost with advancing age of power. This has been explained elsewhere, but an average trend of the repair costs determined from a study of 10,983 locomotives shows a rapid rise from the first to the third year and from then on a gradual increase (See Fig. 1). For a steam locomotive of 3,000 Potential H.P., as used in the preceding acceleration calculations, the repair costs per locomotive mile, based on the average trend mentioned, are as follows:

Age	*Repair Cost per mile*	*Age*	*Repair Cost per mile*
1	\$.12	11	\$.35
2	.20	12	.36
3	.26	13	.37
4	.28	14	.385
5	.29	15	.395
6	.30	16	.405
7	.31	17	.42
8	.32	18	.43
9	.33	19	.44
10	.34	20	.45

These costs per mile can be obtained for a steam locomotive of any horse-power by multiplying the cost per horse-power unit shown in the average cost trend curve by the potential horse-power of the locomotive in question and dividing by 10,000.

The maintenance costs of internal combustion powered road locomotives have not as yet been established due to the newness of this type of equipment. We have however, a reasonably accurate repair cost trend line for internal combustion switching locomotives based on information furnished to an American Railway Association committee. From the above-mentioned study of steam locomotive costs, we know that the maintenance of steam switchers is greater than for steam road engines. We have therefore plotted in Figure 1, the cost of repairs for steam road engines (Curve A), steam switch engines (Curve B), and for internal combustion switch engines (Curve C). Curve D, for internal combustion road units was drawn the same percentage under the internal combustion switcher curve as the steam road engine curve is under the steam switcher curve. This may be used for calculating purposes.

Having a repair cost trend for both types of power, the average annual cost of repairs over their economic lives may be determined from the formula:

$$\text{Average Annual Repair Cost} = \frac{U\ (S+RN-RA+TN^2+TN-2\ TNA-TA+TA^2)}{N}$$

where: N = Economic life
U = Average annual H.P.U. performance of locomotive
A, R, S and T from repair cost trend curve (Figure 1)

Both this formula and that for economic life have been explained in a previous issue of this magazine.

8. *Interest on Book Value*

The initial investment in an internal combustion locomotive is much greater than in an equivalent steam locomotive. In order to ascertain a correct interest charge, it is first necessary to determine the economic life of the equipment. This can be found in accordance with a method described in a previous issue of this magazine and shown in the example at the end of this article. This method assumes that an amortization charge is made each year which reduces the investment in equal annual amounts. Interest at any rate, usually 5 per cent, is charged against the remaining investment, or book value, and is found from the formula:

$$\text{Average annual interest} = \frac{(N+1)\ E\ C}{2\ N}$$

where: N = Economic life
E = Interest rate
C = Original capital investment.

9. *Amortization of the Investment in Equipment*

This is the amount to be charged each year to the operating expense for the service of the engine. It is that part of the capital investment, which, spread equally over the life of the locomotive, will completely amortize the investment at the end of its life. It is seen that the amount so charged will be governed by the number of years the locomotive is to be operated, while at the same time, it, in turn, will be one of the factors in determining the length of time the locomotive can be economically used.

In order to evaluate this item in the operating statement, the investment is divided by the indicated life, as found by the economic life formula, to arrive at a proper annual amortization charge.

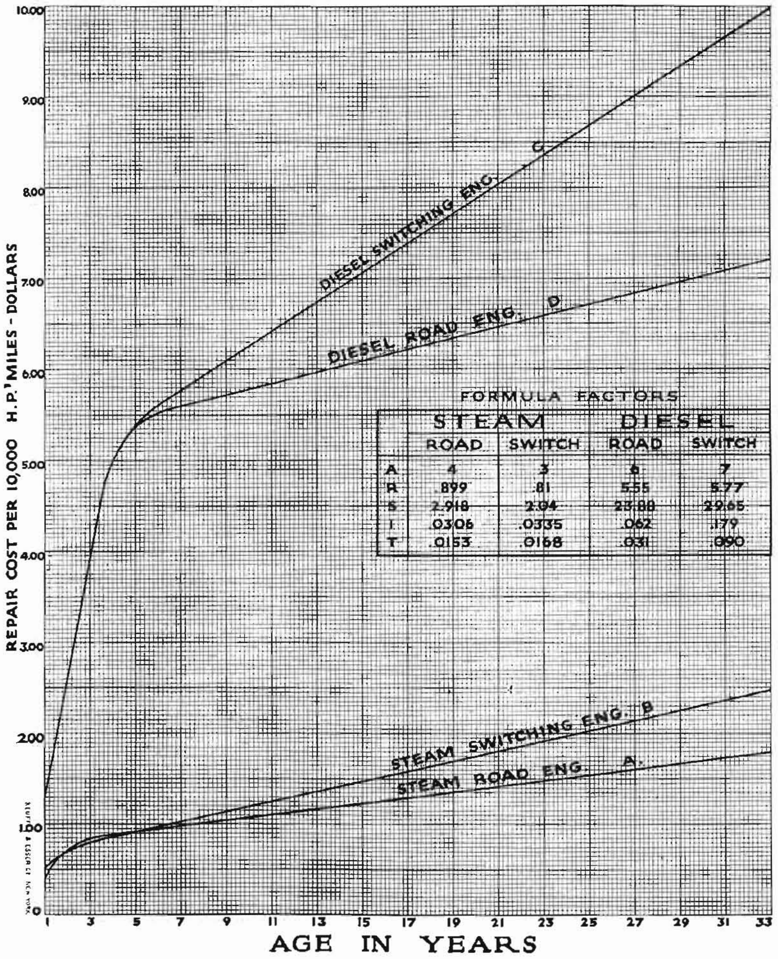

Figure 1. Repair Costs of Steam and Diesel Power in Various Types of Service

10. *Taxes and Insurance*

The rate of taxation and assessment varies greatly in different states and is therefore difficult to evaluate over the life of the equipment. As assessments are based on book value, this item would be greater for an internal combustion train than for a steam train, due to the higher original cost of the former.

Example

Having given a means of evaluating each of the items making up operating costs for the two types of motive power an example will be shown, to serve as a pattern in drawing up a comparative statement of operating costs.

Suppose the establishment of a high speed service is being considered between two cities 300 miles apart, over fairly level country, where the tracks and curves will stand the speed. The train will make a round trip each day, on a schedule of 4½ hours each way. This leaves plenty of time for servicing of either engine between runs. To maintain a service like this 365 days per year would require at least two units of either steam or internal combustion, as one could not possibly be available all the time. Each unit would therefore make 110,000 miles per year, and the operating cost will be set up on that basis.

Let us assume that the traffic requires something more than the small three-car units and that the internal combustion train will be a six-car articulated train weighing 300 tons, total, and requiring 1,800 horse-power to maintain the schedule. A 4-6-2 type steam locomotive, using light cars, could haul 300 tons back of the tender and maintain the schedule. Such a locomotive would weigh about 250 tons, with tender, loaded. The first train would cost, today, about $500,000.00 and the steam engine with six cars at $40,000.00 each, about $340,000.00. The steam engine would have 3,180 potential horse-power, which may seem out of proportion to the 1,800 horse-power in the internal combustion train, but which is necessary due to its greater weight and lower thermal efficiency.

A Diesel engine locomotive of equivalent rated horse-power could not deliver the same horse-power at speeds as the steam engine and its cost would be prohibitive. Even with the higher horse-power of the steam locomotive, the cost is much less than the internal combustion motive power unit. Naturally it takes more coal and water to haul this weight, but this is only one item in the operating cost.

Summarizing, we have:

	Steam	*Internal Combustion*
Length of run, miles	300	300
Mileage of each power unit per year	110,000	110,000
Schedule for run, hours	4½	4½
Total weight of train, tons	550	300
Rated horse-power	3,180	1,800
Cost of train, dollars	340,000	500,000
Number of cars	6	6
Weight of each car, tons	50	30

With the above data we are in a position to draw up an operating cost statement for these two trains. First we will determine the economic life of the two motive power units, to have something on which to base interest and amortization. This is determined separately for the steam locomotive and train, but as a unit for the internal combustion train (as separate costs are not available on the motive unit and cars), from the formula:

$$\text{Economic Life}=\left(\sqrt{\frac{\frac{C}{U}+S-RA-TA+TA^2}{T}+.25}\right)+.5$$

which has been explained elsewhere.

where:

		Steam Locomotive	Internal Combustion Train
Capital Investment	C=.........	\$100,000	\$500,000
H.P.U. performance	U=.........	34980	19800
Repair cost	S=.........	2.918	23.88
constants	R=.........	0.899	5.55
(See Fig. 1)	A=.........	4	6
	T=.........	0.0153	0.031
Economic Life, N, years	=.........	13	24

Note: H.P.U. = Horse-power of engine X mileage, divided by 10,000.

The economic life of the steam engine has been calculated above. The life of the cars is in excess of this, so in figuring depreciation and interest, a life of 24 years has been assumed to agree with the internal combustion train life.

1. *Fuel*

Neither the steam nor Diesel train will work at 100 per cent capacity over the whole run, as in some cases they will be assisted by grade, in others, speed restrictions will hold them down and decelerating for stops will require no power.

We will assume a load factor of 75% for the steam and 80% for the Diesel unit.

Assuming that the steam locomotive will evaporate 6 pounds of water per pound of coal, and has a maximum evaporative capacity of 53,000 pounds of water per hour, then it will use 8,833 pounds of coal per hour at 100% load factor and 6,625 pounds at 75%. On the 4½ hour run this will amount to 29,813 pounds or 99.4 pounds of coal per mile. For 110,000 miles per year this is 5,467 tons, which at \$2.00 per ton is \$10,934.00. To this must be added stand-by and terminal coal which we will assume as 500 pounds per hour, and 30 pounds per square foot of grate area respectively. The train makes a round trip of 600 miles per day which consumes 9 hours. Of the remaining 15 hours, the fire will be maintained 3 hours (between runs at one end) and dumped for the remainder. Therefore the stand-by coal will be 1,500 pounds per day, and the terminal coal (dumping and rebuilding) 30 pounds for each of the 80 square feet of grate area or 2,400 pounds, a total of 3,900 pounds per day. As the units will operate 182.5 days a year, this amounts to 356 tons per year, which at \$2.00 per ton is \$712.00. The total coal bill for the steam locomotive is therefore \$11,646.00.

Fuel used by the internal-combustion-electric locomotive will be about 0.50 pounds per horse-power hour at 80% load factor. Therefore 1,800 x 0.80 x 0.50 = 720 pounds of oil per hour for this unit. On a 4½ hour run 3,240 pounds or 432 gallons will be used. At 5 cents per gallon this is \$21.60 per trip or 7.2 cents per mile. For 110,000 miles the fuel cost will be \$7,920.00.

2. *Water*

The steam engine evaporates 53,000 pounds of water per hour at maximum capacity. At 75% load factor the water used is 39,750 pounds per hour. In the 4½ hours, 300 mile trip, 178,875 pounds or 21,474 gallons are used. This is 71.6 gallons per mile. In 110,000 miles the steam locomotive would use 7,876,000 gallons, which at 4 cents per 1,000 gallons would amount to \$315.00.

The cost of cooling water for the internal-combustion engine would be negligible.

3. *Lubrication*

This item averages about \$0.005 per mile for steam engines, therefore for 110,000 miles the cost of lubrication is \$550.00. The internal combustion engine costs about \$0.02 per mile and for 110,000 miles this is \$2,200.00.

4. *Other Supplies*

This item covers tools, waste, etc., and is about $0.003 per mile for both steam and internal combustion, and for 110,000 miles amounts to $330.00.

5. *Enginehouse Expense*

We will assume that the engines are serviced after each round trip, therefore the enginehouse cost will be $8.00 per round trip for the steam and $4.00 for the Diesel locomotive. For 1,825 round trips in 110,000 miles this will amount to $1,460.00 for the steam and $730.00 for the Diesel locomotives.

6. *Crews' Wages*

Based on $0.15 per mile for an engineer and fireman this item will amount to $16,500.00 for 110,000 miles, for both types of power.

7. *Locomotive Repairs*

In determining the value of this item we have used the trend lines mentioned previously and shown in Figure 1. The values to be used in the average annual operating cost formula are:

	Steam— Locomotive	*Internal Combustion*
U	34,980	19,800
S	2.918	23.88
R	0.899	5.55
N	13	24
A	4	6
T	0.0153	0.031

For the repair cost of the cars we have used 1.5 cents per mile.

The average annual repair costs of the two trains will then be:

	Steam	*Internal Combustion*
Maintenance Cost—Motive Power Unit	$33,341.00	$110,865.00
Maintenance Cost—Cars (110,000 miles @ $0.015)	9,900.00 (6 cars)	8,250.00 (5 cars)
Maintenance Cost—Train	$43,241.00	$119,115.00

8. *Interest on Investment*

This item is 5 per cent of the capital expenditure for the equipment over its economic life and is calculated from the formula:

$$\text{Average Annual Interest} = \frac{(N+1)\,E\,C}{2\,N}.$$

where:

	Steam		*Internal Combustion*	
	Motive Power Unit	*Cars*	*Motive Power Unit*	*Cars*
N=Economic life, years ..	13	24	24	24
E=Interest rate, per cent....	5	5	5	5
C=Capital investment ..	$100,000.00	$240,000.00	$500,000.00	

Substituting these values in the above formula, we find interest charges are:

	Steam	*Internal Combustion*
Motive Power Unit	$2,692.00	....
Cars	6,250.00	....
Total train	8,942.00	$13,021.00

9. *Amortization*

Having determined the economic life of the two trains we can divide the initial cost by this life to find the amount to be charged each year to amortization.

For the steam engine this is $100,000.00÷13 or $7,692.00 for the motive power unit and $240,000.00÷24 or $10,000.00 for the cars, or a total of $17,692.00. For the internal combustion train this is $500,000.00÷24 or $20,833.00.

10. *Taxes and Insurance*

Taxes and assessments vary widely and decrease with increasing age of the equipment, but we will assume 0.75% of the original investment annually as an average value over the life of the equipment. For the steam train this is, $340,000.00 x 0.75 = $2,550.00 and for the internal combustion train $500,000.00 x 0.75 = $3,750.00.

Table 3 lists the values explained above and shows how a railroad can calculate the comparative annual average operating cost of high speed service with either steam or internal combustion power. Unlike switching service where there is a great deal of stand-by time and a low load factor, this high speed service requires continuous operation at a high load factor which accounts for the high fuel cost of

Cost Item	Column 1 Steam *Economic Life 13 Years*	Column 2 Internal Combustion *Economic Life 24 Years*	Column 3 Internal Combustion *Assumed Life 15 Years*
1. Fuel	$11,646.00	$ 7,920.00	$ 7,920.00
2. Water	315.00	....	....
3. Lubrication	550.00	2,200.00	2,200.00
4. Other Supplies	330.00	330.00	330.00
5. Enginehouse Expense	1,460.00	730.00	730.00
6. Crews Wages	16,500.00	16,500.00	16,500.00
7. Maintenance	43,241.00	119,115.00	109,388.00
8. Interest Charges	8,942.00	13,021.00	13,333.00
9. Amortization	17,692.00	20,833.00	33,333.00
10. Taxes and Insurance	2,550.00	3,750.00	3,750.00
Total	$103,226.00	$184,399.00	$187,484.00
Cost per Mile	$0.938	$1.676	$1.704

In setting up an operating cost comparison, it should properly be the cost for maintaining a service and not one train. For one round trip a day every day in the year at least two motive power units should be available. The cost per mile for this service would then be double that shown above which is for one train.

Table 3. Average Annual Operating Costs for Steam Equipment and Internal Combustion Unit for a service of 110,000 miles per year

the internal combustion train. The greater initial investment in the internal combustion train accounts for its higher interest charges.

The only item in the above statement that might form a basis for argument is the cost of repairs for the Diesel-powered units. We have assumed it in a manner which seems reasonable. The restrictions of locomotive size require that such engines operate at high speed and we know the maintenance cost of high speed internal combustion engines is high. The life of airplane engines is calculated in hours. Also it must be noted that the repair cost shown is the *average* annual cost over the economic life of the locomotive. In a life of 24 years the motive power unit certainly will require extensive if not complete replacement. Further, the maintenance of this high speed service is much more severe than that of any other type of service to which Diesel engines have been applied. In any case, it is conceded that their maintenance costs will be higher than steam. How much more, anyone is entitled to estimate for himself in drawing up an operating cost statement.

Such a statement gives a clear picture of the costs of the services as viewed from an engineering and accounting viewpoint but does not attempt to evaluate the advertising value of the new types of high speed trains.

It should be clearly understood that Columns 1 and 2 are based on an economic life of the equipment which will give the lowest *average* annual operating cost. In other words the economic life is that number of years service during which the total cost of locomotive operation, including the amortization of the investment, reaches its lowest yearly average cost.

The two factors that determine economic life are the decreasing annual amount required for amortization and the increasing cost of repairs. If anyone does not agree that repair costs rise with increasing age, or believes that the rise will be at a lower rate than shown in Figure 1, then the economic life of the equipment will be lengthened over that shown above.

The lower the cost of the equipment, and the greater its mileage, the shorter is its economic life. As the internal-combustion equipment in the above example is calculated for the same mileage as the steam, but costs more, the result is a longer economic life. If 24 years seems too long a life for this equipment, it is possible to make up an operating cost statement for any assumed life by simply substituting the assumed life for N in the operating cost formula. Assuming a lower life than that shown in Column 2 will lower the repair cost item, but increase the interest on book value and amortization charges. The increases will exceed the lower repair item (or else 24 years would not be the economic life and give the lowest average annual operating costs). To illustrate this, let us assume that the Diesel equipment would only last 15 years. Column 3 in Table 3 is set up on this basis and illustrates the above statements.

The intent of this discussion is to show the proper method of setting up a comparative statement of operating expense, based on sound principles, and not to press any claims or values for the separate items. Each problem must be evaluated on its merits, and if fairly handled, we believe will show the high speed steam train to be more economical than internal combustion. As far as catering to public favor through streamlining, the steam locomotive and cars can be made quite as bizarre looking as any high speed internal combustion train.