ECONOMIC AND PHYSICAL CONSEQUENCES OF OPERATING RESPECTIVE CAR WEIGHTS OVER TRACK STRUCTURES

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ABSTRACT

The American railway industry is in a competitive environment in which it must seek to lower its total cost per net ton mile. This is especially true in the hauling of bulk commodities such as coal. Adoption of the 80-ton nominal car size (220,000 lbs. gross) instead of the 100-ton car size (263,000 lbs. gross) is one means of achieving lower total costs. The 100-ton car grew out of the traditional rule of thumb, "The bigger the car -- The lower the costs", which has its roots in regulatory costing which allocated costs more on an historic basis than on a predictive basis.

Now that the 100-ton car has become sufficiently used to afford clear-cut observations of its consequences, it is apparent that the dominant mode of rail-life determination will shift from wear to fatigue-induced defects, with approximately a halving of rail life. Other maintenance-of-way costs will increase substantially but not as dramatically as rail-related costs.

Car investment costs (on a net-ton-mile basis) are larger for the 80-ton car and tend to reduce the maintenance-of-way cost differential which favors the 80-ton car, although within the range of car utilization employed in unit train operations, the net cost advantage of the 80-ton car is considerable.

Other variable cost categories have a slight variability with axle-load, if any, and are largely negligible; although if they could be accurately assessed, they would probably favor the 80-ton car. One possible exception to this is the category of locomotive-related costs, including fuel, which has been included quantitatively in this analysis.

The net result is that the total cost of moving bulk-commodity traffic by rail can be reduced considerably by adopting the 220,000 lb. car instead of the 263,000 lb. car. The amount of this economic advantage varies from 37¢ per thousand net ton miles at a car utilization rate of 50 loaded car miles per car day, to 65¢ per thousand at a rate of 200 loaded car miles per car day.

ECONOMIC AND PHYSICAL CONSEQUENCES OF OPERATING RESPECTIVE CAR WEIGHTS OVER TRACK STRUCTURES

by Robert E. Ahlf

Competitive advantage is the fundamental issue in the prosperity and survival of any industry. It is especially true of the railway industry. The biggest growth area for our industry has been, and promises to be, the hauling of coal. Yet, even in the long-distance hauling of coal, competition is keen. River barges, especially in some regions, are hauling considerable amounts of coal traffic that would otherwise move by rail. Coal slurry pipelines are right on our heels. Their proponents wouldn't be campaigning to build them if they didn't see an opportunity to undercut the railways. Our industry needs every advantage it can muster. Economic advantage is the thing that really counts, especially in an industry such as ours, to which economists refer as a mature industry using a relatively mature unit train technology. Consequently, additional economic advantages in our industry are likely to occur, not so much in terms of dramatic breakthroughs, as in terms of relatively small perfections. Thus we can ill afford to pass up an opportunity to lower our cost per net ton mile.

In the heavily-regulated environment under which the rail industry has been suffering for a number of decades, a costing system has evolved which will stand up under regulatory questioning. Because regulators are heavily preoccupied with the 'evidence' of historic accounting data, such a costing system has been more reflective of past expenditures than predictive of future costs. This is particularly true in the area of track-maintenance cost variability with car size. Since the beginning of our industry, there has been a trend toward larger cars. This has generated a sort of inertia which manifests itself in the generality that "the bigger the car - the lower the transportation cost". Unfortunately, this "acceptance by default" of the 100-ton car is now showing some very undesirable cost effects that are growing more alarming as time progresses.

Prior to the widespread use of continuous welded rail, rail life generally was determined by end-batter at the joints and by the amount of headwear which would result in flanges contacting the tops of joint bars. With welded rail, chief engineers could look forward to greater allowable headwear for there were no ends to batter and no joint bars for flanges to contact. With the heavier rail sections, rail lives of roughly a billion gross tons were anticipated. The 100-ton cars have squelched any hopes of achieving that kind of rail life. Fatigue-induced defects, accelerated wear rates, shelling, and metal flow are cutting rail life to roughly half what otherwise would be expected.

Line and surface are more difficult to maintain under 100-ton cars, and require more costly, more frequent cycle maintenance. More costly than that, however, is the increased need for spot maintenance where specific areas of instability rapidly deteriorate. Ballast degradation is intensified, adding to the muddy ballast problem. In the long run, this is going to require much greater reliance on ballast shoulder cleaning, complete undercutting, and sledding periodically to restore resiliency to the ballast. Subgrades are, to a much greater extent, overstressed with the 100-ton cars. Settlement problems, and uneven line, surface, and cross-level are the costly result. Timber bridges are having to be rebuilt more frequently as a result of the crushing and shearing stresses imposed on the timber by these heavier axle loads. This particularly true of pile caps, which, in many cases, are being replaced with prestressed concrete.

The problem is not traffic volume, nor the gross tons per year; the problem is the axle loading of the nominal vehicle size which is carrying the traffic. The driving question which must be answered is simply, "What nominal car size will provide the most economical transportation per net ton mile, all costs considered. Regardless of how we have chosen to <u>allocate</u> costs in the past, if it is more costly to move net ton miles in 100-ton cars than in lighter cars, we should be emphasizing lighter cars.

The answer to this question is entangled in many factors, of which track cost is but one. To adequately assess the problem, it must be simplified to the extent that it can be visualized and assessed. For this purpose, an economic comparison will be drawn between the 100-ton car and a conventional, efficient, lighter car. Refer to Slide Number <u>1</u>.

COMPARISON OF CARS

80-TON CAR ($41,808)

GROSS WEIGHT	220,000 LBS.
TARE WEIGHT	54,000 LBS.
LADING WEIGHT	166,000 LBS.
NET/TARE RATIO	3.07
LENGTH	44 FT., 2 IN.

OPEN-TOP, 3-POCKET HOPPER, FOUR-AXLE, ROLLER-BEARING, 33 INCH WHEELS.

100-TON CAR ($45,100)

GROSS WEIGHT	263,000 LBS.
TARE WEIGHT	63,000 LBS.
LADING WEIGHT	200,000 LBS.
NET/TARE RATIO	3.17
LENGTH	53 FT., 1 IN.

OPEN-TOP, 4-POCKET HOPPER, FOUR-AXLE, ROLLER-BEARING, 36 INCH WHEELS.

SLIDE 1.

To compare the variable costs of moving coal in the two car sizes, it is not necessary to analyze in detail every variable cost element; only those which differ with car size. The two cost categories which have the greatest impact on this analysis are Maintenance of way and structures and car investment. Other costs which have a minor impact are locomotive fuel, investment and maintenance.

Car maintenance is generally found to be a net balance. It is generally accepted that it costs less to maintain an 80-ton car than a 100-ton car, and that this difference is largely offset by the larger number of 80-ton cars needed to carry the same freight moved in a train of 100-ton cars.

Train labor costs increase slightly as axle loading decreases. The costs of enginemen vary slightly with the weight of the locomotive. The costs of conductors and trainmen vary slightly with the number of cars on the train. Because of the slight variance of these costs, a very large increase in locomotive weight and a very large increase in cars-on-train are necessary to produce a significant increase in train labor costs. The use of 80-ton versus 100-ton cars does not result in large enough differences in locomotive weight and train size to significantly affect train labor costs. Because 100-ton cars largely move in large blocks, trainloads, or unit trains, switching labor costs are likewise relatively insensitive to car size.

Accident and derailment costs appear to vary more with respect to specific car design than with respect to axle loading. Thus, accident and derailment statistics are reflective of the relative proportions of these respective designs within the car fleets, as well as of the rates of utilization of these respective designs. Also, there are many cases where the 100-ton cars are restricted off the worst trackage, giving the lighter cars a higher rate of exposure to high risk environments. These factors tend to obscure any statistics available on accident and derailment costs on a car-size (axle load) basis. Also, if all other factors could be held equal for comparative purposes, the increased rate of track deterioration resulting from the use of heavier axle-load cars would aggravate the track-related accidents and derailments -- an indirect consequence of the larger cars. Because of the unavailability of statistics on accidents and derailments with respect to the above factors, such costs are treated as an intangible in this economic comparision; although it is believed that were they available, they would work to the economic favor of the lighter car.

Reference to Slide number 2 will illustrate the reletive equivalence of the two car sizes insofar as capacity is concerned. Six 80-ton cars and five 100-ton cars are virtually equivalent in total coupled length, deadweight of cars, and tons of freight carried. Although not shown on the drawing, the two car sizes are also virtually identical in height and width. Thus, as far as line capacity, track capacity, and train length are concerned, there is virtual equivalence.

EQUIVALENT CAPACITY

80-TON CARS:

(83 NET TONS/CAR)

267 FEET

498 TONS COAL
162 TONS CARS
REQUIRES 3,238 LBS. DRAWBAR PULL AT 40 MPH.

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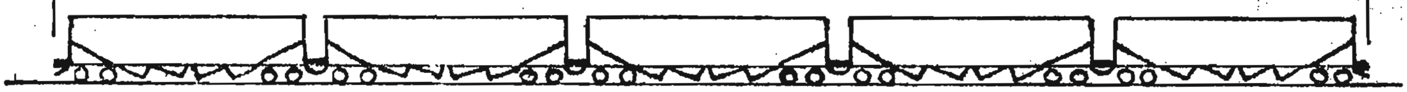
100-TON CARS:

(100 NET TONS/CAR)



265½ FEET

500 TONS COAL
157.5 TONS CARS
REQUIRES 3,031 LBS. DRAWBAR PULL AT 40 MPH.

SLIDE 2.

The only physical characteristics that are really different are the lighter axle load and its beneficial effect on track combined with its 6.8% increase in required drawbar pull (both of which will be discussed later).

Another capacity consideration is that on high-traffic-density lines 100-ton cars require tracks to be closed to train operation more often to permit maintenance-of-way activities. This is a necessary result of the shortened track component lives, accelerated deterioration, and need for increased non-programmed maintenance as a result of using these heavier axle-load cars, instead of the lighter axle-load 80-ton cars. For purposes of this analysis, this factor remains an intangible, but it works to the favor of the lighter cars.

The remaining variable costs are not significantly sensitive to car size. Thus, to determine the cost difference in using 100-ton versus 80-ton cars, the following costs will be analyzed and compared:

Maintenance of Way & Structures

Car Ownership

Locomotive Fuel, Ownership & Maintenance

MAINTENANCE OF WAY AND STRUCTURES

In developing the assessment of railroad maintenance costs, it must be emphasized that this economic comparison and this paper are based on a study of 28 profitable Class I U.S. railways, and are not reflective of any one railway in particular and do not necessarily represent the policy or position of any one particular railway.

This is necessary to avoid confusing the current spending of one particular road with the long-run, normalized maintenance costs of the industry. To accomplish this, using as large as possible a cross-section of profitable U. S. Railroads, the 1978 R-1 Reports of these 28 roads were analyzed and utilized to produce a maintenance of way and structures costing data base which treats the 28 roads as if they were one large road. This avoids the variances from normal of any one particular road; and by analyzing only the profitable roads, it avoids the extremes of the bankrupts, and of most roads suffering extensive deferred maintenance.

For purposes of this analysis, there are three categories of total maintenance of way and structures costs:

1. Costs which are fixed, and do not vary with tonnage or with axle load.

2. Ton-mile variable costs which vary in direct relation to the mechanical action of the track under load.

3. Ton-mile variable costs which vary in direct relation to the service life of rail.

To establish the relationships of these costs with axle load, it is first necessary to determine the amount of the costs at current normalized levels, then to break down the costs into the above three categories, and lastly to assess how each of the last two categories varies with axle load.

This normalized maintenance of way and structures spending of the 28 roads was added up and treated as one huge road. This total spending, including capital, as well as expenses, for maintenance of way and structures in 1978 amounted to $3,374,177,000 or $4,082,754,000 in 1980 dollars.

The ton-mile variable costs are then broken out of these accounts and applied to the 1,586,502 million gross ton miles of these 28 roads as follows, in 1980 dollars. For details, refer to Appendix A.

Costs Which Vary With Mechanical Action of the Track	Costs Which Vary With Rail Life	Remaining Fixed Costs
$1,609,618,000	$677,242,000	$1,795,894,000
or 101.5¢/1000 gross ton miles	or 42.7¢/1000 gross ton miles	
39.4%	16.6%	44.0%
	56% Variable	

Costs Which Vary With Mechanical Action of the Track

Now the question remains, how do these two variable cost categories vary with the axle loading of the two respective car sizes? The work of the late Professor Talbot of the University of Illinois was utilized for the first category, which includes the variable portion of ties, as well as ballast, surfacing, and maintenance, bridges, road property damaged, highway grade crossings, and the respective portions of roadway machines, small tools and supplies, and fringes. The primary limitation of Dr. Talbot's work, as applied to this analysis, is that it treats the track structure as a continuous beam on an elastic foundation. Particularly with the heavier cars, the elastic foundation assumption is not quite sufficient, for the track is being stressed beyond the elastic limit of some of its components, especially the subgrade. Use of Dr. Talbot's work is therefore conservative. Attention is beginning to be directed to this problem, and hopefully it will become better documented within a few years. An analysis conducted by Michael Roney of the Canadian Institute of Guided Ground Transport indicates that this category of costs would have a differential of an additional 20% between the 80-ton and the 100-ton car if the inelastic behavior of the rail support system were recognized. Therefore, the omission of the inelastic behavior understates the track costs resulting from the use of the heavier cars by a considerable amount.

The Talbot relationships can be used to determine the amount of rail deflection (a measure of the mechanical action of the track) under differing axle loads, and under different conditions of rail support (track modulus). Because the rail deflection is an indicator of the mechanical action of the track, it is assumed that it is also an indicator of the wear of the track components below the rail (ties and ballast), and an indicator of the deterioration of the track with usage -- the cause of the need for lining and surfacing. Used in this fashion, the amounts of deflection are not the central object; they are merely used as indicators of cost variability.

Dr. Talbot's basic equation is:

$$Y_o = \frac{-P}{2u}\sqrt[4]{\frac{u}{4EI}}$$ where P = wheel load in pounds
u = modulus of elasticity of rail support, in psi.
E = elastic modulus of rail steel, in psi.
I = moment of inertia of rail, in $inches^4$.

As long as the same nominal speed is used in the comparisons of the respective wheel loads, and as long as the rail section and track modulus are held constant, Y_o varies linearly with the wheel load P. Because of this linearity, there is no need to separately evaluate loaded and empty cars; the costs can be directly tagged to the average car, which for American Railroads in 1978 carried 55.1 net ton miles per loaded car mile. This corresponds to a loaded car weight of 167,800 pounds and an empty car weight of 57,600 pounds. Because this is an average cost applied to average traffic moving in average cars, the average 80% empty return ratio is applied. This yields an average car weight of 106,940 pounds.

In projecting this cost relationship for 80-ton and 100-ton cars moving primarily bulk commodities, the typical unit train's 100% empty return ratio is used in computing the average car weights of 137,000 pounds and 163,000 pounds, respectively.

To enable consideration of good and bad track, as well as average track, three respective track moduli are compared.

The following table summarizes these results expressed in cents per 1,000 gross ton miles (1980 dollars):

	55.1-ton car	80-ton car	100-ton car
u=2000(avg.trk.)	101.5¢	130.0¢	154.7¢
u=1000(poor trk.)	177.2¢	226.9¢	270.0¢
u=4000(good trk.)	59.0¢	75.6¢	90.0¢

The above table illustrates not only the impact of heavy cars on track maintenance costs other than rail, but it also illustrates the favorable cost effects of maintaining good track versus poor track.

Costs which vary with Rail Life

It has been common practice to speak of rail life in terms of first position life; that is, the life period up to which the rail is removed from its original position for placement on branches, sidings, yards, industry tracks, sold secondhand, or scrapped. There is great diversity of practice among railroads in secondhand use of rail. Factors include:

The proportion of main lines to other track mileage.

The amount of planned branch line upgrading.

Relative conditions and needs of respective lines.

Track construction and retirements.

From the R-1 reports, we see that American railroads are laying more secondhand rail than new rail, indicating that, on the average, rail is being extensively "cascaded". In general, lines having a single trunk line of heavy tonnage with few branches and yards will tend to squeeze as much first- position life out of their rail as possible, then sell or scrap all but the small amounts needed for their yards or industry tracks. However, roads having networks of secondary mains, secondary routes, branches, etc. often deliberately remove rail from its first position prior to the end of its life for replacement of highly inferior rail on the secondary lines. Thus, any meaningful comparison of rail lives must look at total rail life, not merely at first position.

As a result of the 100-ton car, not only is rail life being reduced, but also the most limiting factor which determines rail life is shifting from wear to fatigue-related defects. Under the lighter cars, rail resistance to bending was generally adequate, provided rail support was kept sufficiently strong. Under these conditions, rail wear and end-batter were the major determinants of rail life. With the advent of welded rail, end-batter dropped out of the picture, and likewise the criterion that main line rail should not be allowed to wear to the point that flanges strike the joint bars. Thus, for continuous welded rail, a wear up to 25% of head loss became acceptable. With the heavier rail of today, and loaded only with 55,000 lb. axle loads, a total rail life of well over one billion gross ton miles could be predicted (and was) for tangent track.

Now, the 100-ton car, with its 65,750 lb. axle load, is changing all of that. Rail head contact stresses, previously of minor importance in determining rail life, are now a dominant factor. These stresses approaching the plastic yield point are resulting in the rapid propagation of fatigue-related defects which are becoming the primary limitation on rail life in tangent track.

Depending upon the defect rate which a railway is willing to live with, tangent rail life is being reduced to less than one half of what it would otherwise be with the lighter cars. Rail life in curves continues to be limited by abrasive wear heavily aggravated by roller bearings, even with the larger car size; however, even this determinant of rail life is greatly reduced by the heavier cars.

The problem of reduced rail life as a result of 100-ton cars is descending upon the industry in a deceptive way. Rails that were used for the lighter axle loadings during their earlier lives were work-hardened by the many cycles of loading at well below their yield points. This makes the rail less susceptible to being damaged by the high contact stresses. Thus, the use of 100-ton cars on work-hardened rail has tended to mislead some of the industry into thinking the problem would not be so bad after all. But now that new rail is immediately experiencing the effect of large volumes moving in 100-ton cars, the results are much worse and more rapid.

Theoretical analyses of rail life, variable as it is with so many factors, have been conducted; however, by now, some actual experience is occurring. A number of North American roads have now lived with predominately 100-ton cars on new rail for a considerable length of time, and their predictions and conclusions are most interesting, even when it is recognized that conditions and acceptability of certain problems vary widely from road to road. Without mentioning individual roads by name, some examples follow:

> An iron ore road, using cars grossing 210,000 pounds on 33-inch wheels obtained a first position rail life of 800 million gross tons with 112-pound jointed rail. This rail was removed with 1/8-inch headwear because of end batter and bolt hole breaks. It has since been cropped and welded for second-position use of at least 200-300 million more gross tons.

> A heavy-tonnage bridge road, carrying mixed trafiic, is removing rail from first positon which has carried over 1,000 million gross tons, work-hardened prior to the advent of significant quantities of 100-ton cars. Newer, first-position rail, work-hardened under a mix of 100-ton, and smaller cars, is being removed at 600 million gross tons.
>
> A road operating heavy tonnage coal lines carrying 70 million gross tons per year in cars of 263,000 pounds has already accumulated 300 million gross tons of this traffic on new 136-pound continuous welded rail. By the time this rail had carried 200 million gross tons, it was developing defects at the rate of one per year per track mile. Removal of this rail from first position at an age of 400-450 million gross tons is planned, with 450 million gross tons considered really optimistic. Furthermore, this road questions whether there will be sufficient remaining life in this rail to make it worthwhile to use it on lower density lines in second position. It is believed that if this rail is removed at 400 million gross tons, it will be so defect-ridden that only about 50% will remain for second position use of an additional 100 to 150 million gross tons.
>
> By contrast, the above road also operates a line carrying light, mixed traffic of 20 million gross tons per year on 115-pound rail which has already carried 700 million gross tons in the first position with essentially no defect problem.

From these examples and others, plus the analytical data developed to date, it is concluded that with the 100-ton cars, the industry is in for a drastic reduction in rail life. Considering first and following rail positions, a 50% reduction in rail life as a result of using 100-ton versus 80-ton cars appears to be a sound conclusion, and the variable portion of track maintenance cost which varies with rail life will increase from 42.7¢ to 85.4¢ per thousand gross ton miles.

Frequently the question is raised, "Can't we just lay specially treated or alloyed rail which will last longer under the 100-ton cars?" In response to this question, bear in mind that we must be sensitive to the economics. Although solid data are still scarce on the performance of some of these exotic rails, enough evidence has developed to indicate that they do in fact reduce the abrasive wear on curves, and reduce the fatigue-induced defects on tangents.

However, to the extent these exotic steels increase rail life under 100-ton cars, they also increase to an even greater extent the rail life under 80-ton cars. Consequently, the heat treated or alloyed steels do not narrow the gap in rail lives associated with 100-ton vs. 80-ton cars, but likely will somewhat widen it. Thus, if the industry continues to encourage the proliferation of 100-ton cars, it doesn't make much economic difference whether we adopt specifically alloyed and heat-treated rail, or whether we use conventional rail and relay it more often. The important point is that in either event the 100-ton car cuts our rail life roughly in half and therefore roughly doubles our rail-related track maintenance and capital costs in the long run.

Summary of MW&S Costs

Ignoring the fixed portion of these costs, the variable portions (mechanical-action related and rail-life related) are summarized on the top half of Slide number 3.

The foregoing costs for poor, average, and good track refer only to rail support conditions, and not to rail size, type, or condition. For example, poor track refers to poor drainage, subgrade, ballast, and ties, but with average rail. Conversely, good track refers to good rail support with average rail. Based on data from the R-1 Reports, average rail for the 28 roads would be a 117-pound section.

Conversion of these costs to a net-ton-mile basis assumes a 100% empty return. For the 80-ton car, we have 166,000 pounds net divided by (220,000# loaded + 54,000# empty) = 0.606. For the 100-ton car, we have 200,000 pounds net divided by (263,000# loaded + 63,000# empty) = 0.613. Our cost table expressed in cents per thousand net ton miles, is shown on the lower part of Slide Number 3.

SUMMARY OF M.W.&S. COSTS

VARIABLE COSTS (1980 LEVEL)

(¢ PER 1000 GROSS TON MI.):

	80-TON CAR	100-TON CAR
POOR TRACK	270	355
AVERAGE TRACK	173	240
GOOD TRACK	118	175

(¢ PER 1000 NET TON MI.):

	80-TON CAR	100-TON CAR
POOR TRACK	445	580
AVERAGE TRACK	285	392
GOOD TRACK	195	286

SLIDE 3.

CAR OWNERSHIP

The method of determining this cost has been to use comparative quotes for a purchase of 80-ton cars which occurred at the approximate time of another purchase of 100-ton cars, and to obtain their cost ratio. This has then been applied to a 1979 quote, inflated to 1980 dollars, resulting in a cost of $45,100 for a 100-ton car and a cost of $41,808 for an 80-ton car. Conversion to daily cost is based on a capital recovery factor of 0.13147 for a 15-year life and a nominal car finance cost of 10%. To apply these time costs to a summation which includes the mileage costs of MW&S requires that a productivity rate be assumed. Rather than assume a single productivity rate (which varies greatly depending on the service characteristics of the traffic and operation), a table of costs is prepared for several productivity rates as follows:

	80-ton Car	100-ton Car
1980 Purchase Cost	$41,808	$45,100
Annual Cost	$ 5,496	$ 5,929
Daily Cost	$ 15.05	$ 16.24
Cost Per Net Ton Mile @ 1 loaded mile per car day	$ 18.133¢	$ 16.240¢
Cost Per Net Ton Mile @ 25 loaded miles per car day	725¢	649¢
Cost Per Net Ton Mile @ 50 loaded miles per car day	363¢	325¢
Cost Per Net Ton Mile @ 75 loaded miles per car day	242¢	216¢
Cost Per Net Ton Mile @ 100 loaded miles per car day	181¢	162¢

	80-ton Car	100-ton Car
Cost Per Net Ton Mile @ 125 loaded miles per car day	145¢	129¢
Cost Per Net Ton Mile @ 150 loaded miles per car day	121¢	108¢
Cost Per Net Ton Mile @ 175 loaded miles per car day	104¢	93¢
Cost Per Net Ton Mile @ 200 loaded miles per car day	91¢	81¢

The above table shows not only how car ownership costs vary with respect to car size; it also shows how sensitive these costs are with respect to productivity, or car utilization.

LOCOMOTIVE FUEL, OWNERSHIP, AND MAINTENANCE

These costs vary with axle load, but only to a small extent, and therefore, are herein analyzed with less detail than the previous cost categories. Generally, these locomotive-related costs vary on the average with the drawbar force required to move the traffic. Required drawbar force is the sum of several resistance forces which vary in extent and proportion with the operating conditions of the particular lines of railroad. These include primarily grade resistance, curve resistance, train resistance, and acceleration resistance. Grade resistance and curve resistance vary directly with the total gross tons moved and are not variable with axle loading provided the net-to-gross ratios are the same. This being the case for all practical purposes with the 80 versus 100-ton cars, we are left to consider only train and acceleration resistances. Because a route specific, train specific, and highly variable percentage, probably in excess of 50%, of locomotive-related costs are grade and curve-related, we cannot simply use the total locomotive-related costs for the 28 roads considered, and assume they will vary with car sizes.

On the other hand, that portion of locomotive-related costs which is related to train resistance and acceleration resistance, varies with total gross tons, and also with axle load. Train resistance is conventionally defined as the force in pounds per gross tons of car and lading necessary to move a given freight car on straight, level track at a constant speed in still air. Acceleration resistance is the additional force necessary to increase the speed from one constant speed to another.

To obtain basic locomotive-related costs with as small as possible a component for grade and curve resistance, nine unit train operations were examined on a railroad which is relatively flat and straight but which has fairly typical amounts of starting, stopping, and speed-changing. These costs, including loaded and empty trains of nominal 100-ton cars, ranged from 206.8¢ to 437.8¢ per thousand net ton miles, and averaged 281.6¢ per thousand net ton miles, in 1979. Raised to an estimated 1980 level these costs are 328.0¢ per thousand net ton miles.

The relationship of these costs to car size, as indexed by train resistance, is determined by use of the Davis Equation:

$$R = 1.3 + \frac{29}{w} + bV + \frac{cAV^2}{wn}, \text{ where}$$

b = 0.045
c = 0.0005
A = cross-sectional area = 103.3 $feet^2$
V = speed, in MPH
n = 4
w = 27.500 for loaded 80-ton car
w = 6.750 for empty 80-ton car
w = 32.875 for loaded 100-ton car
w = 7.875 for empty 100-ton car

Using the above equation, the resistances for both loaded and empty cars, and for both 80-ton and 100-ton cars were computed. For comparison of drawbar pulls, the actual drawbar pull was computed for 100 80-ton loaded cars and for 100 80-ton empty cars; as well as for 83 100-ton loaded cars and 83 100-ton empty cars. All of the above comparisons were made for speeds of 10,20,30,40, and 50 MPH, respectively. This was illustrated on Slide Number 2 for the cases of 80- and 100-ton cars moving loaded at 40 MPH.

Assuming a complete round trip for each trainset, 50% loaded miles and 50% empty miles, the combined loaded and empty drawbar forces were summed for each trainset at the respective speeds.

The ratios of these forces are as follows:

SPEED	Ratio of Sum of Loaded and Empty Drawbar Forces of 80-ton Cars to 100-ton Cars, Each Trainset Carrying 8,300 Net Tons of lading
10 MPH---------------------------	1.100
20 MPH---------------------------	1.095
30 MPH---------------------------	1.094
40 MPH---------------------------	1.099
50 MPH---------------------------	1.097

Fortunately for purposes of comparing car sizes, speed has very little to do with the ratio of total drawbar forces required to move trains of 80-ton cars versus trains of 100-ton cars, carrying the same net tonnage of loading. Thus within the speed range of 0 to 50 MPH, the penalty for using 80-ton cars instead of 100-ton cars ranges between a 9.4% and a 10.0% increase in locomotive-related costs. For the purposes of this analysis, we will use 9.7%, with the following average difference in locomotive-related costs in 1980 cents per thousand net ton miles:

80-ton Cars	100-ton Cars
360¢	328¢

The above is a highly conservative approach to placing an economic value on the increased drawbar pull needed to pull 80-ton cars, instead of 100-ton cars. It assumes that in either case, the trains will be moved at the same nominal speed and that locomotive consists and fuel consumption (in aggregate) will be increased accordingly. Such is, in fact, not likely to result. Looking back at our comparisons on Slide Number 2, 3238 lbs. of drawbar pull are required to move the six 80-ton cars carrying a volume of coal equal to that of five 100-ton cars requiring 3031 lbs. drawbar pull. In both cases a 40 MPH. speed is assumed. If we were to slow the 80-ton car train down to 36 MPH., the drawbar pull for the 6 cars would reduce to 3025 LBS. -- almost identical to that of the 5 equivalent 100-ton cars at 40 MPH.

In most railroad operations, slowing of the nominal speed of a coal train from 40MPH. to 36 MPH. would not noticeably interfere with line capacity or the cycle time of cars and locomotives, and this course of action would probably be used, instead of the alternative of increasing the locomotive-related costs to maintain exactly equal speeds.

SUMMARY AND CONCLUSIONS

The following table summarizes the above three significant cost categories which vary with axle load. It should be noted that this is not a table of variable costs (costs which vary with traffic volume); it is a table of that portion of variable costs which vary with axle load.

Car Utilization Rate, in Loaded Car Miles Per Car Day	MW&S		Car Owner-Ship		Loco.Fuel, Ownership &Mtce.		Total of Costs Varying w/Axle Loading	
	80T	100T	80T	100T	80T	100T	80T	100T
25	285	392	725	649	360	328	1370	1369
50	"	"	363	325	"	"	1008	1045
75	"	"	242	216	"	"	887	936
100	"	"	181	162	"	"	826	882
125	"	"	145	129	"	"	790	849
150	"	"	121	108	"	"	766	828
175	"	"	104	93	"	"	749	813
200	"	"	91	81	"	"	736	801

Further summarizing the cost differences, we have:

Car Utilization Rate, in Loaded Car Miles Per Car Day	Economic Penalty Resulting From Use Of 100-Ton Cars Vs. 80-ton Cars, In Cents Per 1000 Net Ton Miles - 1980 Level -
25	(-1¢)
50	37¢
75	49¢
100	56¢
125	59¢
150	62¢
175	64¢
200	65¢

Additional Penalties Not Included Above

As mentioned earlier, this analysis is conservative in that it throws the benefit of doubt to the favor of the 100-ton car. If, for example, the effect of inelasticity of rail support is considered, there is good reason to believe that the above economic penalties would increase by an additional uniform 8¢ per thousand net ton miles. This represents a 20% increase in the cost differential pertaining to the costs related to the mechanical action of the track.

Although difficult to isolate from the R-1 accounts, there are two rail-related costs, not specifically addressed in this analysis, which will increase very substantially if the trend toward using 100-ton cars were to continue. These are the costs associated with rail detector services and inspections, and the costs associated with nonprogrammed change-outs of defective rails often under emergency conditions.

Effect of Track Condition

The above penalties have been put together on the basis of average track. As used in this analysis, average track refers to the kind of track over which the average gross ton mile moves. This is a considerably better track than the average of all track miles. Thus, "average" as used herein, is really pretty good track in the common sense of the word. "Good track" as used in the MW&S cost analysis is really superior track. The costs related to the mechanical action of the track are quite sensitive to track quality as well as to axle loading, thus poor track exhibits a much greater differential between 80-ton and 100-ton cars than does good track.

DIFFERENTIAL OF MW&S COSTS WITH RESPECT TO 80-TON VS. 100-TON CARS

Poor Track	135¢/1000 NTM	} 28¢
Average Track	107¢/1000 NTM	} 16¢
Good Track	91¢/1000 NTM	

Thus, the penalty table listed earlier in this summary would increase by an additional 28¢ per thousand net ton miles if track were poor instead of average. Conversely, it would decrease by 16¢ per thousand net ton miles if track were good instead of average.

Impact of 100-ton Cars on Track Maintenance Priorities and Practices

There are staggering implications of rail life being determined by fatigue-related defects as a result of 100-ton cars, instead of by wear with 80-ton and lighter cars. If the proliferation of 100-ton cars continues, no longer can main lines be inspected ultrasonically or magnetically two or three times a year. This will have to be done bi-monthly, perhaps even monthly on the heaviest-density lines, and accompanied by very well-organized and meticulous record keeping. Nonprogrammed rail change-outs, once a feature primarily of decrepit branch lines, will become increasingly prevalent on the main lines. Even the programmed rail renewals will have to be managed more stringently, with rigid financial implications. When rail wear was a primary criterion for rail renewal, postponing the relay of rail for a few years because of budget constraints could be tolerated. Such will not be the case when rail life is governed by the incidence of defect-propagation. With defects on a given rail installation rapidly increasing, the postponement of relaying that rail will be considerably more dangerous.

The problems of increased subgrade consolidation (often differential), increased ballast abrasion, degradation, mudding, and cementation, and the resulting increase in the need for lining and surfacing are beginning to be felt already. Basic structural remedial work, such as complete undercutting, plowing, sledding, cribbing, and ballast shoulder cleaning will be much more extensively required. The same is true of subgrade stabilization to attempt to provide a stronger trackbed support in areas of weak soil. Roadbed drainage, of fundamental importance anyway, will become more critical, especially in areas of weaker, more moisture-sensitive soils.

Sensitivity to Car Utilization

The 100-ton car was an attempt by the rail industry to gain additional productivity out of its heavy investment in freight cars. Reference to the cost-listing at the beginning of this summary indicates the futility of this, relative to the more difficult, but much more rewarding, alternative of increasing the productivity of freight cars by producing more loaded car miles per car day. The way to improve utilization of cars is to move them; we have exceeded the point of diminishing returns in trying to cram more freight into even larger ones. How to accomplish this is another subject.

Recommendations

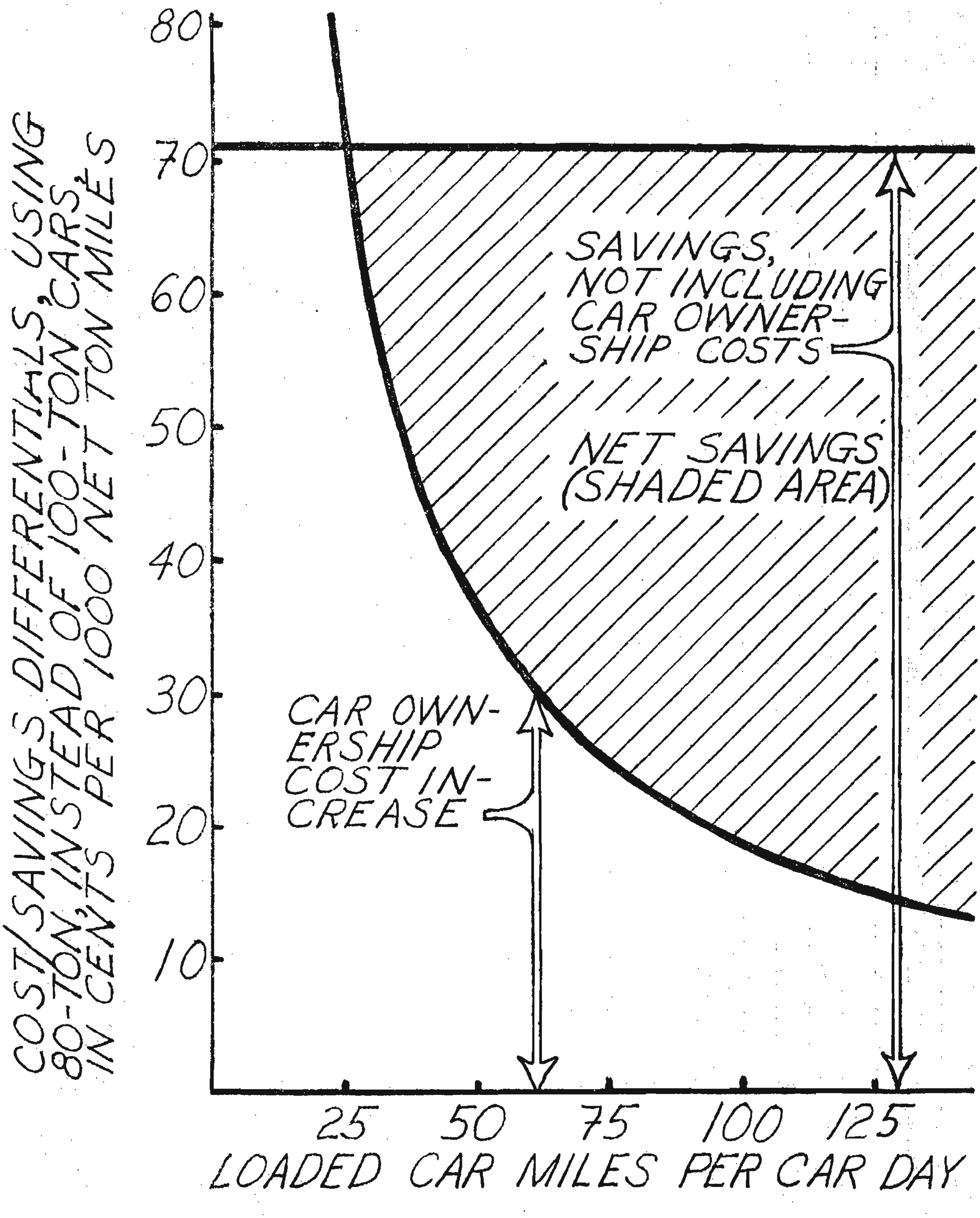
Referring again to the cost penalty chart, it is a logical conclusion to recommend that the railroad industry stop building and ordering 100-ton cars, and direct its purchases to 80-ton cars. The advantages of doing this are greatest in the services where cars are well utilized, such as unit trains and trainload operations. About the only economic use for the 100-ton car is in operations involving short hauls and lengthy idle times, especially if high-cost specialty cars are involved. Ironically, for the past decade, the industry has followed the reverse course.

It would be too great a shock to the industry to quickly limit the allowable axle load of existing cars; however, it would be very sensible to set an upper limit on the axle load of new cars yet to be constructed which would correspond to the 220,000-pound car, or a maximum of 55,000 pounds per axle.

A very large percentage of 100-ton cars is owned by shippers or car-leasing companies. All indications are that this trend will not change abruptly. Therefore, shippers must be motivated to build, purchase, or lease the smaller cars. A practical means of doing this is to insert a differential in each shipper-car freight tariff which would adequately encourage the shippers to gradually adopt lighter cars. This differenctial should fit within the range of negotiability illustrated on Slide Number 4. The horizontal lines represent the maximum amount of differential which a railroad could afford to offer, and the curved lines represent the minimum amount of differential necessary to offset the shippers' higher car ownership costs. The area below the horizontal line and above the curved line is the "range of latitude". Note how the effect of car utilization drives the relationships.

For example, with average track, with car prices of $41,808 and $45,100, and with car utilization of 100 loaded car miles per car day, it would cost a shipper 19¢ per thousand net ton miles to provide 80-ton instead of 100-ton cars. The railroad will obtain savings of 75¢ per thousand net ton miles if the shipper can be induced to convert.

ECONOMIC SUMMARY



SLIDE 4.

the difference (56¢) is the latitude of negotiability. Notice how this latitude of negotiability narrows if cars are utilized less. At 75 loaded car miles per car day, it becomes 49¢; and at 50, it becomes 37¢.

Summarizing the recommendations derived from the graph for general conditions:

1. A railroad should purchase 80-ton cars rather than 100-ton cars for operations which will average in excess of 25 loaded car miles per car day.

2. To provide adequate monetary incentive for shippers to furnish 80-ton, instead of 100-ton cars, railroad will have to write economic differentials into tariffs, no less than:

38¢	per	MNTM	at 50	Loaded	car	miles	per	car	day
26¢	"	"	" 75	"	"	"	"	"	"
19¢	"	"	" 100	"	"	"	"	"	"
16¢	"	"	" 125	"	"	"	"	"	"
13¢	"	"	" 150	"	"	"	"	"	"
11¢	"	"	" 200	"	"	"	"	"	"

and no greater than 75¢ per thousand net ton miles.

3. As quickly as possible, railroads should restrict their new car purchases to a maximum axle load of 55,000 pounds on 33-inch wheels, and should encourage shippers to do likewise by use of the appropriate tariff differentials.

4. During the remaining life of 100-ton cars, they should be used in low-mileage service where their detrimental physical and economic effects are minimized.

5. Light-loading of existing 100-ton cars is not economical unless there is a car surplus, because of the significant reduction in the net-to-tare ratio if conventional 100-ton cars are light-loaded. Thus, it is likely that every new 100-ton car will continue to carry 100 tons for the remainder of its life, at a considerable economic loss to the railroad, as compared with purchase of 80-ton cars at the outset.

6. The heavy-car problem remains largely an economic problem today, except on those lines where the 100-ton cars have an unusually high frequency of occurrence. There is a time-lag in the detrimental consequences of the 100-ton car, and it has not yet fully caught up with the industry, in general. The time to correct the 100-ton car problem is now -- before the rail-defect incidence and other track problems become so intense and widespread that they produce not just an economic problem, but an operating and maintenance crisis.

7. The industry should, as quickly as possible, perfect a car for unit-train transporation of coal, in order to fully exploit

its economic advantage. The 100-ton car does not do this, it is sub-optimum, economically. The 80-ton car is an economic improvement, but it has some problems which render it less than perfect. Improving the dynamic characteristics of the 100-ton car will help only marginally; the real problem is gross weight on rail, and improved dyanamics will only mitigate the problem somewhat.

Once the industry fully accepts this problem, fully realizes the economic and competitive advantages of solving it, and begins to earnestly grapple with it, the industry will develop solutions. Running about and saying that the 100-ton car is here to stay and trying to fabricate all solutions around that premise --- is not going to solve the problem. The 25-ton car, the 50-ton car, the 70-ton car, and the steam locomotive were all "here to stay". But nothing is sacred in the world of competitive transport economics except improving net economic efficiency, and when it is fully realized that there are alternatives superior to the 100-ton car, the superior car will dominate new car orders.

I do not think the conventional 80-ton car is the optimum answer. I think it is merely an improvement over the 100-tonner. If we will be willing to explore a bit, I think we can find a car which will do the following:

A. Weigh 220,000 lbs. fully loaded.

B. have a superior net-to-tare ratio compared with conventional 80- or 100-ton cars.

C. Carry between 86 and 90 tons of coal.

D. Utilize conventional steel for its construction.

E. Offer a rotary-dump-gon version which will fit conventional rotary car dumpers designed for 100-ton cars; as well as a trestle-dump-hopper version which will maintain the conventional ratio of 1.88 tons of carrying capacity per foot of car length.

F. Improve the steerability of wheels with respect to rail.

G. Have a lower center of gravity then conventional 80- or 100-ton cars.

H. Reduce fuel consumption by reducing the cross-sectional area of the car.

I. Cost about the same to mass produce as a conventional 80-ton car.

J. Result in a 14 to 16% reduction in the total net cost of transporting coal by rail over long hauls.

In fact, I'll even bet that right now someone is diligently working on such a design!

DERIVATION OF BASIC MW&S COST SUMMARY CATEGORIES OF 28 CLASS I ROADS

Total Maintenance of Way and Structures R-1 Accounts are considered, including Capital Spending (p. 35, col. e), and Operating Expenses (pp. 55-56, col. h).

For purposes of this analysis, the accounts considered variable (later to be adjusted for the fixed portion of tie costs) are:

Source	Line	Account	1978 Dollars ($000)
p.35,col.e,	line 6,	Bridges, Trestles, and Culverts	$ 58,616
	line 8,	Ties	16,147
	line 9,	Rails	62,368
	line 10,	Other Track Material	64,314
	line 11,	Ballast	14,120
	line 12,	Track Laying and Surfacing	29,723
	line 28,	Roadway Machines	56,369
p.55,col.h,	line 10,	Bridges, Trestles, and Culverts	$ 58,772
	line 11,	" " "	4,410
	line 12,	Ties	196,461
	line 13,	"	17,308
	line 14,	Rail	151,002
	line 15,	"	8,261
	line 16,	Other Trk.Material	136,009
	line 17,	" " "	16,203
	line 18,	Ballast	44,374
	line 19,	"	2,149
	line 20,	Track Laying and Surfacing	531,946
	line 21,	" " "	81,452
	line 22,	Road Property Damaged	32,988
	line 23,	" " "	5,692
	line 24,	" " "	1,223
	line 29,	Highway Grade Crossings	31,791
	line 30,	" " "	2,567
p.56,col.h,	line 109,	Roadway Machines	$118,733
	line 110,	Small Tools and Supplies	71,687
	line 112,	Fringe Benefits	173,258
	line 113,	" "	26,418
	line 114,	" "	75,963
			$2,090,324

(or $2,529,292 in 1980 $000)

With the exception of cross-tie-related costs, the above are considered approximately 100% variable. Tie life variability is assessed as follows:

Tie Life

Based on an independent study of one road, main lines have 3,160 cross ties per average track mile, not including bridge and switch timber. Similarly, light branches have 2,238 cross ties per average track mile.

From p. 99 of the R-1 Reports, the following mileages and traffic densities were obtained for four distinct main track categories, and from p. 104, the respective 1978 tie installations were obtained:

Category A Tracks (Having 20 or more million gross tons per year) 47,043 miles averaging 31.4 MMGT/Year 6,904,601 cross ties installed.

Category B Tracks (Having 5 to 20 million gross tons per year) 32,515 miles averaging 11.0 MMGT/Year 3,875,371 cross ties installed.

Category C Tracks (Having 1 to 5 million gross tons per year) 23,594 miles averaging 2.6 MMGT/Year 2,444,574 cross ties installed.

Category D Tracks (Having less than one million gross tons per year) 29,824 miles averaging 0.45 MMGT/Year 1,522,935 cross ties installed.

Assuming an average of 3,160 cross ties per average track mile in the first three categories, and 2,238 in the last, the following tie life -- tonnage density relationships were calculated, assuming that the aggregate 1978 renewals of the 28 roads represented normalized conditions:

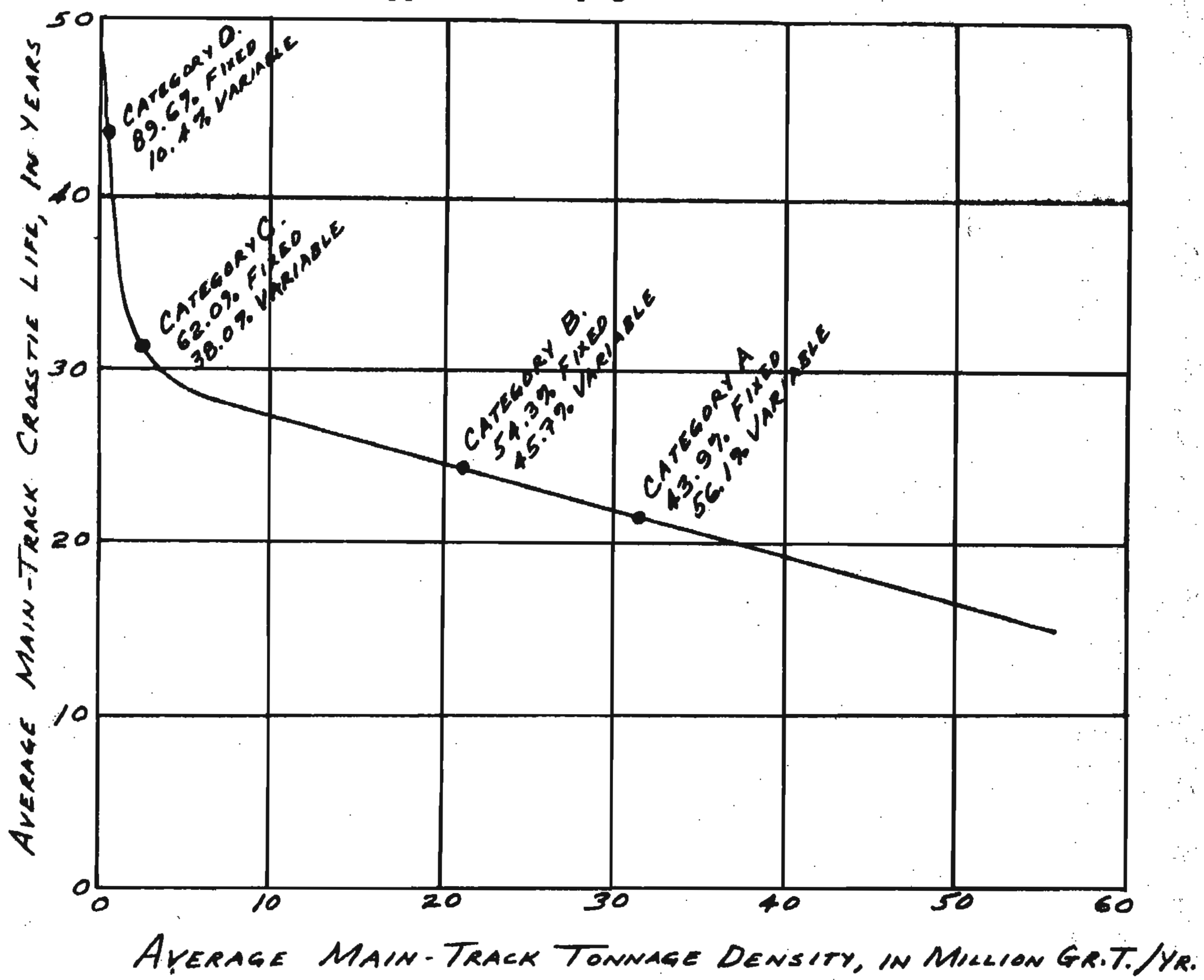
Category A-----6,904,601 ties/yr.-----21.5 yr.life

Category B-----3,875,371 ties/yr.-----26.6 yr.life

Category C-----2,444,574 ties/yr.-----30.4 yr.life

Category D-----1,522,935 ties/yr.-----43.9 yr.life

Plotting Tie Life as a function of traffic, we have:



The intercept with the vertical axis represents the "no-traffic" tie life, whereby decay would be the sole criterion. The area beneath the curve therefore represents the fixed-cost proportion of tie costs, and the reduction of the curve below 49 years represents the tie-life loss as a result of traffic (the variable-cost proportion). The average variability, 45.6%, corresponds to an average tie life of 26.6 years. The remaining 54.4% of tie-related costs is fixed, and therefore, must be subtracted from the $2,529,792,000.

Tie Cost

The material cost of ties, including cross, switch, and bridge, can be retrieved directly from the R-1 accounts, but the labor, fringes, tools, machinery, and supplies are buried within several R-1 accounts which also include such items applied to rail, ballast, surfacing, and general maintenance. To get around this problem, REPORT NO. FRA/ORD78/2 "ECONOMICS OF CONCRETE AND WOOD TIE TRACK STRUCTURES" by Battelle-Columbus Laboratories and Bechtel, Inc., was utilized to obtain cross tie installation costs. The cost per cross tie for installation, distribution, and disposals, includes equipment, tools, labor, fringes, etc. for a 31-man gang renewing 812 ties per day, which is a representative production figure. This costs $6.52 per cross tie in 1977 dollars and was inflated to $7.17 in 1978 dollars for later combination with the material costs from the R-1 Reports.

First, the $7.17 must be adjusted to reflect the higher unit costs of installing switch and bridge ties, which average 90 per average mile (based on 3,160 cross ties per mile out of 3,250 total ties per mile). Thus, for every 812 cross ties installed, there are 23 bridge and switch ties. Utilizing a study of one railroad, the installation cost (not including material) of bridge and switch ties is 3.76 times that of installing a cross tie.

Adjusting the installation cost to reflect an average ratio of switch and bridge ties, we have:

$$\frac{\$7.17 \times 812 + (3.76)(\$7.17) \times 23}{812 + 23} = \$7.71 \text{ per average tie (all types inc.)}$$

The material cost of ties (all types included) for the 28 roads is obtained by summing the three R-1 accounts (p. 35, col. e, line 8 and p. 55, col. h, lines 12 and 13) to obtain $229,916,000. The quantity of these ties, (obtained from p. 100, col. i, line 8 of the R-1 Reports) was 17,947,941 in 1978. This yields an average tie material cost (all types included) of $12.81, which combined with the average installation cost of $7.71, produces an average 1978 tie cost of $20.52. Inflated to 1980 dollars, we have $24.83 per tie.

Variable Cost

Applied to the 17,947,941 ties, the average tie cost of $24.83 yields a total of $445,647,375, of which 45.6% is variable and 54.4% is fixed.

Variable Tie Cost = $203,215,203
Fixed Tie Cost = $242,432,172

Subtracting the fixed tie cost from the original $2,529,292,000 leaves a total variable cost of $2,286,860,000, rounded off to the nearest thousand.

From the R-1 Reports, total spending by MW&S cost categories, including capital, as obtained by adding (p. 35, col. e, line 33; and p. 56, col. h, line 151), was $3,374,177,000 in 1978, dollars, or $4,082,754,000 in 1980 dollars. Subtracting the variable portion, we have a fixed cost of $1,795,894,000, and a variable proportion of 56% of the total.

Separation of Rail Costs

The remaining task is to separate the variable cost of $2,286,860,000 into the two components necessary for separate analysis -- those costs varying in relation to the mechanical action of track, and those costs varying in relation to rail life.

Unlike tie costs, rail costs are 100% variable, but like the tie costs, the rail installation costs are buried within the R-1 accounts so that they must be retrieved in a similar manner.

All rail and turnout material costs are included in the R-1 Rail and in the R-1 OTM accounts, in thousands of 1978 dollars:

p. 35, col. e, line 9--------	$ 62,368
p. 35, col. e, line 10--------	64,314
p. 55, col. h, line 14--------	151,002
p. 55, col. h, line 15--------	8,261
p. 55, col. h, line 16--------	136,009
p. 55, col. h, line 17--------	16,203
	$438,157

The quantities of rail laid by these 28 roads in 1978 was 5,684 miles, from p. 102 of the R-1 Reports. The same Battelle-Bechtel report used to obtain representative tie installation costs has been used to obtain representative rail installation costs. The cost to install a mile of rail includes unloading and distribution of new rail and material, and the cost of removing the old rail and material, assuming a 44-man rail laying gang relaying a half track mile per day, including equipment, tools, rail train, mechanics, labor, fringes, and living accommodations. This cost $16,200 per track mile in 1977 dollars, and was inflated to $17,820 in 1978 dollars. This cost is based on continuous welded rail, although a certain amount of bolted rail is laid new, particularly in heavy-curvature territory.

Included in the above material costs are turnouts, which are not included in the above installation costs. Again, an analysis of a particular railroad has been used to prepare an adjustment factor. This factor is comprised of the ratio of the installation cost of a turnout relay compared to that of relaying a mile of rail, and modified by the average occurrence of turnouts, as follows:

$$\frac{\text{Installation cost to Relay Turnout}}{\text{Installation cost to Relay One Track Mile}} = 0.23$$

$$\frac{\text{Number of Main-Track Turnouts}}{\text{Number of Main-Track Miles}} = 0.86$$

$$0.23 \times 0.86 = 0.20$$

Adjusting the installation cost of a rail relay to include turnouts, we have (1.20)($17,820), or $21,384 per track mile. Applied to the 5,684 track miles relayed by these 28 roads, we have an installation cost of rail and turnouts of $121,547,000 to the nearest thousand 1978 dollars. Combined with the $438,157,000 material cost, we have $559,704,000, which amounts to $677,242,000 when inflated to 1980 dollars.

Remaining Costs Varying with Mechanical Track Action

Subtracting our total rail cost from the total variable cost, we have $2,286,860,000 - $677,242,000, which leaves $1,609,618,000 as the total cost which varies with mechanical action of the track.

TANGENT RAIL LIFE EXPERIENCES OF NORTH AMERICAN ROADS

An iron ore road, using cars grossing 210,000 pounds on 33-inch wheels obtained a first position rail life of 800 million gross tons with 112-pound jointed rail. This rail was removed with 1/8-inch headwear because of end batter and bolt hole breaks. It has since been cropped and welded for second-position use of at least 200-300 million more gross tons.

An iron ore road, using cars grossing 240,000 pounds on 36-inch wheels, is obtaining a life of 600 million gross tons on its 140-pound continuous welded rail, under slow speed operations. The cars of this road are capable of carrying 100 tons, but are deliberately light loaded to reduce excessive deterioration of track.

An iron ore road, using cars grossing 248,000 pounds, is obtaining a life of 400 million gross tons on its jointed 140-pound rail largely because of surface bending and heavy corrugations. This rail will be cropped, welded and reused in second position with remaining life still unknown.

A heavy-tonnage bridge road, carrying mixed traffic, is removing rail from first position which has carried over 1,000 million gross tons, work-hardened prior to the advent of significant quantities of 100-ton cars. Newer, first-position rail, work-hardened under a mix of 100-ton, and smaller cars, is being removed at 600 million gross tons.

An iron ore road, using cars grossing 254,000 pounds on 132-pound rail of 78-foot lengths, is removing rail at 400 million gross tons. At an age of 285-300 million gross tons, defect propagation rapidly accelerated, and by 400 million gross tons it had reached 0.73 defects per year per track mile, with annual tonnages up to 50 million gross tons.

A heavy tonnage road, now using mostly 263,000-pound cars, on 131-pound continuous welded rail, work-hardened under lighter axle loadings is removing this rail at 750 million gross tons, with no remaining life. Other jointed rail under 263,000-pound cars, is being removed at 400 million gross tons as a result of rail-end batter. This road predicts a total life of 600 million gross tons on heavy rail when welded at the outset, but has not yet developed sufficient tonnage on the new rail to assess its defect-related life.

A road operating heavy tonnage coal lines carrying 70 million gross tons per year in cars of 263,000 pounds has already accumulated 300 million gross tons of this traffic on new 136-pound continuous welded rail. By the time this rail had carried 200 million gross tons, it was developing defects at the rate of one per year per track mile. Removal of this rail from first position at an age of 400-450 million gross tons is planned, with 450 million gross tons considered really optimistic. Furthermore, this road questions whether there will be sufficient remaining life in this rail to make it worthwhile to use it on lower density lines in second position. It is believed that if this rail is removed at 400 million gross tons, it will be so defect-ridden that only about 50% will remain for second position use of an additional 100 to 150 million gross tons.

By contrast, the above road also operates a line carrying light, mixed traffic of 20 million gross tons per year on 115-pound rail which has already carried 700 million gross tons in the first position with essentially no defect problem.

Another road which now carries heavy traffic volumes in cars grossing 263,000 pounds is experiencing high defect propagation rates early in the life of its heavy rail, and expects to allow it to remain in first position for only 400 to 500 million gross tons. By contrast, this road used to obtain 700 to 800 million gross tons in first position under cars weighing not in excess of 220,000 pounds.