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Economies of Scale in Railroading†

*by Edward Miller**

THERE ARE TWO possible meanings for a statement that railroading is a decreasing cost industry. One is that if the existing railroad system somehow got substantially more traffic than they carry now their costs would increase less than in proportion. (The miles of right of way are assumed to be held at their present level.) The other is that if we doubled the length of railroad without increasing the traffic per mile, their costs would increase less than in proportion. The policy questions for which the two concepts are relevant are quite different. If the question is whether the merger of two railroads will produce cost savings, we want to know how changing the length of railroad while holding the density constant will affect costs (Density is gross ton-miles per mile of road).

However, for most other questions of transportation policy, there is an implicit assumption that any increases in railroad traffic will be handled on the existing network without significant construction of new trackage. This is certainly a correct assumption for today. In general, when someone involved with the railroad industry asserts that it is a decreasing cost industry, he means that average costs decrease with density. That will be the meaning used in this paper.

One could examine how average costs per ton-mile varied with some measure of aggregate railroad size, such as total ton miles. Since ton-miles is the product of the ton-miles per mile of route and the miles of route, and since the variance in railroad length is much greater than the variance in density, what would be really examined is how costs varied with the length of the railroads. A knowledge of this would be useful in deciding whether to merge two short railroads to make one long one, but is not useful for most other transportation studies.

This study will attempt to determine whether the marginal costs of handling additional traffic on the existing rail network is lower than the average costs. The data used will be Interstate Commerce Commission cost data for Class I railroads for 1968. The dependent variables used are the costs per mile of performing various functions. These are obtained by dividing ICC costs by the miles of road. The independent variables used were also deflated by the miles of road.

From an econometric viewpoint dividing all variables by miles of route makes the data more homoscedastic. Any element of railroad expense can be considered as being made up of a part that varies with output, and a random element. The magnitude of this random element varies with the size

**Energy Policy Office, Executive Office of the President, Washington, D.C.*

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of the railroad. It is probably roughly proportional to some measure of the size of line. The best procedure then becomes to divide all data through by some measure of size. The measure used here is average miles of road operated.

The argument can be visualized by imaging a simple plot of total expenses for maintaining track versus number of ton-miles carried.

Given the wide variation in railroad size, most of the railroads will fall in a cluster around the origin, forcing the line through the origin. The slope of the line will be determined by the few large railroads (four in the drawing—see Figure 1). The experience of the other railroads has little impact on the final equation estimated (beyond forcing it near the origin). In spite of a sample with many railroads, one's results have really been determined by these four. The traditional tests of significance grossly overstates the precision of the results.

The diagram shows that with railroads of widely differing size the line of best fit will be forced to pass near the origin. This implies that total costs will be found to be roughly proportional to output, or that there are no economies of scale.

TRAIN COSTS

Certain costs of railroad operation are a function primarily of the number of trains operated, and not of the number of cars included in the train. Among these are train crew costs, the part of locomotive costs that are a function of locomotive miles, part of signalling costs, and the part of maintenance costs that consist of repairing the wear and tear caused by the locomotive and caboose. As long as a train capable of handling more freight is being run over the route, the marginal costs is the cost of adding an additional car to that train. This does not apply to the main lines where traffic is sufficiently heavy so that the trains are being operated near capacity. Here additional traffic is likely to require the running of additional trains. That there is a substantial amount of excess capacity in many trains is indicated by the average length of freight trains which was 71.2 cars for 1968 (including cabooses and passenger type cars carried in freight trains), which is substantially less than the maximum that can be physically handled.

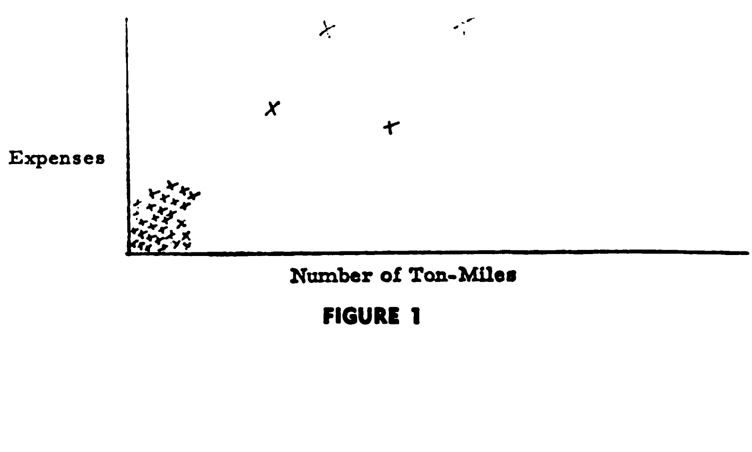

FIGURE 1

The data does confirm that train length varies with the amount of traffic on a line. Regressions of 75 railroad's average freight train length versus the revenue ton-miles of traffic per mile of track gave the following equation:

$$\text{Length} = 52.5 + \underset{(.64)^{1}}{4.15} \text{ million revenue ton miles per mile} \qquad R^2 = 36.95$$

In other words, the train length was 52 cars plus 4.15 cars per million revenue ton-miles. The *t* statistic of 6.54 shows that this increase in train length with density is not accidental.

A similar result is obtained when the dependent variable is the gross weight of freight trains. Here the equation is:

$$\text{Weight} = 3{,}003 + \underset{(.0423)}{.2783} \text{ million revenue tons per mile} \qquad R^2 = 37.23\%$$

Thus, a major source of economies of scale in railroading is the ability to run longer trains as the density of traffic increases.

The cost per car of improving service by running more trains decreases with the number of cars handled on the line. As traffic increases, there will come a time in which the railroad decides to improve the service by running more frequent trains. This will normally occur before it is necessary to schedule more trains in order to physically handle the traffic. Thus, the observed changes in cost with increased traffic understates the economies that would be obtained if service was held constant. Part of the potential savings is used to give improved service.

This is a general problem in costing of many modes of transportation since the use of additional vehicles to carry added traffic will usually result in a more frequent service. Thus, even where costs are not decreasing, there may be increasing returns because the value of service, and total consumer's surplus is increasing.

VARIABILITY OF TRAIN-MILES WITH TRAFFIC OVER TIME

So far, it has been argued on the basis of both technical considerations, and cross-sectional regressions, that an increase in traffic should produce a less than proportional increase in train miles. Unfortunately, observations over time do not support this. Regressions of the number of freight train miles 1955-1969 (the years of the latest AAR published statistics) on the number of car miles shows that increased traffic has resulted in a more than proportional increase in train miles:

$$\text{Train miles} = -\underset{(22{,}888)}{149{,}490} + \underset{(.78)}{19.20} \text{ car miles} - \underset{(233.9)}{1384.4} \text{ time} \qquad R^2 = 98.23\%$$

The constant term is negative and significant ($t = -6.53$). The term

1 Numbers in parenthesis are standard errors.

for the number of freight car miles is highly significant (t = 24.57) indicating that each additional 52.1 cars leads to an additional train. This seems implausibly low considering that the average length of freight trains is 70.0 cars (1969). A similar pattern is observed when separate equations are run for the three districts. The co-efficients are remarkably similar with the number of additional train miles per thousand car miles being 17.17 in the East, 19.91 in the South, and 20.52 in the West. In all cases, this is substantially above the average ratio.

When the number of train miles was regressed on the number of ton miles and time the equation was:

$$\underset{}{\text{Train miles}} = \underset{(15932.)}{3305} + \underset{(.0216)}{.5565}\ \text{Revenue ton miles (millions)} - \underset{(346.75)}{8662.79}\ \text{TIME}$$
$$R^2 = 98.38\%$$

Here the constant term is positive but not statistically significant (t = .207). The coefficient for revenue ton miles was highly significant (t = 25.75) indicating that each 1800 tons required the running of an additional train.

Very similar results are obtained when the districts are examined separately. With ton miles and time as the explanatory variables, the constant term was non-significant in all cases, and the coefficient for tons was .499 for the East, .530 for the South, and .637 for the East, and was highly significant in all cases.

Results for 1929-1969

The results given above cover only the period 1955-1969. Regressions were also run covering the entire period 1929-1969 (using a data series compiled from the 1970, 1955, and 1945 Railway Facts of the AAR). Using car-miles and time the best equation was:

$$\text{Train miles} = \underset{(28,386)}{-179,866} + \underset{(.86)}{19.18}\ \text{freight car miles} - \underset{(347)}{6,681}\ \text{Time}$$
$$R^2 = 93.86\%$$

The coefficient for car miles is highly significant as is that for time (t = −19.25). It is particularly interesting to notice that the coefficient for car miles is almost identical to that found only for 1955-1969, indicating an additional train for each additional 52.1 cars. The measure of time used was (the year of observation − 1969). This had the effect of giving the year 1969 a value of 0, and earlier years negative numbers.

A slightly higher explanatory power was obtained by using revenue ton miles (in millions) as the explanatory variable giving:

$$\text{Train miles} = \underset{(24,429)}{-171,901} + \underset{(.0316)}{.8079}\ \text{Revenue ton miles} - \underset{(418)}{11,100}\ \text{TIME}$$
$$R^2 = 95.27$$

The highly significant variable for revenue ton miles indicates that each additional 1238 revenue ton miles has required an additional train mile. It is not clear why time series regression gave different results than the cross-sectional ones.

If there is a less than proportional increase in train-miles with traffic, one would expect also a less than proportional increase in locomotive miles. Five different equations were estimated and all showed this.
The best was:

$$\text{RLMILE} = \underset{(267.4)}{1139.} + \underset{(.0306)}{.6051}\ \text{FGTM} + \underset{(.187)}{1.829}\ \text{PGTM}$$

$$R^2 = 91.40\%$$

The gross ton miles are in thousands. Notice that the t statistic for the constant term is highly significant at 4.26 and the two variable terms are even more significant ($t = 19.78$ for gross freight ton miles and $t = 9.76$ for passenger gross ton miles). Each mile of track requires annually 1140 locomotive miles plus one locomotive mile for each 1650 freight gross ton miles and 550 passenger gross ton miles.

A small increase in train speed with density was observed. There was also a statistically significant decrease in the percentage of empty car miles with density.

GENERAL EXPENSES

The general expenses of railroad operation include those not directly assignable to transportation, maintenance, or traffic functions, and include general administration and accounting, finance, law, real estate, etc. For all railroads it amounted to $580,800,000 for 1968. The variable which is most useful in explaining general expenses per mile of road is the total of the operating expenses for the maintenance of way, maintenance of equipment, transportation, and traffic functions. In effect the overhead expenses are hypothesized to be a function of the size of railroad operations to be supervised, with the best measure of the size being the amount spent on them. A regression incorporating just this variable was:

$$\text{GEN} = \underset{(296.35)}{-\$1195.33} + \underset{(.0061)}{.117}\ \text{OC (operating costs)}$$

$$R^2 = 83.62\%$$

The constant term is negative and significantly so ($t = 4.03$). Doubling the number of dollars spent per mile in operating a railroad more than doubles the administrative overhead involved. The marginal increments in overhead amount to a little less than 12% of any increase in spending.

However, since the amounts expended on railroad operation per mile increase less rapidly than the traffic carried, the amounts expended for general administration may still increase less than proportionately with traffic. An equation relating general administrative expenses to traffic is:

$$\text{GEN} = \underset{(648.13)}{\$1027.12} + \underset{(.155)}{\$.628}\ \text{REVTM (thousands)} + \underset{(.00294)}{\$.00515}\ \text{passenger miles}$$
$$R^2 = 24.56\%$$

Now the constant term is positive, although not significantly so $(t = 1.58)$ suggesting the presence of economies of density. General expenses increase less than proportionately with traffic. The reader should note that making general expenses as direct function of traffic instead of a function of total operating costs greatly lowers the explanatory power of the equation, (from 83.62% to 24.56%). A partial reason for this is that the output measures are ton and passenger miles, neither of which reflect the greater costs of railroads that originate or terminate a lot of traffic.

There may very well be some economies of scale with railroad size and length, due to spreading certain fixed costs of finance, law, public relations, etc., over a greater number of miles of track. This was tested by adding the logarithm of the total operating costs (not divided by length of road) to the first equation discussed above. This gave:

$$\text{GEN} = \underset{(1888.61)}{\$-4196.63} + \underset{(.00586)}{.1199}\ \text{OC (operating costs)} - \underset{(109.56)}{316.36}\ \text{LOC (log total operating cost)}$$
$$R^2 = 85.32\%$$

The logarithm of total operating costs is statistically significant $(t = 2.89)$ indicating that increasing the size of a railroad, leaving its average density of traffic unchanged will lower the general administrative costs per mile. The magnitude of the effect is that an increase of 2.71 (the mathematical constant e) fold in the size of the railroad (length) will reduce the general and administrative costs by about $300 per mile.

One possible statistical bias should be noted. In a small railroad the general officers and administrative staff may perform certain functions as part of their regular duties which in a larger railroad would be performed by specialized personnel in one of the operating departments. An example would be liaison with large shippers. In a small railroad the president might do much work of this type that would be delegated to the traffic department in a large railroad. Small railroads are also more likely to be subsidiaries of a large system which perform some of the management.

FREIGHT TRAFFIC EXPENSES

The traffic expenses (the railroad's selling expenses) allocated to freight amounted to $242,000,000 for all Class I railroads for 1968. The equation that best explained these expenses on a per mile basis was:

$$\text{Traffic} = \underset{(139.99)}{\$339.48} + \$3.689\ \text{carloads terminated} + \underset{(.3126)}{\$.6579}\ \text{carloads of bridge traffic}$$
$$+ \underset{(.0356)}{\$.1461}\ \text{revenue ton miles (thousands)} \qquad R^2 = 58.39\%$$

The cars of traffic terminated and the cars of bridge traffic exclude coal and iron ore.

The costs of participating in rate bureaus, publishing tariffs, taking an advertisement in a national magazine, maintaining an agent in a particular city, may not vary much with the length of railroad. Thus it would seem logical that the freight traffic expenses per mile of line would decrease with the length of the railroad. The hypothesis was tested by adding the logarithm of the number of miles of railroad (SIZE) to an equation incorporating revenue ton miles. The logarithm was used instead of the absolute value to avoid having the results dominated by the few large railroads in the country. The resulting equation was:

$$\begin{array}{llll} \text{FTRAF} = \$1814.21 & + \$.00224\ \text{REVTM} & - 170.879\ \text{SIZE} & \\ \quad (442.01) & \quad (.00035) & \quad (58.83) & \\ & & & R^2 = 41.63\% \end{array}$$

The t statistic for size (−2.90) is statistically significant indicating that there are economies of scale in the railroad freight sales function.

The above equation understates the extent of the real economies of scale if a large railroad performs the traffic function better than a small one, and overstates it if parents perform it for subsidiaries.

TRANSPORTATION EXPENSES

Transportation expense constitutes about half of total railroad operating expenses. It includes the expenses of operating the trains and billing the traffic, except for maintenance. Before discussing the individual accounts, it is useful to examine the overall behavior of this item of expense. The expenses for operating floating equipment, and for operating coal and ore wharves were deducted as being not a function of the scale of land railroad operations. In general, these expenses are a minor part of total railroad operating expenses, but for certain railroads they are appreciable (such as the Ann Arbor), and could lead to distortions if left in.

The best equation for explaining land transportation expenses was

$$\begin{array}{llll} \text{LTRANS} = \$7779.16 & + .003137\ \text{REVTM} & + \$.0427\ \text{passenger miles} & \\ \quad (2382.59) & \quad (.000572) & \quad (.0108) & \\ & & & R^2 = 44.37\% \end{array}$$

The coefficient for the constant term is statistically significant at t = 3.26. There appear to be a constant expense of \$7800 per mile, which presumably represents the cost of maintaining a minimum level of service. For the whole rail network these costs would amount to \$1,640,000,000, which is 38% of total land transportation expenses. Variable transportation costs appear to amount to slightly less than a third of a cent per revenue ton mile, and 4¼¢ per passenger mile.

TRAIN ENGINEMEN

The category of train enginemen includes locomotive engineers and firemen (except those used for yard switching) and amounts to \$384,100,000 per year. The best equation was:

$$\text{ENGMEN} = \$-113.15 + \$.3118\ \text{FTMILE} + \$.5821\ \text{PTMILE}$$
$$(120.91) \quad (.0800) \quad\quad (.0664)$$
$$+ \$8.367\ \text{FTHOUR}$$
$$(1.132)$$
$$R^2 = 83.62\%$$

The constant term is negative but not significantly so ($t = .936$). It is interesting that the largest error of production is for the Florida East Coast Railroad where the model predicts an expenditure of \$1678.67 per mile for enginemen versus an actual expenditure of \$503.42. This railroad is non-union and has been able to greatly reduce its use of enginemen.

Because the number of trains increases less than proportionately with traffic, the total constant cost per mile of road is greater when the explanatory variables are units of output. Such an equation is:

$$\text{ENGMEN} = \$636.083 + \$.249\ \text{REVTM (thousands)} + \$.00371\ \text{passenger miles}$$
$$(141.659) \quad (.0340) \quad\quad (.000643)$$
$$R^2 = 60.41\%$$

Here the constant term is highly significant ($t = 4.49$) indicating that there are constant enginemen expenses of about \$636 for maintaining service along a mile of track.

TRAINMEN

The category of trainmen includes all expenses for the train crew except for engineers and firemen. This account amounts to \$614,000,000 per year and is the largest item in the ICC accounts. The best equation was:

$$\text{TMEN} = \$-51.34 + \$.3183\ \text{FTMILE} + \$.8402\ \text{PTMILE}$$
$$(191.93) \quad (.1270) \quad\quad (.1054)$$
$$+ \$15.68\ \text{FTHOUR}$$
$$(1.80)$$
$$R^2 = 82.61\%$$

The constant term is negative but not significant ($t = .2675$) indicating that all trainmen costs are variable with the number of trains.

However, since the number of train miles increases less rapidly than the amount of traffic, the total constant cost as a function of traffic is greater. This can be seen if the intervening variable, train miles, is excluded and the costs are regressed directly on measures of output. Such an equation is:

$$\text{TMEN} = \$1199.40 + \$.3516\ \text{REVTM (thousands)} + \$.00541\ \text{PMILE}$$
$$(239.30) \quad (.0575) \quad\quad (.00109)$$
$$R^2 = 52.24\%$$

The constant term is now highly significant ($t = 5.012$) indicating constant costs of about $1200 per mile for trainmen to maintain service along a mile of road.

TRAIN FUEL AND RELATED EXPENSES

For purposes of analysis train fuel ($355,800,000) was combined with several smaller accounts for train and locomotive supplies. These included train power produced ($1,000,000), train power purchased ($21,200,000), water for train locomotives ($1,700,000), lubricants for train locomotives ($25,100,000), and other supplies for train locomotives ($9,600,000). Similar expenses for yard locomotives are in other accounts. The equation of best fit was:

$$\underset{}{\text{FUEL}} = \underset{(72.02)}{-2.83} + \underset{(.04932)}{.3834}\ \text{TMILE} + \underset{(13.00)}{\$108.92}\ \text{DEN} \qquad R^2 = 92.61\%$$

The constant term is not statistically significant ($t = -.309$). However, this does not indicate the absence of any economies of density for fuel and related expenses since average train length increases with density.

When the independent variables are revenue ton miles and passenger miles we have:

$$\text{FUEL} = \underset{(79.72)}{\$320.23} + \underset{(.01914)}{\$.3783}\ \text{REVTM (thousands)} + \underset{(.000362)}{\$.00364}\ \text{PMILE} \qquad R^2 = 89.34\%$$

This shows clearly that there is a statistically significant constant term ($t = 4.016$) even for such an apparently variable expense as fuel.

STATION EXPENSES

The station expenses analyzed here are the sum of account 373 "Station Employees" ($424,900,000 per year) and account 376 "Station supplies and expenses" ($51,100,000 per year). These expenses include not only the costs of accommodating passengers, but also those for billing freight. The ICC accounts allocated $349,300,000 of station employee expenses to freight, but only $75,600,000 to passengers for 1968. Since then the portion allocatable to passengers has probably further declined.

The equation that best explained these items of cost per mile of road was:

$$\text{STEXP} = \underset{(122.30)}{\$860.62} + \underset{(.717)}{\$7.972}\ \text{TERMNM (carloads terminated, non-mineral)}$$

$$+ \underset{(.0324)}{\$.2307}\ \text{passengers carried} \qquad R^2 = 74.78\%$$

There is a marginal billing cost of about $8.00 per car terminated of non-mineral traffic. The expenses are per car terminated because the terminating railroad is responsible for the billing of the customer. If the number of cars of non-mineral traffic originated is included as a variable it has a coefficient of about \$2.00 per car, but this coefficient is not statistically significant ($t = 1.306$).

The Association of American Railroads[2] using data for individual stations also found that there were large economies of scale in station operation.

YARD EXPENSES

For purposes of analysis all of the ICC yard expenses included in the transportation accounts were lumped together. (Accounts 377 through 389). These accounts totaled \$1,046,000,000 for 1968 with the largest single items being for yardmasters and yard clerks (\$223,400,000), yard conductors and brakemen (\$473,600,000), and yard enginemen (\$226,200,000).

The sample of 75 railroads used in the remainder of the analysis included two railroads that apparently did no yard switching, which were excluded from the sample. The parent company apparently does the switching for both lines.

Yard expenses proved to be almost completely explained by the number of yard locomotive miles run:

$$\underset{}{\text{YEXP}} = \underset{(203.30)}{-\$1.02} + \underset{(.087)}{\$4.343}\ \text{YLMILE} \qquad R^2 = 97.20\%$$

The t statistic for yard locomotive miles is an extremely high 49.64 while the constant term is complete insignificant ($t = -.005$). In essence, yard costs are \$4.34 per yard locomotive mile. It should be noted that the number of yard locomotive miles is calculated by multiplying the number of yard locomotive hours by six, with the result that what is really being used as the explanatory variable is yard locomotive hours.

In turn the number of yard locomotive miles per mile of road is best explained by using the miles of yard track per mile of road giving

$$\text{YLMILE} = \underset{(90.02)}{-99.73} + \underset{(154)}{3971}\ \text{YTRACK} \qquad R^2 = 90.32\%$$

This equation could be interpreted as indicating that there is a fixed number of yard locomotive miles required per mile of yard track. This would suggest that yard expenses were fixed in the short run since the size of yards changes only slowly with time. However, this interpretation is probably wrong with the close correlation probably reflecting only that both the number of locomotive miles and the number of miles of track both reflect the need for switching. Unfortunately, measuring this need for switching is difficult.

The best equation explaining yard expenses as a function of the work to

2 Association of American Railroads, Bureau of Railway Economics—A Guide to Railroad Cost Analysis—December 1964—Chapter 6.

be done used the sum of the number of non-mineral cars originated HAND-NM) and the sum of the number of coal and iron ore cars originated and terminated, (HANDM) giving:

$$\text{YEXP} = \underset{(540.26)}{\$1830.41} + \underset{(1.442)}{\$25.55}\ \text{HANDNM} + \underset{(1.474)}{\$4.49}\ \text{HANDM}$$

$$+ \underset{(.042)}{\$.223}\ \text{PCMILE} \qquad (R^2 = 85.80)$$

The number of cars interchanged and the number of freight car miles were not statistically significant. It is striking that non-mineral traffic costs about \$25 per car to originate or terminate while the mineral traffic costs about \$4.50. Only a small fraction (12 - 13%) of the total variance could be explained by using only car miles or gross ton miles.

ROAD ENGINEHOUSE EXPENSES

This account includes the expenses of operating the enginehouses where locomotives used in road service (similar expenses for yard locomotives are included elsewhere) are refueled, cleaned, lubricated, etc. The expenses of actually making repairs are included under the maintenance of equipment accounts. These expenses amount to \$97,000,000 per year.

The best equation was:

$$\text{REHOUS} = \underset{(48.71)}{\$113.01} + \underset{(.0117)}{\$.0862}\ \text{REVTM} + \underset{(.00021)}{\$.00104}\ \text{PMILE} \qquad R^2 = 57.00\%$$

SIGNAL, INTERLOCKER, AND DRAWBRIDGE OPERATION, AND CROSSING PROTECTION

For convenience in analysis, signal and interlocker operation (\$46,500,000 per year), crossing protection (\$13,300,000 per year) and drawbridge operation (\$6,400,000), were combined. The resulting equation was:

$$\text{SIGOP} = \underset{(103.37)}{\$83.75} + \underset{(.0368)}{\$.121}\ \text{TMILE} \qquad R^2 = 12.91\%$$

The average railroad has 2617 train miles per mile per year making the best estimate of the percentage of the costs that are fixed for a typical railroad 20%. However, the t statistic for the constant term is very low (.810) indicating all of these costs could easily be variable with the number of trains.

The above estimates, being derived from cross-sectional data give the very long term response to changes in traffic. In the short and medium term, there is unlikely to be much variability since once a system of signals or crossing protection has been put in, the costs do not vary with the number of trains on the track. The empirically observed variation in [illegible] costs with the level of traffic is due to the installation of more expensive systems as the traffic increases.

As shown earlier, the number of trains increases less than proportionately with the amount of traffic carried. Thus, the variability of these costs with number of trains indicates fixed costs that do not vary with the level of traffic. When these costs are regressed on measures of final output, the following equation was obtained:

$$\text{SIGOP} = \underset{(98.09)}{\$260.47} + \underset{(.0236)}{\$.0175}\ \text{REVTM (in thousands)} + \underset{(.000445)}{\$.00110}\ \text{PMILE}$$
$$R^2 = 9.71\%$$

The constant term is now statistically significant (t = 2.66), and approximately four times as large as when train miles was the explanatory variable.

DISPATCHING COSTS

Total expenses for dispatching trains amounted to $63,900,000. This account covers train masters and others responsible for directing the movement of trains. It is one that would logically be expected to be related to the number of trains dispatched. The equation for this account was:

$$\text{DISP} = \underset{(64.92)}{\$116.05} - \underset{(.03615)}{\$.011319}\ \text{PTMILE} + \underset{(.0326)}{\$.0920}\ \text{FTMILE}$$
$$R^2 = 10.56\%$$

Neither the constant term nor the term for passenger trains is statistically significant. It is not clear why the coefficient for the number of passenger trains should be negative (although not significantly so).

Since the number of trains increases less than proportionately with tons hauled, the actual constant costs for train dispatching may be greater than indicated above. An equation relating costs to final output is:

$$\text{DISP} = \$180.27 + \$.0299\ \text{REVTM (thousands)} + \underset{(.000232)}{\$.000020}\ \text{PMILE}$$
$$R^2 = 8.07\%$$

Here the constant term is statistically significant (t = 3.52).

COMMUNICATIONS

The total railroad expenses for communication system operation for 1968 was $46,400,000. The best equation for this account was:

$$\text{COMM} = \underset{(57.98)}{\$-73.85} + \underset{(.000353)}{\$.00225}\ \text{CMILE}$$
$$R^2 = 35.77\%$$

Notice that the constant term, although not statistically significant (t =

−1.274) is negative. There appear to be no economies of density in communications.

LOSS AND DAMAGE

Loss and damage payments cost the railroads \$177,400,000 per year. The equation that best explained these costs was:

$$\text{LD} = \underset{(84.34)}{\$215.44} + \underset{(.0198)}{\$.1394}\ \text{REVTM (thousands)}$$

$$R^2 = 40.42\%$$

There is no reasonable reason for the loss and damage expenses to have a significant constant term. The fact that there is one ($t = 2.55$) is probably due to there being a greater proportion of easily damaged freight on the less dense lines. This could be because many of the lines with high densities are ore or coal roads.

This does not really show that the loss and damage is proportional to the ton-miles involved. Most loss and damage is discovered only after the freight car is opened. Unless it is actually known which railroad caused the damage, it is apportioned to all of the railroads involved, usually in the same way as the rate is divided. The division is usually heavily influenced by length of haul over each line. Thus when we find that ton-miles is the best variable for explaining the railroads costs for loss and damage, we are not necessarily showing that the true loss and damage costs increase in proportion to the length of the haul. In any case, loss and damage costs are clearly completely variable with the amount of traffic.

MAINTENANCE OF WAY EXPENSES

The best known source of decreasing costs in the railroad industry is in right of way maintenance expenses. To get an estimate of these expenses, the total right of way maintenance expenses were regressed on the gross ton-miles of traffic per mile to give:

$$\text{MAINT} = \underset{(\$716.34)}{\$3663.65} + \underset{(72)}{\$461}\ \text{DEN (million ton miles per mile)}$$

$$R^2 = 36.16\%$$

The constant term here has a t statistic of 5.11 which is highly significant. There appear to be constant costs of about \$3600 per mile of road for right of way maintenance. However, the coefficient for density is also highly significant ($t = 6.43$). It appears that per mile right of way maintenance expenses increase by \$460 per million gross ton miles. The average railroad has a gross traffic density of about nine million gross ton-miles per mile. Such a railroad would have variable costs totaling \$4149 and fixed expenses of \$3600 per mile. Thus, about 47% of right of way maintenance expenses vary with traffic. This is probably a low estimate of the constant costs because it treats as variable the costs of maintaining very long lived structures (bridges for instance) whose value per mile varies with the density.

For reasons of service, dense railroads are typically maintained to higher standards than railroads with a low density of traffic. On the main track a high level of maintenance is required since the benefits from well maintained track are likely to be proportional to the number of carloads of traffic affected. On a low density track, the number of carloads of traffic affected is less and repairs are postponed much longer. Thus, even if all maintenance was due to passage of time, there would be a positive correlation between traffic and maintenance. This effect introduces a statistical bias.

The cost of the railroad right of way includes not only the costs of maintaining the right of way, but the costs of the capital tied up in the right of way. A regression of the per mile value of railroad fixed investment on density is:

$$\text{Investment} = \underset{(\$35{,}027)}{\$75{,}729} + \underset{(\$3{,}505)}{\$16{,}786}\ \text{Density} \qquad R^2 = 23.91\%$$

The constant term is statistically significant at the 5% level indicating that part of rail investment does not vary with the level of traffic. The best estimate of this investment is $75,000 per mile. The coefficient for density is also significant ($t = 4.789$), with each million gross ton miles accounting for an additional $16,800 in investment. For a railroad with average density it appears that about a quarter of investment is fixed even in the long run.

The investment per mile of track is an important determinant of the costs of maintaining that track. This variable when used alone has a higher explanatory power than density used alone. The relevant equation is:

$$\text{MAINT} = \underset{(554.61)}{\$4208.43} + \underset{(.001916)}{.01518}\ (\text{INVESTMENT PER MILE}) \qquad R^2 = 46.22\%$$

This equation suggests that each increment in investment will produce an increment in annual maintenance costs equal to 1.5% of the original cost of the investment. In addition, there is a fixed cost of $4200 per mile for expenses not related to investment.

THE VARIABLE ACCOUNTS IN MAINTENANCE OF WAY

Maintenance expenses for the roadway maintenance,[3] bridges,[3] tunnels,[3] and elevated structures,[3] fences, snowsheds and signs,[3] removing snow, ice, and sand; maintaining public improvements, and right of way expenses, should not be appreciably influenced by changes in the amount of traffic over a line. These expenses, decided to be fixed on the basis of engineering consideration, amounted to $143,700,000 for 1968, or 10.2% of total expenses.

The remaining 89.8% of the maintenance of way expenses were grouped together as the potentially variable portion of total expenses. The best equation was:

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3 Only the expenses for running tracks were taken as fixed.

$$\text{ROWVAR} = \$3114.67 + \$.4345\ \text{DEN (in thousands of gross ton miles)}$$
$$(679.77) \quad (.0679) \qquad R^2 = 35.92\%$$

The variable costs of maintenance for right of way are 43.5¢ per thousand gross ton miles.

If the same exercise is done for the fixed portion of right of way expenses the equation is:

$$\text{ROWFIX} = \$54.98 + \$.0265\ \text{DEN}$$
$$(68.29) \quad (.0638) \qquad R^2 = 17.10\%$$

Although the correlation with the amount of traffic (density) is statistically significant ($t = 3.8806$), these expenses are little affected by the level of traffic. This indicates how statistical costing without the benefits of a knowledge of railroad operations can lead to error. There is a correlation between traffic and the expenses for these accounts because lines were only constructed to high standards where much traffic was expected. After construction, lines with high expenses for these items were kept in operation only if there was sufficient traffic to cover these expenses.

MAINTENANCE OF RIGHT OF WAY ACCOUNTS

It is useful to examine the different right of way maintenance accounts separately because some items that display a statistical relationship with the amount of traffic may be of a type that are known not to vary appreciably with traffic (maintenance of tunnels).

Rails —

$$\text{RAIL} = -1.873 + 35.35\ \text{DEN}$$
$$(61.258) \quad (6.535) \qquad R^2 = 31.30$$

This equation indicates that expenditures for purchase of rails are proportional to the gross ton miles of traffic, and run about $35 per million gross ton miles.

Ties —

A regression of expenditure for the purchase of ties (the expenses of laying them is in "track laying and surfacing") gave:

$$\text{TIES} = \$217.38 + \$26.41\ \text{DEN}$$
$$(69.26) \quad (6.93) \qquad R^2 = 16.58\%$$

Track material —

For all running tracks the total national expenditure is $64,200,000.

$$\text{TMAT} = \$171.19 + \$16.86\ \text{DEN}$$
$$(40.02) \quad (4.00) \qquad R^2 = 19.54\%$$

Ballast —

$$\text{BALLAST} = \underset{(24.97)}{\$70.77} + \underset{(2.500)}{\$7.036}\ \text{DEN} \qquad R^2 = 9.79\%$$

Track Laying and Surfacing —

The equation for track laying and surfacing was:

$$\text{TLS} = \underset{(92.08)}{\$763.27} + \underset{(9.22)}{\$57.84}\ \text{DEN} \qquad R^2 = 35.05\%$$

For a typical railroad about 59% of track laying and surfacing expenses are fixed.

Since much of track laying and surfacing expenses are for replacing ties and rail it was expected that a measure of the rate of rail and ties replacements would provide a better measure of the demand for track laying and surfacing. Thus, expenditures for purchase of rails, and ties were both tried as independent variables. The resulting equation explained only 17.10% of the total track laying and surfacing expenses, versus the 35.05% explained by density.

Roadway Maintenance—This account indicates some of the problems associated with statistical costing of maintenance of right-of-way expenses. There are no items in this account that should vary with the level of traffic. This account covers costs of earthmoving, including removing slides and washouts, patrolling the roadbed, and controlling vegetation along the right-of-way. For running tracks this account amounted to \$64,700,000 for 1968. Yet statistically this account does show a significant dependence on traffic levels.

$$\text{ROADM} = \underset{(32.14)}{\$233.23} + \underset{(3.22)}{\$10.08}\ \text{DEN} \qquad R^2 = 11.87\%$$

While the constant term is highly significant ($t = 7.26$) the variable term is also significant ($t = 3.14$). The data would suggest that only 72% of this account is fixed.

However, one would suspect that much of the statistical correlation is spurious. The low density lines tend to be in the Great Plains where flat terrain limits the amount of earthwork utilized, and low precipitation makes the problem of clearing vegetation from the right-of-way minimal. Likewise, the highest density lines are often those carrying either ore or coal through hilly territory where much earthwork is normally required.

This bias is in turn a symptom of the more fundamental bias that lines were built only if it was believed that they would carry enough traffic to cover the cost of building them. As a result there is a correlation between density and the investment per mile (including earthwork) in a line. Likewise, major rebuilding projects have been undertaken on the lines with the heaviest traffic in order to either reduce grades, or shorten distances. Also, the minimum traffic for which it was worthwhile keeping a line open varies with the cost of doing so, which in turn varies with the level of traffic. For instance a line which is subject to frequent landslides and washouts will probably be abandoned unless it carries a high level of traffic. Thus, although there is a statistical correlation between roadway maintenance expenses and traffic, additional traffic can be run over existing track without affecting the level of expenses for roadway maintenance.

Depreciation—A similar bias applies to the right-of-way and structures depreciation account which was $165,100,000, for the whole system in 1968. This account covers all depreciation of right-of-way and structures. A simple regression of depreciation per mile on gross ton miles per miles is:

$$\text{DEP} = \underset{(103.30)}{\$271.27} + \underset{(10.34)}{\$72.12}\ \text{DEN} \qquad R^2 = 40\%$$

The constant term is statistically significant ($t = 2.626$) as is the density term ($t = 6.977$). There can be no doubt that the depreciation charges per mile vary strongly with the amount of traffic per mile. From the equation it appears that depreciation is only 29.5% fixed in the long run.

However, in the short run all of this expense is fixed since it isn't until a structure requires replacement that there is any discretion with regard to depreciation. Even in the long run some part of the apparently variable portion is fixed. This would apply to the depreciable portion of the right-of-way, especially bridges. The railroad cannot fail to replace these structures as needed if the line is to be kept open. Thus, even in the long run these depreciation expenses are fixed even though at the time of construction of the line they were variable with the expected level of traffic. (Charges in this category would be larger if tunnels and grading expenses prior to 1969 were considered depreciable). Items that would fall in this category (engineering, other right-of-way expenditures, grading, tunnels and subways, bridges, trestles and culverts, fences, snowsheds, and signs and power transmission systems) had a total depreciation expense of $56,400,000. A large part of the $31,000,000 for signals and interlockers also falls in this category.

Roadway machines—This account covers the costs of repairing (but not replacing) roadway machines such as inspection cars, portable cranes, pile drivers, etc. (However, rail mounted equipment repairs are included in maintenance of equipment under work equipment). It amounted to $50,700,000 for 1968. There was an additional $15,800,000 in the depreciation accounts for roadway machines. A regression against density gave:

$$\text{RMACH} = \underset{(42.10)}{\$51.26} + \underset{(4.21)}{\$26.40}\ \text{DEN} \qquad R^2 = 34.97\%$$

Although one would expect total maintenance costs to vary with either locomotive miles, or gross ton miles, the best fit was actually obtained using revenue ton miles and passenger miles. This was:

$$\text{RLOCMT} = \underset{(126.34)}{\$637.73} + \underset{(.0303)}{\$.2684}\ \text{REVTM} + \underset{(.00057)}{\$.000315}\ \text{PMILE} \qquad R^2 = 65.62\%$$

An attempt was also made to estimate expenses on a per locomotive basis with the Canadian Pacific Lines in Maine removed from the sample (because of atypically high expenses). The best equation was:

$$\underset{}{LFIX} = \underset{(2290)}{\$7130} + \underset{(.0175)}{\$.1352\ LOCMIL} + \underset{(.1363)}{\$.2157\ YARDLM} - \underset{(352.69)}{\$355.15\ LSIZE}$$

$$R^2 = 47.95\%$$

The marginal cost of maintaining locomotives is 14¢ per mile (including the yard locomotive miles) with there being an additional 21¢ per mile for yard locomotive miles. The negative coefficient for the size of the railroad suggests economies of scale in locomotive maintenance.

FREIGHT CAR REPAIRS

The total expenses for freight car repairs were $493,300,000. The equation that best explains these expenses per mile of road is:

$$FCREP = \underset{(282.55)}{-\$34.65} + \underset{(.0018)}{\$.0100\ FCMILE} + \underset{(10.886)}{\$182.56\ FCARS} \qquad R^2 = 84.29\%$$

The constant term is statistically insignificant, providing no evidence of any economies of density. The other two terms are highly significant. ($t = 5.51$ for the number of freight car miles, and $t = 16.77$ for the number of cars owned). The best approximation to costs is 1¢ per car mile plus $180 per car per year. Since the average freight car covers 20,779 miles per year (in 1968) the costs per car mile amounts to at least 53% of total costs. The actual proportion is probably higher because the number of car miles used in the above equation is the number of miles run by all freight cars on that railroad (including foreign cars). Thus, it is at best only a proxy for the number of miles run by cars owned by the railroad. Since the cars owned are the actual number the railroad must maintain, it tends to take on a higher explanatory power.

When size (the logarithm of the number of miles of road) was added to the above equation and certain railroads with few cars dropped, it became:

$$FCREP = \underset{(896)}{\$1642.} + \underset{(.000188)}{\$.0104\ FCMILE} + \underset{(11.61)}{\$175.30\ FCARS}\ \underset{(116.34)}{\${-233.07}\ SIZE}$$

$$R^2 = 84.92\%$$

The coefficient for size is negative and just barely significant ($t = 2.00$) suggesting that there are economies of scale in freight car repair.

PER CAR REPAIR EXPENSES

Attempts were also made to explain freight car repair expenses on a per car basis. Before this was done it was necessary to eliminate several railroads whose car repair expenses exceeded $2000 per car. These railroads were subsidiaries of other railroads and typically owned only cabooses. The excluded railroads included the Duluth, Winnipeg & Pacific (owned by Canadian National); the Georgia, Southern and Florida (Southern owned); Mongahela (Penn-Central and B&O), the Northwestern Pacific (Southern Pacific), Pennsylvania-Reading Seashore Lines (Penn-Central, Reading), and the Piedmont Northern (Seaboard Coast Line). This reduced the number of observations to 69. The resulting equation was:

$$\underset{}{FCFIX} = \underset{(70.72)}{\$371.01} + \underset{(.000878)}{\$.00931}\ FCMIL - \underset{(7.34)}{\$20.44}\ FCSIZE \qquad R^2 = 65.60\%$$

The other interesting feature of the above equation is that the logarithm of the number of freight cars owned is statistically significant ($t = 2.786$). This indicates that there are economies of scale in freight car repairs, with an increase in the number of cars owned by 2.71 (the mathematical constant e), reducing the per car repair costs by \$20 per car. Gallomore, in his study of railroad mergers has reported that the largest single source of savings claimed in merger proceedings was from consolidating repair shops. This is consistent with the results here.

MAINTENANCE OF EQUIPMENT OVERHEAD

For purposes of analysis maintenance overhead was defined to include all maintenance of equipment accounts except for equipment depreciation and those directly allocated to the maintenance of locomotives, freight cars, passenger cars, floating equipment, and work equipment. Included in this category is superintendence, insurance, health and welfare benefits, injuries to persons, maintenance of shop machinery, etc. These miscellaneous accounts amount to \$233,300,000 for all class one railroads. The best equation made these expenditures a function of the amounts spent on the different maintenance of equipment functions (MEALOC), totaling \$1,082,700. The equation was:

$$MEOH = \underset{(75.29)}{\$278.92} + \underset{(.01022)}{.1579}\ MEALOC \qquad R^2 = 76.60\%$$

This equation gives substantially better results than using revenue ton miles and passenger miles which can explain only 34.91% of the variance. The above equation shows a statistically significant ($t = 3.70$) constant term of \$280 per mile.

CONCLUSIONS

The evidence shows that for a wide variety of railroad operating accounts the cost per mile increases less than proportionately to the traffic carried. This indicates that there are economies of scale in railroading. If all rates are set at the marginal costs, the total revenue received will fall significantly below the total costs of operating the railroad. This requires either a subsidy, or that some rates be set above marginal costs in order to cover these overhead expense items.