The Economic Life of Locomotives and Its Relation to Locomotive Performance and Operating Expense

By Thomas R. Cook

The function of the railroad is to transport people and goods from one point to another. This should be done with the least possible operating cost. The principal piece of equipment used in this operation is the locomotive. Records show that the expense involved in and controlled by locomotive performance amounts to more than 35 per cent of the total operating expense of the railroads. However, the amount invested in locomotives is only about 7.6 per cent of the total railroad investment.

When the efficient performance of 7.6 per cent of the investment controls over 35 per cent of the total expense of operation, the economy of the plant and its earning ability depend to a large extent on the selection and control of this small portion of the investment.

The items of expense comprising this 35 per cent are:

Locomotive repairs
Crews' wages
Fuel
Water
Enginehouse expense
Lubrication
Other supplies

That this expense of locomotive operation is of great moment in times of economic distress is reflected in the following fact. In spite of obvious deferred maintenance in 1931 and 1932 as compared with 1929, the locomotive's proportion of the total expense has remained practically constant. The actual figures for the Class 1 Railroads were as follows:

1929—Locomotive expense 36.2 per cent of the total
1931—Locomotive expense 35.3 per cent of the total
1932—Locomotive expense 34.8 per cent of the total

There are three factors involved in the determination of locomotive expense, as follows:

1. The age of the machine.
2. The selection of the most efficient design for the work to be done.
3. The economic life of the machine in a given service.

Let us consider the age factor. The average age of the present locomotive inventory of the Class 1 railroads is approaching twenty years. If the average age were reduced to ten years by uniform rate of purchase, the cost of repairs (308 account) would be reduced 23 per cent, amounting on Class 1 roads to approximately $94,000,000 per year, or over 2 per cent of the total operating expense.

It has been found that repair costs show a constant increase as locomotives grow older. From an extensive study we have determined the average cost of repairs of steam locomotives at various years of age, using as a comparative measure the Horsepower Unit (10,000 horsepower miles). These costs can be translated into cost per mile for any given engine by multiplying the cost per Horsepower Unit by the potential horsepower of the locomotive and dividing the product by 10,000.

The tabulation on page 4 shows the increasing cost per Horsepower Unit and the increasing cost per mile for locomotives of 1,000, 2,000, 3,000 and 4,000 horsepower with increasing age.

Studies have indicated that the transportation or constant savings, resulting from the replacement of old power, are somewhat greater than the savings in repairs. It is estimated that the constant savings will amount to about 3 per cent of the total operating expense.

The total savings shown by the new power, therefore, will be about 5 per cent of the total operating expense, which means an increase of 25 per cent in net operating income.

The second factor, "Selection of Power,"

Year of Age	Cost per Horsepower Unit	Cost per Locomotive Mile			
		Locomotives of 1000 H.P.	Locomotives of 2000 H.P.	Locomotives of 3000 H.P.	Locomotives of 4000 H.P.
1	$0.430	$0.0430	$0.0860	$0.1290	$0.1720
2	.720	.0720	.1440	.2160	.2880
3	.869	.0869	.1738	.2607	.3476
4	.899	.0899	.1798	.2697	.3596
5	.930	.0930	.1860	.2790	.3720
6	.960	.0960	.1920	.2880	.3840
7	.991	.0991	.1982	.2973	.3964
8	1.022	.1022	.2044	.3066	.4088
9	1.052	.1052	.2104	.3156	.4208
10	1.083	.1083	.2166	.3249	.4332
11	1.113	.1113	.2226	.3339	.4452
12	1.144	.1144	.2288	.3432	.4576
13	1.175	.1175	.2350	.3525	.4700
14	1.205	.1205	.2410	.3615	.4820
15	1.236	.1236	.2472	.3708	.4944
16	1.266	.1266	.2532	.3798	.5064
17	1.297	.1297	.2594	.3891	.5188
18	1.328	.1328	.2656	.3984	.5312
19	1.358	.1358	.2716	.4074	.5432
20	1.389	.1389	.2778	.4167	.5556

Table Showing the Increasing Cost of Repairs of Steam Locomotives with Increasing Age, Compiled from a Study of the Repair Costs of Over 10,000 Locomotives Representing over 26,000 Locomotive Years

is becoming more and more important and requires careful analysis for the following reasons:

1. The rapid development of the locomotive and its appurtenances is hastening the economic obsolescence of the existing power.
2. To obtain the greatest return on the dollars invested, power must be designed for the specific service.
3. To obtain the least operating cost, the power must be used intensively, with more rapid turnover than has prevailed.
4. As a rule, power purchased today is so heavy that it cannot be as economically set back in lighter service as in the past.

Overshadowing this entire picture is the necessity of determining the economic life of a locomotive in a given service. By the economic life of a locomotive is meant that number of years of service during which the total cost of locomotive operation, including the amortization of the investment, reaches its lowest yearly average cost. Additional years of service, beyond this point, would result in increased average annual cost.

We are all aware of the fact that the greatest return on the investment in any piece of productive equipment is obtained with the greatest intensity of use. This is true of locomotives producing gross ton- or car-miles.

The economic life of a locomotive is dependent on its first cost, its miles per year, and the trend cost of locomotive repairs on a given road. The magnitude of this problem and its major effect upon earnings indicate the desirability of careful analysis of present costs and the selection of power that will give the greatest return on the dollar invested.

In the April, 1933, issue of Baldwin Locomotives appeared an article entitled "The Relation of Locomotive Operation to Railroad Net Operating Income." That article demonstrated that the total annual average operating expense of a locomotive decreased rapidly up to a certain length of service and then started to increase.

This is illustrated by Figure 1, in which the total cost is shown in the form of a curve. It will be noted that the least cost of transportation is obtained, with this particular fleet of locomotives, in slightly over fourteen years. To retain this minimum average the fleet should be replaced with new power at this time.

Figure 2 shows the factors which make up the total cost curve of Figure 1. In analyzing

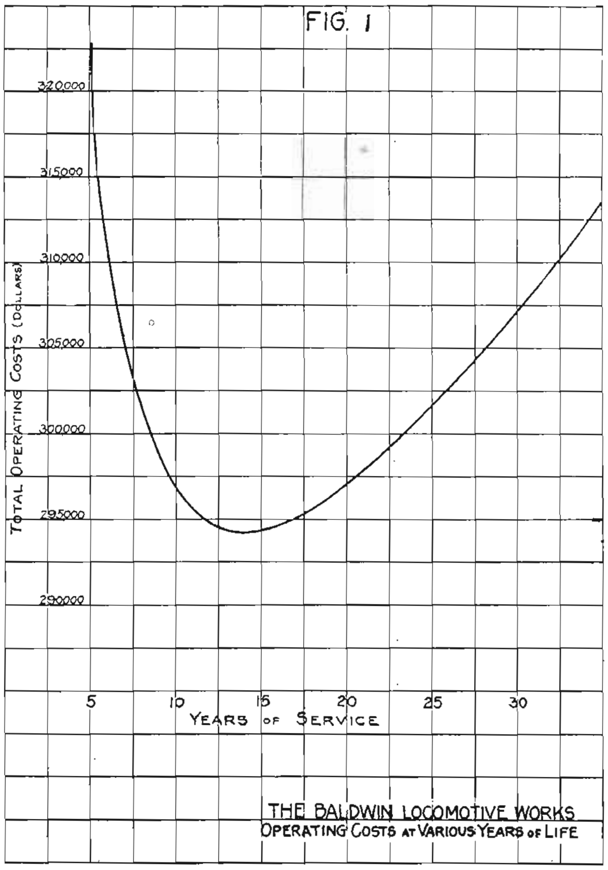

Figure 1—Curve Showing the Average Annual Cost of Operation of Three Locomotives for Various Lengths of Life

Figure 2 from the standpoint of economic life, three pertinent facts are evident:

1. The constant costs of the service have no bearing on the economic life of the locomotive. These constant costs comprise crews' wages (train and locomotive), fuel, enginehouse costs, water, lubrication, and other supplies.
2. Interest on book value and taxes and insurance decrease at such a small rate that their effect on the economic life is negligible. The omission of these factors in the case shown in Figures 1 and 2 changes the economic life from 14.2 to 14.4 years, an increase of only 0.2 of a year.
3. The two factors that determine the economic life of the locomotive are the decreasing annual amount required for amortization during the period of service, and the increasing cost of locomotive repairs.

It is quite evident that the economic life is that number of years when the increase in the average annual cost of locomotive maintenance becomes equal to the decrease in the annual amount required for amortization. This is the point on the curve (Figure 1) where the average annual cost starts to increase.

Equating the expression for these two factors and solving for "N," the economic life, we obtain the following expression or formula:

Equation (1)

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

Where—

- N = The economic life in years.
- A = Year at which the repair cost trend becomes a straight line.
- C = Investment in dollars.
- U = The average horsepower unit performance of the locomotives, i.e. the average miles per year multiplied by the potential horsepower and divided by 10,000.
- S = The sum of the repair costs per Horsepower Unit for the years 1 to A inclusive.
- R = The cost of repairs per Horsepower Unit at the year A.
- T = ½ the annual increase in cost of repairs from the Ath year on.

NOTE—The derivation of Equation (1) is shown in the Appendix on page 10.

In order to illustrate the factors used and to provide a basis for concrete demonstration of the above formula, we have shown in Figure 3 the trend cost of repairs of 10,983 locomotives. They are from fifteen trunk lines and represent 26,401 locomotive repair years. The cost of maintenance was obtained principally from records of the years 1927, 1928 and 1929. That was the period when the roads had reached a constant low cost of maintenance and prior to the effect of any deferred maintenance caused by the depression.

Returning for a moment to Equation (1), we find that we can change its terms so that "N" represents, not the economic life of one locomotive but the economic life of one horsepower. In Equation (1) we have the term "U = annual average Horsepower Units." In other words, $U=\frac{PM}{10,000}$, where "P" is the potential horsepower and "M" the average miles per year. Similarly, the expression "C = investment in dollars" can be changed to "c," which represents $\frac{C}{P}$, or the investment in one horsepower.

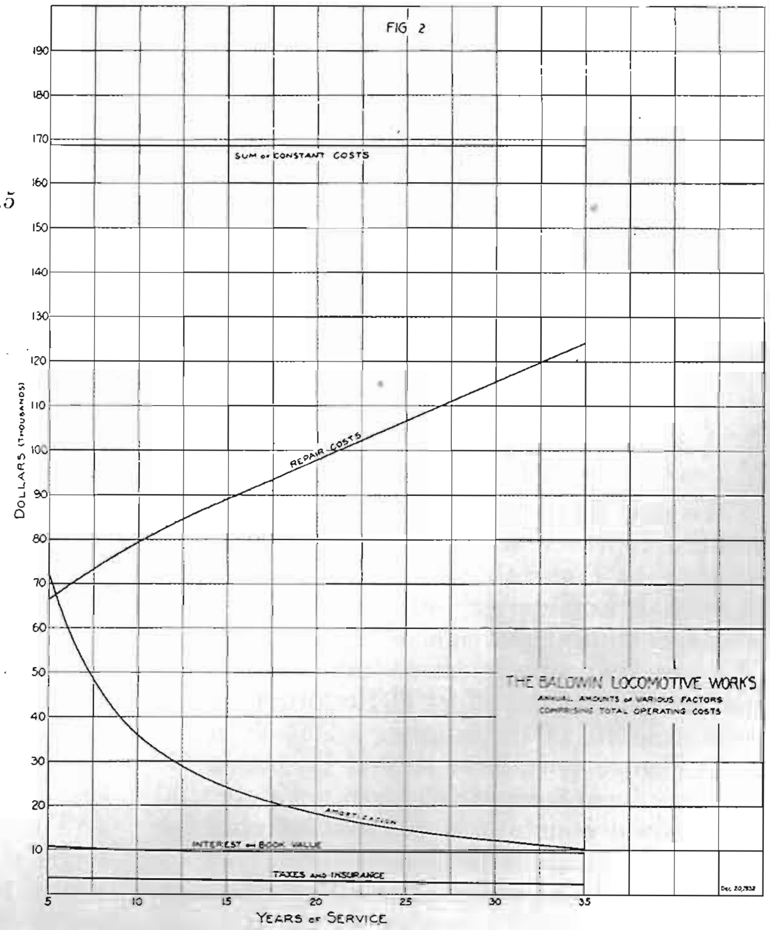

Figure 2—Curves Showing the Various Factors Which Make up the Total Cost Curve Shown in Figure 1

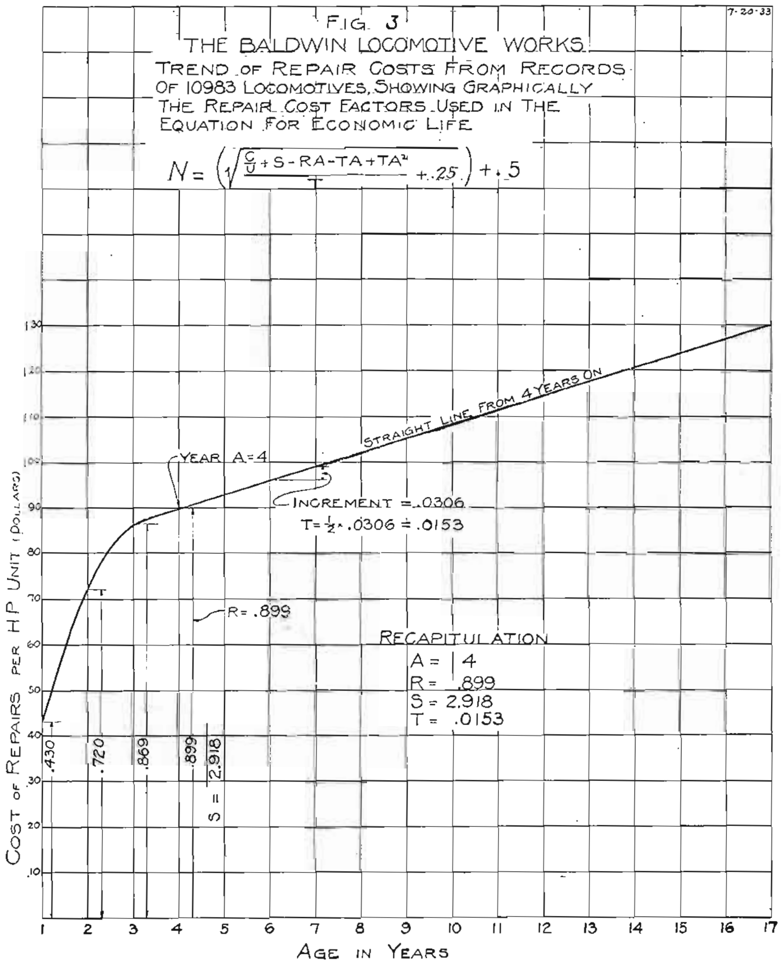

Figure 3—Trend of Repair Costs from Records of 10,983 Locomotives, Showing Graphically the Repair Cost Factors Used in Equation (1)

Substituting in Equation (1) the above expressions for "U" and "C," and the cost factors as shown in Figure 3, and solving for the economic life of one horsepower, we have:

$$N=\left(\sqrt{\frac{c}{M\ .00000153}-32.063}\right)+.5 \quad \text{Equation (2)}$$

We now have the economic life of a locomotive represented by an expression containing two variables: first, the cost per potential horsepower and, secondly, the average annual mileage of the locomotive. We can keep one of these factors constant and determine the effect of the other on the economic life of the engine.

In Figure 4 we have solved Equation (2) in curve form, keeping the cost per potential horsepower constant at $25 and varying the average mileage of the locomotive.

The resultant curve shows that the economic life becomes shorter as the average mileage is increased. In other words, if the locomotive costs $25 per potential horsepower and you can get only 10,000 miles per year service, you must run the locomotive more than 40 years to get the value out of the investment. On the other hand, if you can obtain a use of 90,000 miles per year, the locomotive should be replaced in about 13 years in order to obtain the lowest average cost for the service.

The retirement of a locomotive at the end of its economic life should not be confused with the question of the justification of replacing old power with that which is modern. The latter problem necessarily takes in service conditions, the comparative efficiency of the locomotives and the fuel and water savings.

Again we take Equation (2) and solve it with the mileage constant and the cost per potential horsepower varied. Figure 5 shows ten curves obtained by solving in this manner. The curves cover constant mileages of 20, 25, 30, 35, 40, 50, 60, 70, 80 and 90 thousand miles per year, with the cost per potential horsepower varying from $18 to $32. From this plot you can determine the economic life of any locomotive, knowing the average annual mileage and the cost per potential horsepower.

Figure 5 illustrates two well known facts: first, the lower the cost of the locomotive, the shorter its economic life; secondly, the greater its average mileage, the shorter its economic life.

In using the results shown on Figures 4 and 5, it should be remembered that these are obtained by using the repair cost factors taken from studies of 10,983 locomotives and represent average repair costs only. Each railroad, due to its specific conditions, has a trend cost of its own which should be used for more accurate determination of the economic life of its locomotives.

The average yearly operating cost of a locomotive in a given service can be determined for the period of economic life or any given period of years by the following formula:

Equation (3)

$$O=K+\frac{(N+1)EC}{2N}+\frac{C}{N}+\frac{U(S+RN-RA+TN^2+TN-2TNA-TA+TA^2)}{N}$$

Where—

O = Average yearly operating cost for the period in question.

K = Constant annual costs; the sum of the following:

- Crews' Wages
- Fuel
- Lubrication
- Other Supplies
- Water
- Enginehouse Costs

E = Interest rate (or desired rate of return) on capital.

The other symbols are the same as shown under Equation (1).

Economic Life of Switch Locomotives

Due to the fact that the potential horsepower of a switch locomotive varies considerably with respect to the weight on drivers, it is not always a good measure of the work done. On the other hand, in pure switching or shunting operations the locomotive can perform work in relation to its weight on drivers, and a unit of measure based upon this factor is more consistent and is a measure that allows of comparison with other types of power. A unit of this kind can be expressed as 100 weight-ton hours. On this basis the formula for the economic life of switch locomotives becomes:

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

Where—

N = Economic life in years.

C = Investment in dollars.

W = Weight on drivers in 100 tons.

H = Hours service per year.

A = Year at which repair cost trend becomes straight line.

S = Sum of trend cost of repairs 1st to Ath year.

I = Increment in cost of repairs after trend line becomes straight.

R = Cost of repairs per 100 Weight-Ton Hours at Year A.

U = 100 Weight-Ton Hours performance = WH.

T = ½ Increment I.

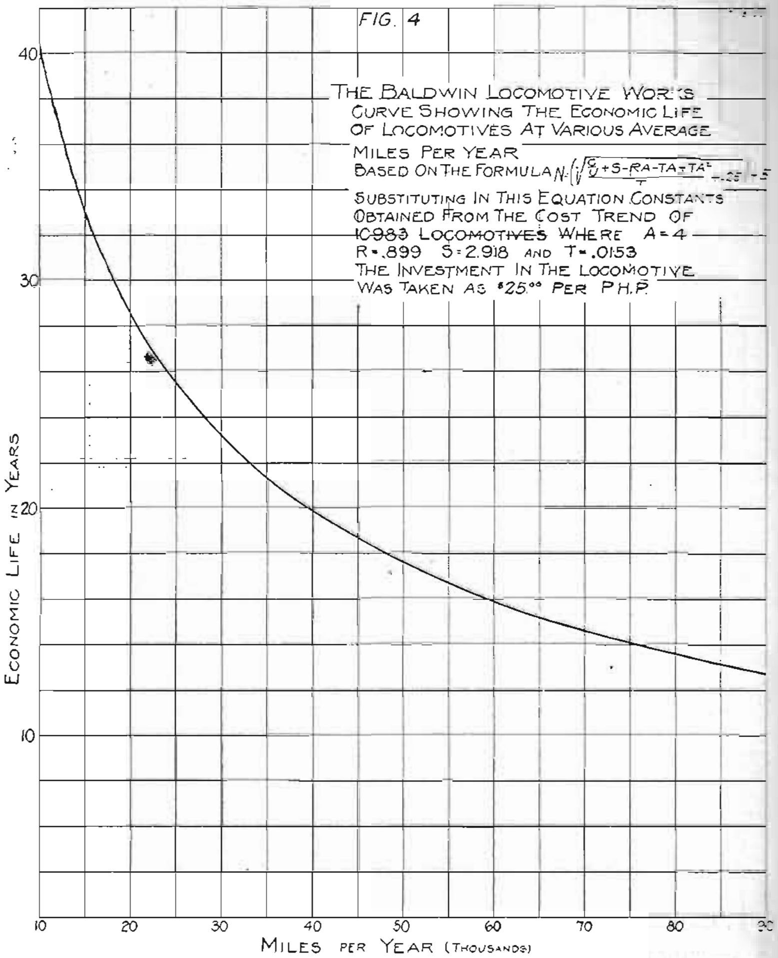

Figure 4—Curve Showing the Relation Between the Economic Life of Locomotives and Their Average Annual Mileage

Values of the above repair factors, based on the average of 1,913 steam switch locomotives on sixteen roads, are as follows:

A = 5
S = 3.545
R = .864
T = .024

Substituting the above values we have:

$$N=\left(\sqrt{\frac{\frac{C}{U}+3.545-4.32-.12+.60}{.024}+.25}\right)+.5$$

$$=\left(\sqrt{\frac{\frac{C}{U}-.295}{.024}+.25}\right)+.5$$

Substituting WH for U:

$$N=\left(\sqrt{\frac{\frac{C}{WH}-.295}{.024}+.25}\right)+.5$$

into issue is the cost trend curve. When such a trend curve of repair cost satisfactorily expresses the increase in the cost of repairs on the road in question, the entire solution gives a correct picture.

Appendix

The derivation of the Equation (1) for the economic life of locomotives:

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

Where—

- N = The economic life in years.
- C = Investment in one locomotive.
- P = Potential horsepower.
- M = Average miles per year.
- A = Year at which the repair cost trend becomes a straight line.
- S = Sum of trend costs of repairs per H.P.U. from the 1st to Ath year inclusive.
- I = Increment in cost of repairs per H.P.U. after cost trend becomes a straight line.
- R = Cost of repairs per H.P.U. at year "A."
- U = Average annual H.P.U. performance of the locomotive.
- T = ½ Increment I.

The decrease in the average annual amount for amortization becomes

$$\frac{C}{N-1}-\frac{C}{N}$$

The increase in the average annual cost of repairs becomes:

$$\frac{U(S+RN-RA+TN^2+TN-2TNA-TA+TA^2)}{N}$$

minus

$$\frac{U(S+RN-R-RA+TN^2-TN-2TNA+TA+TA^2)}{N-1}$$

Equating the above two expressions, and solving for the unknown quantity N, we have:

$$N^2-N=\frac{\frac{C}{U}+S-RA-TA+TA^2}{T}$$

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

Q.E.D.

Following is the derivation of the expression of the average cost of repairs for the Nth year:

The average number of increments I in N−A years $=\frac{1+(N-A)}{2}$

The total number of increments =

$$\frac{1+N-A}{2}\times(N-A)=\frac{N^2+N-2NA-A+A^2}{2}$$

The cumulative cost of repairs for the Nth year = the average H.P.U. per year multiplied by the sum of the costs per H.P.U. for each of the years =

$$U\left[S+R(N-A)+\left(\frac{N^2+N-2NA-A+A^2}{2}\right)I\right]$$

$$=U\left[S+RN-RA+\left(\frac{IN^2+IN-2NIA-IA+IA^2}{2}\right)\right]$$

Substituting T for I

$$=U[S+RN-RA-TN^2+TN-2TNA-TA+TA^2]$$

The average cost of repairs for the Nth year is then

$$\frac{U[S+RN-RA+TN^2+TN-2TNA-TA+TA^2]}{N}$$

Q.E.D.

The average cost of repairs for the N-1 year is obtained in the same manner.