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Addresses of Authors

Allen, Roy A., Research and Test Department–Technical Center, Association of American Railroads, 3140 South Federal Street, Chicago, Ill. 60616
Detmold, Peter J., Canadian Pacific, P.O. Box 6042, Station A, Montreal, Quebec H3C 3E4, Canada
Ditmeyer, S. R., Burlington Northern Railroad, 176 East Fifth Street, St. Paul, Minn. 55101
Eisele, Donald O., LTK Engineering Service, Pennsylvania Building, 1500 Chestnut Street, Philadelphia, Pa. 19102
Greenwood, William E., Burlington Northern Intermodal, 3500 Continental Plaza, 777 Main Street, Ft. Worth, Tex. 76102
Grimm, Curtis M., College of Business and Management, University of Maryland, College Park, Md. 20740
Hargrove, Michael B., Research and Test Department, Association of American Railroads, 1920 L Street, N.W., Washington, D.C. 20036
Harris, Robert G., School of Business Administration, University of California, Berkeley, Calif. 94720
Harvey, Scott B., Research and Test Department, Association of American Railroads, 1920 L Street, N.W., Washington, D.C. 20036
Levine, Harvey A., Association of American Railroads, 1920 L Street, N.W., Washington, D.C. 20036
Lewis, A. T., Consolidated Rail Corporation, 6 Penn Center Plaza, Room 601, Philadelphia, Pa. 19103-2959
Martin, J. R., Southern Railway System, 185 Spring Street, S.W., Atlanta, Ga. 30303
Olson, P.E., Swederail Consulting AB, 10550 Klarabergviadukten 80, Stockholm, Sweden
Reiff, Richard P., Research and Test Department–Technical Center, Association of American Railroads, 3140 South Federal Street, Chicago, Ill. 60616
Rhodes, Robert G., A.T. Kearney, Inc., P.O. Box 1405, Alexandria, Va. 22313
Rister, M. F., Missouri-Kansas-Texas Railroad System, 506 W. Chestnut Street, Denison, Tex. 75020
Ross, B. A., American Electric Power Service Corporation, 1 Riverside Plaza, P.O. Box 16631, Columbus, Ohio 43216
Schmidt, J. J., 3526 Jamestown Road, Davidsonville, Md. 21035
Sjokvist, E. H., Electromotive Division, General Motors Corporation, 9301 55th Street, Lagrange, Ill. 60525
Way, George H., Association of American Railroads, 1920 L Street, N.W., Washington, D.C. 20036
Webb, H. G., Atchison, Topeka and Santa Fe Railway Company, 4100 South Kedzie Avenue, Chicago, Ill. 60632
Wetzel, James A., Consolidated Rail Corporation, 6 Penn Center Plaza, Room 601, Philadelphia, Pa. 19103-2959

Foreword

The first TRB-sponsored meeting devoted solely to a wide range of subjects that all relate to the railroad industry was held in May 1985. The American Railway Engineering Association, Railway Progress Institute, and American Shortline Railroad Association joined TRB and the Association of American Railroads (AAR) in organizing this conference.

Finding a subject of common interest was easy. Productivity is a common denominator for all TRB railroad committees and indeed for all railroad people. In a highly competitive transportation environment, productivity becomes synonymous with survival. This conference will not have been worthwhile no matter how eloquent its many papers, some of which are published in this Record, unless what was discussed today is translated tomorrow into actions. It is not enough to talk here about the critical problems and challenges that the railroad industry faces; something must be done about them.

The University of Illinois was selected as a venue for this gathering of course because the facilities met the need and Illinois is central to most of the United States. But beyond those important considerations, the University of Illinois has always been closely associated with railroads and railroad technology. The university had a Department of Railway Engineering complete with professors of railway civil, railway mechanical, and railway electrical engineering. The AAR laboratory facilities in Chicago, now called the AAR Technical Center, had their beginning on the University of Illinois campus. The rolling load machines at the Technical Center were developed by Cramer there in 1932 and still carry their University of Illinois identification. It is a testimony to Cramer's fine engineering that these machines not only still work but also play a key role in the evaluation of rail and rail joint assemblies.

It was also at the University of Illinois that Arthur N. Talbot conducted much of his laboratory work and analyses between 1918 and 1940, which is considered the single most important contribution to understanding the mechanics of railroad track under load. Before Talbot, track design was a black art. He turned that art into understandable engineering.

Last, it was at this university that Bill Hay continued to have faith in the contribution that railway engineering could make to this industry when most other universities in the United States abandoned railway engineering subjects. The achievements that Hay and his students have made are enormous, but even more important was keeping alive the notion that railroad engineering was worthy of continued attention in academic circles. The pendulum has swung and many universities see great potential in the studying and teaching of railway technology again, but there was a period of about 20 years when Bill Hay and this university were virtually alone. It appears entirely appropriate to hold this conference where much of what railway engineers deal with started and where it was kept alive when many believed that railway engineering offered no more challenges worthy of academic pursuit.

George H. Way, Jr.
Conference Chairman

Toward Practicality in Defining and Measuring Railroad Productivity

HARVEY A. LEVINE

ABSTRACT

The standard definition of productivity as being the relationship between the factors of production and physical output (goods or services or both) is accepted and the various and commonly used measures in the railroad industry are critically evaluated. Problems range from the credibility of data to the difficulty in separating changes in ton-miles due to productivity versus shifts in traffic consist. The conclusion is reached that there are many indicators of railroad productivity but no reliable overall standard acceptable for all purposes. Thus the adoption of productivity measurements is a function of the use of those measurements. For instance, relatively simple productivity measurements are available as a basis for making capital investment decisions. On the other hand, highly sensitive uses of railroad productivity changes, such as adjusting the rail cost adjustment factor or increasing labor wages, demand precise productivity measurements, which are currently not available. Given the problems of calculating railroad productivity (e.g., assets that float throughout the country and are used by railroad competitors, long-lived assets, a multitude of output factors, and the inability to properly calculate the value of capital stock) it is unlikely that an overall railroad productivity measure can be developed that would satisfy the standards of precision, reliability, and general application.

The author's first and short-lived approach to addressing the issue of defining and measuring railroad productivity was to act as the reluctant draftee in presenting a summary of a literature search. After all, productivity has been studied thoroughly and a uniform method of measuring productivity in general, and railroad productivity in particular, has never been universally accepted. Second, he led a public session on productivity, sponsored by the Interstate Commerce Commission, some 12 years ago and the results of that conference were inconclusive. And finally, in a current ICC proceeding (Ex Parte No. 290, Sub.-4), he is on record as stating that railroad productivity cannot be properly measured. Still, given the elevation of productivity as a key ingredient to America's future, and more to the point, as the possible linchpin to the survival of this country's railroads as private entities, a revisit, and a fresh approach, appears in order.

The approach here was to spend a minimal amount of time in defining productivity (a textbook definition will suffice) so as to focus on the problems of measuring productivity relative to potential uses of productivity measures. Such an approach would steer away from the traditional conclusion that a precise productivity standard is beyond expectation; rather, it would relate various uses of productivity standards to different levels of productivity measures, and in some cases, productivity indicators. Thus, some of the major problems in measuring productivity have been identified, potential uses of productivity adjustments in the railroad industry are examined, and the conclusion is reached that the proper measure of productivity largely depends on the use of the adopted standard.

DEFINITIONS AND MEASUREMENT CONCEPTS

Although the term "productivity" may be an often misunderstood term, its definition is clear in economics literature. Simply put, productivity is the relationship between input factors (labor, capital, and other expense items) and output (goods or services or both). When this relationship is measured over time, and later relationships are higher than earlier relationships, productivity is believed to have increased. A literature search has revealed three basic types of productivity measures as follows:

1. Single-factor productivity: The measure of output related to a single measure of input (e.g., output to labor or output to capital). A popular measure of single-factor productivity in the railroad industry is ton-miles to hours of labor.
2. Total-factor productivity: The measure of output related to the two major input factors--labor and capital. Thus, the substitution of, say, automation for manpower is accounted for in this measurement.
3. Total productivity: The measure of output to all input variables, including the so-called "intermediate purchases," such as materials and supplies.

No matter which of the productivity measurements is used, it is emphasized that all of these factors (labor, capital, and intermediate purchases) affect productivity. Thus, even a single-factor measure, such as ton-miles per labor hour, does not alone really measure labor productivity because a change in the output (ton-miles) may have been caused by changes in capital and intermediate inputs.

PROBLEMS OF MEASURING RAILROAD PRODUCTIVITY

Although there are a host of problems associated with the measurement of productivity (including the assignment of weights to the inputs and the measurement of intermediate purchases), this paper focuses on primary issues associated with the labor and capital inputs, and the seemingly ubiquitous output measure of ton-miles.

Input Factors

Labor

For years analysts have divided ton-mile output by labor input to measure railroad productivity. This method has obvious flaws (all productivity gains cannot be assumed to be caused by labor only) and has been highly criticized, but rarely on the basis of the quality of the labor input measure.

Indexes of labor productivity and compensation per hour, unit labor costs, and related measures for broad economic sectors are published by the Bureau of Labor Statistics (BLS). These measures, which show changes in the relationship between output and employment or employee hours, provide information about productivity, prices, wages, employment, and economic growth. These indexes are prepared for the following sectors of the U.S. economy:

1. Quarterly and annual measures:
   a. Business sector,
   b. Nonfinancial corporations,
   c. Nonfarm business sector, and
   d. Manufacturing (total, durable, and nondurable);
2. Annual measures:
   a. Agriculture;
   b. Mining;
   c. Transportation;
   d. Communications;
   e. Utilities;
   f. Wholesale and retail trade;
   g. Finance, insurance, and real estate; and
   h. Government enterprises.

The BLS has also developed a multifactor productivity program that measures output per unit of labor and capital input. However, only data for the private nonfarm business and manufacturing sectors are available at this time--nothing yet for total transportation or for railroads. Therefore, the only available BLS "productivity" data applicable to railroads are those indexes that show input only. As will be discussed later, the BLS has a railroad capital stock measure, but it has not yet been integrated into a productivity index.

The BLS annual labor publication *Productivity Measures for Selected Industries* provides a prime example of productivity data that actually measure only output per unit of labor input. Because of the sharp decline in railroad employment, especially over the past 5 years, the output gains reflected by the BLS indexes are undoubtedly overblown as productivity indicators. For example, the BLS index for railroad transportation, as shown in Table 1, produces productivity gains from 1977 to 1983, ranging from 30.3 percent for output per employee (all workers) to 40.7 percent for output per employee hour (production workers). It is patently obvious to those familiar with the railroad industry that employees did not work 30 to 40 percent harder, or faster, in 1983 than they did in 1977; simply stated, innovation and capital investment produced productivity gains that BLS attributes to rail labor.

TABLE 1 BLS Railroad Productivity Measures

	Output per Employee Hour (%)		Output per Employee (%)	
Year	All Workers	Production Workers	All Workers	Production Workers
1977	100.0	100.0	100.0	100.0
1978	104.5	104.7	104.5	104.6
1979	104.7	104.8	105.4	105.5
1980	107.3	108.4	105.5	106.2
1981	111.7	113.5	109.0	110.1
1982	115.9	119.4	110.2	112.6
1983	136.6	140.7	130.3	133.2

Aside from the serious deficiency related to the use of labor only, another problem associated with its use as a single input factor is the selection of the proper divisor. For example, is the number of employees or man hours the more appropriate measure? If the latter were to be used, would man hours worked or man hours paid for be the better choice? In the railroad industry, merely identifying "freight service employees" is no simple task--some employee classifications straddle both freight and passenger operations. In fact, this problem is so pervasive that statisticians frequently calculate the employment (or man-hour) base on the basis of the ratio of freight operating expenses to total operating expenses. Although this concept may provide a simple estimate of productivity, it obviously falls far short of depicting precise productivity measures--and the same can be said of all productivity measures that use railroad labor as an input component. This fact has been recognized in a number of studies by pundits in the field of transportation economic research. For example, a 1973 study on railroad productivity by a federal task force (1) found serious deficiencies in the use of labor as the input segment of a single-factor productivity equation. The study cited these three basic flaws:

1. Rail labor inputs have declined more rapidly than capital inputs,
2. The railroad industry has increasingly employed relatively more outside labor services, and
3. Man hours understate the growth of inputs needed to produce output and to maintain the rail plant at given standards.

Capital

Obtaining a true measure of a capital input and translating that into a unit of capital service is a similar and equally perplexing problem. A fixed capital input should be a measure of the quantity of capital services utilized in providing transportation services. The quantities of each type of fixed capital should then be weighted by the implicit cost per unit of capital services. However, it is quite difficult to do this: capital is generally owned by the company using it and imputations are necessary to calculate the value of the input of capital services and the implicit unit costs (rental values) of these services in the absence of market transactions. In concept, capital services are the machine hours or service hours provided by various types of equipment and structures. In practice, it is difficult, if not impossible, to obtain detailed measures of equipment hours. (Instead, it is usually assumed that the flow of capital services over time is more or less proportionate to the stock of capital held.)

A measure of the stock of capital should reflect the reductions in the flow of services due to increasing down time for repairs and maintenance, as well as the decline in efficiency due to the wear and tear of prolonged use. These estimates of capital stock should be consistent for a long period of time, measurable (obtainable), and detailed enough to provide an informative picture for a particular industry.

The most ideal data for estimating a constant-dollar capital stock input would be gross value of investment for land, structures, and equipment by year purchased, along with estimates of the average lives and the age distribution of the assets. (Data on age distribution are necessary to help determine the efficiency loss that occurs as equipment ages.)

The estimation of railroad capital inputs is a more complex problem. Difficulties arise because the capital inputs of land, structures, and equipment are diverse (they tend to have long lives) and because much of the investment is made over a period of years. This makes it harder to obtain an accurate valuation for a base year.

Reports on capital inputs for railroads contain only the total gross book value with no distribution of assets by age grouping. A dollar value for land owned by railroads is also difficult to achieve because its value depends more on its location than on its time of acquisition.

BLS and the Department of Commerce provide similar series of capital stock measures by using what they consider to be reliable data for total investment in road and equipment of Class I and Class II railroads. These series were broken down into plant and equipment shares according to the relative shares of annual expenditures for additions and betterments to road and equipment and property. The primary source of the data was the ICC, specifically, Transport Statistics and Statistics of Railways in the United States; other data came from the American Railway Car Institute. Because of data limitations, it was possible to include only the equipment portion of leased property.

These measures do not explicitly take changes in technology into account. Changes in the productive capability of assets are reflected only to the extent that they are reflected in the real cost of the assets. More important, these are capital stock measures, not productivity measures, and they are estimates, not actual data. Nonetheless, the BLS and Bureau of Economic Analysis (BEA) measures complete the first step in the quest to find out how much a unit of capital contributes to a unit of output.

But after surrogate capital stock estimates are obtained, these data then need to be transformed into estimates of capital services to make them useful in creating a capital productivity and total productivity index. Otherwise, the dreaded "output per unit of capital expenditure" is obtained, and not true capital productivity. BLS and other organizations are still in the early research stages of the measurement of capital productivity.

Output: The Ton-Mile Problem

Determining the appropriate output measure or measures is a major problem that has generally been overlooked in the railroad industry. This is because the overwhelming number of cases focusing on productivity adopt the ton-mile as the single-factor output of railroad freight productivity. The attributes of the ton-mile measure are that it is readily available as a statistical measure (railroads report it to the ICC), it appears to be a homogeneous standard among carriers, and it represents the two major elements of ratemaking--weight and distance. However, in terms of productivity, the issue regarding the ton-mile factor is, Do railroads produce solely ton-miles? The answer, of course, is a resounding no.

Railroads, and thus railroad labor and capital, provide a capacity for transportation that includes the right-of-way (track, tunnels, bridges, etc.), locomotive power, hauling capacity (cars), and related facilities (repair shops, terminals, transloading equipment, etc.). Thus, some railroad employees produce outputs that may be best described as measures--among others, number of cars handled, train miles, couplers repaired, and tons of rail laid. In a 1973 study of railroad productivity, Paul H. Banner of the Southern Railway System adopted four measures of railroad productivity, with the following weights (2):

Output Measure	Weight (%)
Car loads	38.6
Car miles	31.2
Train miles	18.1
Overhead	12.1

Banner concluded that over the period of time he studied, when the preceding output measures are used instead of ton-miles, a far different productivity result is produced.

Aside from the problem that ton-miles is not necessarily the proper measure of railroad output, the ton-mile suffers from two other major deficiencies. First, it can be affected by changes other than fluctuations in productivity. For instance, if a railroad gains coal traffic at the expense of losing some business of a much lighter (but possibly more profitable) commodity, can productivity be said to have increased simply because ton-miles accelerate? After all, the shift in traffic consist requires no additional labor or capital input. Thus, in using ton-miles as the railroad output, shifts in traffic must be excluded from the measurement if productivity changes are to be estimated with some degree of accuracy; this task is no simple endeavor. For example, between 1972 and 1982 railroad ton-miles per employee increased by 45 percent, whereas total tonnage declined by 12.4 percent. Rhetorically speaking, is the increase in ton-miles per employee largely due to a shift toward coal traffic (up to 40 percent during this period), an increase in labor productivity, an increase in capital productivity, a combination of factors, and so forth? Shifts in the proportional tonnages of commodities carried over various distances, whether of the magnitude of the 10-year gain in coal traffic or a less dramatic shift, result in changes in both unit costs and input-output ratios. When shifts to heavier products occur, the railroads generate more output per unit of input, but this is not because of an increase in productivity.

Second, the ton-mile measure is not always a homogeneous standard because one ton-mile can be far different than another; in fact, the rates for shorter distances are generally higher on a unit basis than those for longer distances, and this is why commodities have different ratings even though they may have the same densities. Thus, although the ton-mile measure provides knowledge as to overall railroad output, it is extremely limited in its use as part of the productivity equation.

PROPOSED USES OF RAILROAD PRODUCTIVITY MEASURES

Given than no single acceptable measure of railroad productivity exists, or is likely to be developed, the issue of measuring productivity is best examined within the context of proposed uses. After all, the required level of precision for any standard depends largely on its proposed application. Listed in the following sections are a number of potential uses of railroad productivity measures and a brief discussion of the need for precision.

Investment Criteria

Part of many investment decisions is the degree to which productivity is increased and cost savings ensue. In this case, rather simplistic measures of productivity can be adopted because the input variable is often limited to a single capital asset (e.g., a locomotive, freight car, or repair facility). For example, the productivity of a single freight car may be measured by its added weight, longer life, or greater use. Such productivity indicators (not measurements) as ton-mile per freight car mile or per freight car hour may be legitimate factors in the investment decision. Of course, in some other instances, both labor and capital are involved and the needed productivity indicator becomes more complex.

General Indicators

Both Congress and the ICC tend to treat the railroad industry differently if the industry is thought to be unproductive (inefficient) as opposed to productive. The National Transportation Policy, established as the preamble to the Transportation Act of 1940, and the more recent Staggers Rail Act of 1980 focus on the public policy need to encourage "honest and efficient" railroads; in essence, shippers are best served when railroad inefficiency is minimized. Consequently, under regulation railroad mergers are more likely where efficiencies exist, railroad rate increases are less likely where inefficiencies exist, and railroad abandonments are more likely where lines are of light density and unprofitable (unproductive).

A number of productivity indicators may be used for the foregoing purposes without acceptance of any single productivity measure. For instance, by using the simplistic data presented in Table 2, it can be generally concluded that the railroad industry has become increasingly more productive over the past 10 years. An increasing number of ton-miles have been produced in the face of declining employment, less miles of route, and relatively less equipment. Although the indicators in Table 2 are far from productivity measures, when used in concert with other indicators, they form a picture of greater productivity, but at an undefinable level of precision. Still, they are useful for examining general public policy and regulatory perspective.

Wage Adjustments

Another area in which so-called productivity gains are used is in support of demands for increased wages and wage supplements. Although labor should certainly benefit from true productivity gains, along with management, investors, shippers, and the general public, there is no justification for basing wage and fringe benefit increases on imprecise output data that are merely masquerading as productivity measures. As long ago as 1962 the President's Council of Economic Advisors addressed some aspects of productivity in a study entitled Guideposts for Noninflationary Wage and Price Behavior. As stated by Burton N. Behling, an economist with the Association of American Railroads, in January 1964:

> Productivity is a guide rather than a rule for appraising wage and price behavior for several reasons. First, there are a number of problems involved in measuring productivity change, and a number of alternative measures are available. Second, there is nothing immutable in fact or in justice about the distribution of the total product between labor and non-labor incomes. Third, the pattern of wages and prices among industries is and should be responsive to forces other than changes in productivity.

Economic theory supports the notion that labor is generally entitled to wage increases where it increases its marginal productivity rate, but to use an imprecise measure as the standard for wage increases can only accelerate a major problem associated with railroad costs, that is, that in 1984, the average railroad employee earned about $43,000 annually ($34,000 in wages and $9,000 in fringe benefits), whereas the industry's chief competitor, the trucking industry, paid its employees an average wage of $26,000. Obviously, historic railroad wage increases based on ill-defined productivity in-

TABLE 2 Single-Factor Productivity Indicators in Freight Service

	Freight Revenue Ton-Miles per							
Year	Employee[a] (000,000s)	Employee Hour	Avg Route Miles Operated in Freight Service (000,000s)	Active Locomotive (000,000s)	Serviceable Freight Car (000s)	Freight Car Mile (000s)	Freight Train Mile (000s)	Freight Train Hour (000s)
1967	1.4	579	3.4	42.1	457	24.3	1.7	34.9
1968	1.4	590	3.5	43.2	490	24.7	1.7	35.4
1969	1.5	611	3.6	44.6	512	25.3	1.8	35.7
1970	1.5	616	3.7	44.1	511	25.6	1.8	36.1
1971	1.5	605	3.6	41.9	494	25.3	1.7	35.2
1972	1.5	637	3.7	42.0	527	25.6	1.7	34.4
1973	1.7	696	4.1	44.6	575	27.2	1.8	35.4
1974	1.7	695	4.1	43.5	581	27.7	1.8	36.0
1975	1.6	676	3.7	40.4	533	27.3	1.9	37.5
1976	1.7	712	4.1	42.3	577	27.8	1.9	37.7
1977	1.8	738	4.2	43.3	609	28.7	1.9	38.3
1978	1.9	777	4.5	44.6	640	29.5	2.0	38.5
1979	2.0	792	5.0	N.A.	N.A.	31.0	2.1	35.8
1980	2.1	862	5.1	N.A.	N.A.	31.4	2.1	39.0
1981	2.2	906	5.1	N.A.	N.A.	32.5	2.2	42.5
1982	2.2	927	4.6	N.A.	N.A.	33.3	2.3	49.5
1983	2.6	1,073	4.9	N.A.	N.A.	34.0	2.4	48.6

Note: Data are based on the consist of Class I railroads for each respective year, excluding the National Rail Passenger Corporation (Amtrak) and the Long Island Railroad, from various reports of Class I railroads to the ICC.

[a] Freight service employment estimated based on proportion of freight to total operating expenses.

creases have been detrimental to the industry and are inappropriate for future adjustments.

GENERAL RATE INCREASES

In the era before the Staggers Rail Act, the only recourse available to the railroad industry for recovering cost increases was lengthy and costly general rate increase proceedings. As part of the testimony submitted in each proceeding, the railroads were required to develop statistics pertaining to productivity and unit labor costs. In a separate schedule (Schedule G), the railroads were required to calculate the ratio of revenue ton-miles to freight-service hours as a measure of productivity and the ratio of freight labor costs to revenue ton-miles as a measure of unit labor costs. The computations in Schedule G did not succeed in accurately portraying productivity trends in the railroad industry. On the contrary, the computations were an open invitation to confusion and misinterpretation, for two primary reasons. First, the time span covered by the data required by Schedule G was far too brief to reveal meaningful productivity changes. The computations only permitted comparisons of revenue ton-miles per freight service hour in the pro forma year with the base year and in the base year with the previous year. Because the railroad industry is particularly prone to severe year-to-year fluctuations in traffic and employment levels evolving from aberrations in the activities of industries that account for large portions of rail traffic, short-term productivity gains just do not mean much.

Second, as has been said repeatedly, ton-mile output based on a single-factor labor input is not a meaningful productivity indicator. Misinterpretation of the Schedule G data, which was usually self-serving, came in the form of allegations that cost justifications presented by the railroads did not take into account productivity gains that had allegedly reduced the amount of labor and other inputs employed by the railroads. Other protestants argued that the railroads should be required to improve their profits only through productivity gains, not rate increases. Also, in connection with general rate proceedings, the Council of Wage and Price Stability (COWPS) included an analysis of the Schedule G data in its deliberations on the validity of railroad rate increase proposals.

AMERICAN ASSOCIATION OF RAILROADS (AAR) COST INDEX

Section 203 of the Staggers Rail Act of 1980 brought an end to the lengthy general rate proceedings by creating a statutory mechanism to enable railroads to adjust their rates to keep pace with the effects of inflation on railroad costs and to do so without extended regulatory delay. The ICC implemented this statutory mandate in Ex Parte No. 290 (Sub No. 2) by adopting the AAR index as the method of measuring the effects of inflation on railroad costs. It decided at that time not to require a so-called "productivity adjustment" to the changes in costs determined through use of the index. The commission's decision was sustained by the Court of Appeals. However, the commission is again considering whether a productivity adjustment is appropriate and, if so, how to measure productivity.

The railroads' position on this issue is that the proposed adjustment to the AAR index should again be rejected for the following reasons. In the first place, no accurate, reliable index of current changes in rail productivity exists for such a precise adjustment. But even if an accurate index did exist, a productivity adjustment to the AAR cost index would be inappropriate because to the extent that productivity gains are realized by the railroad industry, they are, to a significant extent, already passed on to consumers by competitive pricing in the marketplace. This issue is still in limbo. The commission issued a Notice for Proposed Rulemaking (NPR) on September 27, 1985, asking for comments with replies due in March 1986.

CONCLUSIONS

There are three major conclusions that have ensued from the research undertaken in support of this presentation. First, it is not overwhelmingly important to develop a single, comprehensive method defining or measuring railroad productivity. This is because such a measurement cannot be expected to be universally accepted; it has limited application, and its nonexistence should not undermine the goal of increasing productivity. In essence, there are enough indicators of railroad productivity available to serve as support for capital investment and other managerial decisions so that a single overall measure (given all its definitional problems and related foibles) is not required. Second, productivity measures should not be used to adjust such sensitive areas as wage rates and the rail cost adjustment factor. In the case of wage rates, the lack of an adequate productivity measure coupled with the economic fact that competition is the best standard for determining labor wages make a productivity adjustment inappropriate. In the case of the rail cost adjustment factor, a productivity adjustment is akin to double-accounting in that productivity increases are already passed on to consumers in the form of lower rates in the competitive market. And finally, various measures of productivity can be adopted, depending on the ensuing application. For instance, for a simple analysis of railroad productivity in general, ton-miles, tons, carloads, and so on, related to a host of input variables can be used to show that over the recent past, railroads have produced more output with less labor, track, fuel, fixed facilities, and other input factors.

The task at hand is not to define and measure productivity but rather to shatter the institutional barriers that limit its realization. Much has already been accomplished with the passage of the Staggers Rail Act of 1980, and railroad management has moved forward to exercise its newly found market freedom. Now railroad labor must join forces with management and eliminate antiquated work rules and related procedures. As within the U.S. economy, the viability of the railroad industry is largely dependent on increasing productivity in a highly competitive marketplace.

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Impacts of Regulatory Policy on Rail Productivity

ROBERT G. RHODES

ABSTRACT

The effects of regulation on railroad productivity are discussed, in particular the changes brought about by the Staggers Rail Act of 1980. However, the Staggers Act by itself will not improve productivity; it provides opportunities for improvement, but ways are needed to assess productivity from both an operating and a marketing standpoint in order to manage the opportunities better. Shippers are carefully reviewing their logistics and transportation functions in order to improve productivity, and something of a revolution is occurring in the management of this area.

This conference on the state of productivity in the railroad industry rightly focuses on innovations in technology and operations. Yet, the regulatory and economic environment in which railroads function has substantial influence on productivity improvements.

A good place to begin is with an appropriate definition of productivity as applied to the railroad industry. In its ordinary sense, the acid test of productivity in business is profits. Thus, high productivity usually means high profits; low productivity is a loser for railroads as well as other businesses. Levine, in another paper in this Record, properly presents the standard measures of productivity, that is, single factor, total factor, and total productivity. He then stresses the difficulties encountered in measuring productivity and concludes that the issue is not how to define or measure productivity but how to overcome institutional barriers that inhibit productivity improvement.

REFORMS OF STAGGERS RAIL ACT OF 1980

If Levine is correct in his implication that institutional barriers have inhibited productivity improvements, the Staggers Rail Act of 1980 should have resulted in substantial gains for the railroads. By that act, Congress moved far in the direction of removing the highest institutional barrier and one long complained of by the industry. Today, railroads virtually have a free hand in setting rates insofar as regulation is concerned.

On the low side the Interstate Commerce Commission (ICC) can interpose its control only if a railroad rate fails to contribute to "going-concern value." For minimum rate control, the ICC has defined a "presumptive cost floor" to include only line-haul costs of lading, applicable switching costs and station clerical expense, and other costs that can be shown to vary directly with the provision of service. This level of costs is strictly short run in character and quite low. According to most cost experts, they may approximate a mere 40 percent of ICC's Rail Form A variable costs.

On the high side, a rate is subject to ICC control only if it clears a threshold revenue-to-variable-cost (R/VC) ratio now set at its statutory maximum of 180 percent and if the railroad or railroads can be shown to have market dominance in the movement of the traffic at issue. Even when a rate passes these tests and becomes subject to ICC jurisdiction, the commission in determining maximum rate reasonableness has to consider the act's policy that railroads should earn adequate revenues. To date, the commission's idea of revenue adequacy has been quite liberal. Each year the ICC makes a finding of the current cost of railroad capital, which is used as a measure of the return on investment required for revenue adequacy. The most recent composite after-tax railroad cost of capital found by the commission was 15.3 percent for 1983 (Ex Parte No. 452, Railroad Cost of Capital--1983, served October 31, 1984). This cost of capital may be translated into a revenue adequacy level R/VC ratio based on 1983 Rail Form A costs. The ratio for all Class I railroads combined is 165 percent. Thus, railroads as a whole must obtain average revenues about 65 percent higher than variable costs to achieve revenue adequacy. No railroad was found to be revenue adequate in 1983.

The Staggers Act also seeks to balance the needs of the railroads for adequate revenues with protection for captive shippers against payment of an unreasonable share of railroad revenues. Under the so-called Long-Cannon and management provisions of the act, the commission in determining whether a rate is reasonable must consider evidence concerning (a) traffic carried below going-concern value and the railroads' efforts to minimize such traffic; (b) traffic contributing only marginally to fixed costs and the extent to which such rates could be adjusted upward to maximize revenues from such traffic; and (c) the railroads' mix of traffic and whether one commodity contributes an unreasonable share of the overall revenues. These pricing efficiency criteria thus far have had little impact on the commission's rate decisions. The ICC has yet to rule in favor of a shipper in a rate complaint case under the Staggers Act. The perception of many captive shippers, especially coal shippers, is that the commission has placed too much emphasis on railroad revenue needs. They have complained to Congress that railroads are taking advantage of their captive situation and charging excessive rates. They believe that the ICC has not enforced the shipper protections afforded by the Staggers Act and have turned in frustration to Congress for legislative redress.

In addition to such significant relief in setting rates from former regulatory restraints, railroad contract rates have been legalized. Huge volumes of rail traffic now move under contract rates. The level of these rates is held confidential. Also, the process of adjusting rates upward to compensate for inflationary cost increases in wages, fuel, and materials has been greatly simplified and has done away with the former costly general revenue increase procedures where revenue relief unavoidably lagged well behind rising costs. An additional measure of rate flexibility is provided by the joint rate provisions of the act. The former requirements for concurrences of participating railroads on interline rate adjustments and agreements for new divisions can be circumvented under appropriate conditions to enable railroads to avoid transporting traffic below cost.

These and other rate reforms provided by the Staggers Act have undoubtedly provided measurable relief from what was once called "regulatory strangulation." According to Levine's hypothesis, railroad productivity should have been on the rise since 1980 when the major institutional barrier nearly disappeared.

RESULTS OF REGULATORY REFORM

On the surface at least, the financial picture for the railroad industry has improved. Freight revenue carloadings in 1984 increased 10.6 percent over 1983 and approached the 1980 record of 919 billion. Trailer and container traffic in 1984 exceeded the record set in 1983 by 11.7 percent. Bottom-line profits were also up in 1984. As of the end of the third quarter of 1984, net income for nearly all of the major railroads was greatly improved over the comparable period in 1983. Some of the larger systems have reported record earnings for the entire year.

It is generally conceded that compared with 15 years ago, railroads are producing more ton-miles of traffic with heavier and longer trains, fewer employees, a smaller network, fewer locomotives (with greater power), and fewer (but larger) cars and greater fuel efficiency.

The joy in these reported gains has to be tempered, however, with reality. The vigorous economic growth in 1983 (3.7 percent) and 1984 (6.7 percent) has begun to slow down and the economy is expected to grow at a much slower rate in 1985 and 1986. The effects of reduced economic growth rates have already been reflected in traffic reports. Through 15 weeks of 1985, rail carloadings were down 5.9 percent, trailers and containers down 4.4 percent (14 weeks), and ton-miles down 4.8 percent (14 weeks). What these data indicate is that the traffic recovery in the last 2 years was probably driven to a large extent by economic recovery. If the rail industry is going to hold or raise these traffic and profit levels, it will have to focus on productivity improvements.

The Staggers Act itself will not improve productivity. However, its rate reforms provide a flexible means of transforming productivity gains, if they are achieved, into profitable traffic. Although these reforms were intended to enable railroads to become more competitive, to date, railroad traffic in terms of ton-miles is barely holding its own, whereas truck traffic rose 8.5 percent in 1984 over 1980.

EMPHASIS ON COMPETITION

The passage of the Staggers Act and the Motor Carrier Act in 1980 has erased any doubt that the hallmark of federal policy has become reliance on the forces of competition to achieve adequate and efficient transport services in the United States. This increased emphasis on competition, particularly during the downturn in the economy and the subsequent rise, has activated a growing interest among carriers and shippers in their analysis of rate and cost information. As is well known, motor carriers, faced with almost open entry from new or established intramodal competitors and railroad expansion of piggyback and container service, developed hundreds of rate and service concepts offering discounted rates. Many of these have been designed to take advantage of improved productivity inherent in balanced movements. Railroad marketing departments, too, have reached out to the market with engineered rate and service combinations, especially in contract rates, to attract sustained and profitable loadings. The incidence of large mergers, such as the Union Pacific--Missouri Pacific, the Norfolk Southern, the Burlington Lines, the pending Santa Fe--Southern Pacific, and the possible Norfolk Southern purchase of the Consolidated Rail Passenger Company (Conrail), offers, or could offer, opportunities for shipper-preferred single-line transport.

OPPORTUNITIES TO IMPROVE PROFITABILITY

One could reasonably assume that railroads would seek to maximize their net revenue contributions in their pricing actions. Whatever their objectives in pricing, there is some indication that more could be achieved in this area. During the last few years, A.T. Kearney, Inc., has costed out thousands of individual carload movements from the ICC's Rail Carload Waybill Sample for a number of railroads. [Adjusted Rail Form A costs for each carrier involved in the movements were used. The Uniform Rail Costing System (URCS) has not been adopted by the ICC, and the Railroad Accounting Principles Board, provided for in the Staggers Act, has been funded to establish principles governing cost determinations. The ICC recognizes the Carload Waybill Sample, enhanced with ALK Associates mileages, as the best source of information on railroad traffic flow and characteristics.] Several observations from the results of these studies suggest that there is probably much room for optimizing rates on substantial volumes of traffic.

The following summary for one railroad of an array of the 1982 movements by R/VC ratios is fairly typical of study results of this kind:

R/VC Ratio	Carloads (%)	Cumulative (%)
180 and over	30.1	100.0
150 to 180	12.8	69.8
100 to 150	22.6	57.0
50 to 100	26.9	34.4
Below 50	7.5	7.5

From this summary it will be seen that over a third of the carloads failed to recover their variable costs and 7.5 percent even failed to meet 50 percent of variable costs. Only 43 percent of the traffic met an R/VC ratio of 150 percent, which is below the revenue adequacy level.

Many in the railroad industry would argue that railroads carry little or no traffic that does not contribute to going-concern value. They might well argue that Rail Form A is an inappropriate means of estimating costs for determining rates in a market situation and even dispute the particular adjustments to costs used in these studies. This discussion should not be construed as advocating ratemaking based solely on Rail Form A R/VC ratios. Marketing managers should not rigidly adhere to Rail Form A costs in pricing, because both actual costs and demand characteristics have to be considered. On the other hand, this somewhat typical distribution of R/VC ratios indicates rather clearly that a fairly substantial volume of nonprofitable traffic, as measured by a commonly accepted benchmark, may exist. It appears that identification of nonprofitable traffic, whether by this method or another, forms a beginning of opportunities to improve profitability. Even taking into account short-term pricing actions designed to take advantage of temporal unused capacity and differences of opinion over costing methods, it is hard to understand the large amount of traffic moving below variable costs. Undue reliance on short-term pricing concepts simply to garner traffic and failure to structure rates so as to recover capacity costs in the long run can lead to disinvestment when assets wear out and replacement is not economically justified. Differential pricing in response to demand elasticities is clearly justified in the railroad industry in view of its capital-intensive nature and the presence of substantial common and joint costs. It is reasonable, however, to question whether long-run viability can be achieved by building a revenue base on traffic that contributes only marginally to going-concern value.

Taking a closer look at these data, 82 percent of the carloads having an R/VC ratio of 180 or better were movements of coal. The average R/VC ratio for coal on this railroad was about 180 percent. Coal is one of the few commodities where the railroads may exercise market dominance, at least in some instances, and it is to be expected that the net contribution to revenues would tend to be relatively high for this traffic. Coal also represents for many railroads a substantial revenue base because of the huge volumes transported and therefore increases the importance of recognizing capacity costs in rates. The relatively high net contribution to revenues provides a usable cushion to sustain differentially lower pricing where competition is more severe. However, for the longer pull, pricing of competitive traffic should strive to generate at least some net contribution to revenue beyond short-term considerations.

Such does not appear to be the case for some movements. Piggyback and container traffic has become important to railroads, rising to 13 percent of carloadings in 1984 compared with about 6 percent in 1976. Yet studies indicate that such traffic may contribute little or no net revenue. For the railroad in the foregoing example, the average R/VC ratio for Miscellaneous Mixed Shipments [most if not all of which are trailer-on-flatcar (TOFC) and container-on-flatcar (COFC) shipments] was only 75 percent. Data developed for other railroads show similar low R/VC ratios. Although this segment of traffic has expanded rapidly and has been supported with new capital investments, the pricing policy does not appear to reflect longer-run considerations, including recoupment of investment or replacement of capital assets.

A third indication from these studies also suggests that more detailed study of individual movements could lead to higher net contributions to revenues. For example, a wide range of R/VC ratios has been found for the same commodity between railroads as well as for the same railroad. For example, the railroad in this example, despite the high overall net contributions to revenue for coal, nevertheless transported a substantial volume of coal with an average R/VC ratio of less than 60 percent. Identification and study of nonprofitable movements within otherwise profitable traffic groupings obviously presents opportunities for rate or service changes made possible under the Staggers Act philosophy of rate freedom. Of course, many railroads are in the process of doing this and some have accomplished much more than others. Intensification of this process, however, remains a major opportunity.

For the most part, railroad patrons are the larger industrial companies in the economy. There is a strong indication from recent studies that these shippers are carefully reviewing their logistics and transportation functions as a source for improving productivity. Technological innovation in industrial activity, of course, continues to receive much attention. For example, reports of high-technology applications stimulated by miniaturization of the silicon chip are familiar. But something approaching a revolution in logistics and transportation management is occurring.

In 1979 the National Council of Physical Distribution Management (NCPDM) released a study performed by A.T. Kearney, Inc., entitled Measuring Productivity in Physical Distribution: The $40 Billion Goldmine (1). The intent of this study was to identify the means by which companies measure productivity in logistics and find ways to improve it. At that time, only 15 percent of the companies surveyed were judged to have begun meaningful productivity measurement in distribution. The study, however, did find that opportunities existed to improve physical distribution productivity by at least 10 percent nationwide (hence the gold mine) and that some aggressive companies had found ways to save up to 35 percent of distribution costs.

In 1983 this study was updated and entitled Logistics Productivity--The Successful Companies. By this time, 42 percent of the surveyed companies had begun meaningful measurement programs. This represents a tremendous gain in 5 years. These companies think of logistics in terms of warehousing, inventory carrying, and financial and administrative impact, but the largest component is transportation. A.T. Kearney has estimated that transportation represents almost 50 percent of all logistics costs.

This clear evolution in the level of sophistication in the shipping community did not result purely from a sudden or dramatic realization that transportation and other logistics costs are a major cost of doing business. Rapidly escalating rates alerted senior management to the cost and service implications related to logistics. Out of this came implementation of new organizations to inform themselves and to manage transportation and distribution processes. Deregulation, which placed emphasis on market forces and provided rate freedoms for railroads, also provided shippers the freedom to manage transportation in much the same manner as the rest of their business. The traffic function has become the responsibility of the distribution or logistics manager, who has the responsibility for the total distribution system cost and service.

Many large shippers now understand their transportation options better than ever before. In fact some companies have developed integrated logistics and transportation planning processes that allow for systematic identification and trade-off of marketing, production, and logistics activities and costs to support a total business strategy in the most effective way.

The shipping community has not remained satisfied with its progress to date. Reduced computer costs, software, and more convenient input and output devices have given shippers access to many improved and sophisticated tools for their transportation cost and service decision making. Large shippers can position themselves to know almost as much about rail costs and more about the costs of the competitive modes and alternatives than perhaps the carriers themselves know.

Clearly then, just as relaxation of regulatory restraints on transportation pricing has opened opportunities for railroads to compete more freely for traffic, their patrons have been stimulated to become increasingly more knowledgeable buyers of service.

To summarize, pricing freedom does not guarantee success; it provides an opportunity but success will depend on productivity improvements that will enable railroads to compete effectively and profitably for traffic. On balance, railroads appear to be as well off or better than they were before the Staggers Act, but there has been no improvement and some decline in market share. Based on ICC standards, they remain revenue inadequate. Sufficient data exist to show that railroads may be transporting a fairly substantial volume of traffic that does not contribute adequately to net revenues. Thus, although, as Levine points out, productivity measures are elusive, practical and consistent ways are needed to assess productivity from both an operating and marketing standpoint and specifically whether individual segments or even movements contribute to a railroad's financial success. In developing such tests, the industry should reconcile itself to the need for adapting to a more knowledgeable shipping community that has, through its own productivity measurement, identified its transportation requirements and options and is doing more and more management of its opportunities.

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The Effects of Railroad Mergers on Industry Productivity and Performance

CURTIS M. GRIMM and ROBERT G. HARRIS

ABSTRACT

In recent years a merger wave has swept the rail freight industry. An attempt to measure the effects of recent mergers on railroad productivity and performance is described. Specifically, financial performance [return on investment (ROI) and return on equity (ROE)], capacity, operating characteristics, and operating costs are compared for 1978 and 1983. Mergers appear to have produced some benefits, particularly in improved financial performance and reduced operating costs.

After several decades of poor financial performance, bankruptcies of numerous carriers, rapidly rising public subsidies, and a continuing decline of its market share, the U.S. rail freight industry is now emerging from a process of fundamental change in industry structure and public policy. Federal rail policy has moved steadily toward easing rail regulatory burdens and allowing market forces to operate in the industry.

In conjunction with and in response to these changes, a merger wave is sweeping the industry. Since the restructuring of the northeastern railroads into the Consolidated Rail Corporation (Conrail), five mergers of Class I carriers have been approved by the Interstate Commerce Commission (ICC):

1. 1979: Grand Trunk Western--Detroit Toledo and Ironton (GTW:DTI),
2. 1980: Burlington Northern--St. Louis-San Francisco Railroad (BN:SLSF),
3. 1980: CSX Corporation--Chessie System and Seaboard Coast Line (BOCO:SCL),
4. 1982: Union Pacific--Missouri Pacific and Western Pacific (UP:MP:WP), and
5. 1982: Norfolk Southern Corporation--Norfolk and Western and Southern Railroad (NW:SOUSYS).

The merger wave continues. As of this writing, two railroads, the Soo Line and the Chicago and North Western, are vying for control of the Milwaukee Road and the ICC is conducting hearings on the proposed consolidation of Southern Pacific and Santa Fe. In addition, the U.S. Department of Transportation has recommended to Congress that Conrail be sold to the Norfolk Southern.

The merger wave was set off in part by several government reports advocating mergers, particularly end-to-end mergers, as a partial antidote to the many years of declining traffic volumes and low profitability for most railroads. Reports by the

Task Force on Railroad Productivity (1), the U.S. Department of Transportation (2), and the ICC (3) were among the promerger writings. This literature predicted that rail mergers would generate cost savings and increased productivity, thus improving the financial viability of the industry.

It is now appropriate to assess whether these optimistic projections were accurate. Moreover, with the prospect of additional rail mergers in the offing, a better understanding of the impacts of mergers on rail productivity and performance is essential for making rational policy decisions. This knowledge will aid rail managers in deciding which mergers to pursue and assist policymakers in deciding whether and which mergers ought to be allowed.

In this paper an attempt to measure and analyze the effects of recent mergers on railroad productivity and performance will be made. The methods and findings of prior rail merger studies will be reviewed first. Second, the specific methodology and data to be employed will be detailed. Finally, findings on the effects of mergers on carrier performance will be reported.

REVIEW OF PRIOR MERGER STUDIES

As discussed more fully by Grimm and Harris (4), there are three general approaches to measuring the impact of rail mergers. The first uses regression analysis of cross-section or time-series cost data, with each firm an observation, to gain insights on railroad cost structure. The main result from this voluminous literature is that substantial economies of density exist in the rail freight industry. Thus, to the extent that a merger produces higher traffic densities, all other things being equal, cost savings would be anticipated. A parallel merger may increase densities through consolidation of traffic; an end-to-end merger may do so by diverting traffic from other railroads or funneling traffic over fewer routes on the merged carriers' system.

A second approach to measuring rail merger impacts uses data from individual rail markets. For example, Harris and Winston (5) utilized service quality data in an econometric analysis of 130 major rail markets. The main results were that routings with fewer participating carriers were correlated with faster and more reliable service quality. Their work allows the inference that end-to-end mergers have the potential for significant improvements in both service quality and cost savings.

A third approach is to analyze in detail the consequences of a particular merger, either ex ante or ex post. The ICC conducts lengthy ex ante investigations of proposed mergers to determine whether they are consistent with the public interest. Testimony is received from both proponents and opponents of the merger, and witnesses are cross-examined. In all of the recent consolidation cases, the ICC has concluded that mergers would yield substantial traffic diversion and increased densities, cost savings from elimination of duplicative facilities and transaction costs, and service quality benefits.

The merging railroads also conduct ex ante investigations of the likely impacts of mergers. Assuming that railroads are profit maximizers (though other managerial motives may be important), the spate of recent merger proposals evinces managers' expectations that mergers will improve financial performance. Of course, increased profits could result from either cost savings or reduced competition, so that one cannot necessarily infer expectations of cost savings from private merger initiative.

Individual merger evaluations have also been conducted ex post or retrospectively. Many of these studies have concluded that railroad mergers have not produced significant cost savings. Robert Gallamore's 1969 Ph.D. thesis (6), the most comprehensive merger retrospective, compared premerger and postmerger costs of nine merged railroads. Gallamore concluded that mergers have fallen short of expectations for cost savings.

Gallamore's findings were supported in the more recent merger retrospective study by Sloss et al. (7). The focus of their study was an analysis of the extent to which rationalization attempts--through mergers, abandonments, and rail-highway coordination--have been successful. Sloss et al. noted that (7,p.102) "voluntary merger applications submitted to the ICC have usually been motivated by projections of substantial cost reductions to be obtained through more efficient operations." However, they found that cost improvements were not so great or widespread as projections made in ICC hearings. Furthermore, their summary evaluation of seven mergers approved between 1957 and 1967 showed three successful, two unsuccessful, and two inconclusive, according to changes in the sum of selected performance measures.

Two detailed U.S. Department of Transportation studies of specific mergers further corroborated the earlier conclusions. A 1977 study of the N&W-Wabash-Nickel Plate merger (8) showed that the system had achieved approximately one-half of originally forecast cost savings and that the savings had taken longer than anticipated to achieve. A 1979 retrospective study of the Seaboard Air Line-Atlantic Coast Line merger (9) found that only modest cost savings had been achieved 12 years after merger consummation.

These retrospective merger analyses remain useful in providing methodological guidance. However, the studies are of limited use in predicting impacts of recent mergers because of subsequent changes in ICC merger policy. Historically, the ICC denied approval for the mergers that had the most potential benefits in an attempt to protect weak carriers from more efficient carriers. Before the recent merger wave, the ICC also imposed burdensome conditions as a requirement for approval, thereby saddling merged firms with costs that could offset benefits of a merger. In addition, previous regulatory policies prevented realization of potential merger economies. For example, firms could not fully realize economies of density if prevented from abandoning excess route miles.

It is therefore not surprising that earlier mergers often failed to deliver on their promises. However, ICC merger policy in the recent merger wave has been much more permissive, with few, if any, conditions attached to merger approval. Moreover, regulatory restrictions that earlier hampered realization of merger benefits have been largely removed. It should be noted that although increasing regulatory permissiveness would enable merged carriers to realize cost savings, it might also allow them to exercise market power vis-à-vis other carriers or shippers.

Thus, a review of the merger literature yields conflicting expectations regarding the impacts of recent mergers. The cost structure literature suggests that diverting traffic and increasing densities on the merged lines should result in operating efficiencies. The government-sponsored reports also suggest that mergers should reduce costs and improve performance and productivity. On the other hand, retrospective studies are less sanguine, although this may well be an artifact of restrictive regulatory policies no longer in force. The recent wave of mergers concurrent with regulatory reform necessitates new retrospective analyses to assess the impacts of recent railroad mergers.

METHODOLOGY AND DATA

The methodology will follow that of Sloss et al. (7) whereby impacts across time are compared for merged carriers against a control group of nonmerging carriers. Sloss et al. used a different control railroad for each merger. This is no longer possible, because there are an insufficient number of large railroads not involved in mergers during the relevant period to match one with each merger of carriers. Instead the change in performance or productivity of each merged carrier is compared with the average change of all nonmerging railroads, with Conrail treated separately.

The rationale for breaking Conrail out of the control group is that, although the Conrail "merger" occurred somewhat before the mergers of greatest interest, Conrail experienced dramatic improvements in performance and productivity during the relevant time period. If, as seems likely, many of those improvements were made possible by the restructuring, including Conrail in the nonmerging control group would bias the comparison.

This analysis is intended to compare change in performance or productivity of carriers that merged and of those that did not. For several key indicators, the value for 1978 (the year before the merger wave) was compared with the value for 1983 (the most recent data available). By using carrier R-1 data as reported to the ICC, weighted ratios of each indicator were computed for each merged carrier. For example, in computing return on investment (ROI) for Carriers A and B, which later merged into Carrier AB, the weighted average ROI of the two carriers before the merger, the weighted average ROI of the carriers after the merger, and the percentage difference between the two ROIs were calculated. By comparing the direction and rate of change in those indicators with the average of all nonmerging carriers, inferences can be drawn as to whether merged carriers did better, worse, or no differently than the nonmerging carriers.

In line with the previous discussion of the expected or alleged benefits of rail mergers, four types of performance or productivity indicators were examined.

Financial Performance

In assessing the effects of mergers on profitability, ROI and return on equity (ROE) were used. It was expected that the financial performance of the merged carriers would be better than that of nonmerging carriers for three reasons:

1. If the merger produces cost savings, those should increase profit (either through improved profit margins or, if some or all of the cost savings are passed through in rates, by increased traffic);
2. If the merger produces service quality improvements, those should increase profits, either through higher rates or through increased traffic; and
3. If the merger increases the market power of the merged carrier (either with respect to shippers or connecting carriers), that would increase profitability by enabling the carrier to charge higher rates or obtain a larger share of joint revenues.

Capacity

Because numerous studies have found considerable excess capacity in the rail industry (10), relative changes in miles of road (MR) and switching track (ST) were assessed. Because horizontal mergers allow carriers to rationalize their systems, MR ought to decline through abandonments of redundant lines. Either horizontal or vertical mergers might enable carriers to reduce ST by eliminating redundant yards or by decreasing switching (e.g., by operating more run-through trains).

Operating Characteristics

Prior analysis of rail economics and previous merger studies have identified several major opportunities for achieving cost savings through operating efficiencies. An attempt to assess these claims has been made by examining the following indicators:

1. Line-haul capacity utilization as measured by car miles per mile of road (CM/MR). Horizontal mergers could increase traffic density by concentrating traffic on fewer lines as duplicate lines are abandoned. Vertical mergers could increase traffic density if improved service quality or market power results in traffic diversion to the lines of the merged carrier.
2. Length of train as measured by cars per train (C/TR). Given the well-known economies associated with train length (holding quality of service constant), a vertically merged carrier might be able to increase train length by consolidating traffic over fewer gateways or by assembling more run-through trains or both.
3. Net tons per gross ton as measured by net ton-miles per gross ton-mile (NTM/GTM). There are two main sources of improving the net-to-gross ratio: increasing cars per train (thereby reducing the ratio of locomotive tons to total tons) or reducing empty car miles (an empty 50-ton car moving 1 mi counts as 50 GTM, 0 NTM). Either horizontal or vertical mergers might achieve one or both types of operating efficiency.
4. Switching capacity utilization as measured by carloads originated or terminated per mile of switching track (CLOT/ST). Vertical mergers should improve utilization of switching capacity by reducing the number of switches per car handled, because carriers are able to use more or larger batches in train assembly.

Operating Costs

On the basis of econometric estimates of railroad cost structure and ex ante evaluations of individual mergers, mergers are expected to result in cost savings. Measures for three types of operating costs were used: maintenance-of-way and structure expense per 1,000 net ton-miles (MWS/NTM), maintenance expense per 1,000 net ton-miles (ME/NTM), and transportation expense per 1,000 net ton-miles (TE/NTM). In some cases, operating cost savings would simply reflect changes in operating characteristics (e.g., higher traffic density reduces transportation expenses). It is also possible, though, that mergers might enable carriers to use capital and labor resources more efficiently, even without changes in operating characteristics. Changes in operating costs could measure these efficiencies.

EMPIRICAL RESULTS AND IMPLICATIONS

Figures 1-11 display the changes in performance and productivity indicators for each of the five merged

TABLE 1 Summary Statistics for 1978-1983: Percentage Change in Financial Performance, Operating Costs, Operating Characteristics, and Capacity

Carrier	ROI	ROE	MR	ST	CM/MR	C/TR	NTM/GTM	CLOT/ST	MWS/NTM	ME/NTM	TE/NTM
All others	−62	−32	−12	−2	−5	1	4	−19	22	37	42
Conrail	109	–[a]	−15	−10	−19	3	2	−20	−4	−5	−6
GTW:DTI	−203	−313	−4	10	−11	13	−5	−33	22	19	40
BN:SLSF	139	109	−4	5	12	12	6	24	19	0	17
BOCO:SCL	−10	16	−4	−4	−7	8	0	−25	56	30	34
NW:SOUSYS	0	−29	2	−4	−16	19	0	12	17	9	13
UP:MP:WP	−45	−53	−4	1	−17	−2	15	−7	46	45	43

Note: ROI = return on investment; ROE = return on equity; MR = miles of road; ST = switching track; CM/MR = car miles per mile of road; C/TR = cars per train; NTM/GTM = net ton-miles per gross ton-mile; CLOT/ST = carloads originated or terminated per mile of switching track; MWS/NTM = maintenance-of-way and structure expense per 1,000 net ton-miles; ME/NTM = maintenance expense per 1,000 net ton-miles; TE/NTM = transportation expense per 1,000 net ton-miles.

[a] No data applicable.

carriers under study, Conrail, and the weighted average of all other Class I carriers. These results are also presented in Table 1.

In reviewing the differences in financial performance in Figure 1 (ROI) and Figure 2 (ROE), it is evident that the carriers involved in recent mergers are not typical of the industry as a whole. For 1977-1979, the average ROI of nonmerging carriers was 2.5 percent, whereas the ROIs of merging carriers ranged from 3.1 to 7.8 percent. There are two implications of this marked contrast.

First, whereas regulatory policy had previously prevented mergers of strong carriers with other strong carriers, recent policy has not. Historically, merger policy was intended to protect weak carriers from mergers or force the merger of weak carriers into stronger carriers. Clearly, that policy has changed; if anything, current merger policy may have the effect--if not the intent--of eliminating weak carriers.

Second, the potential benefits of mergers may be related to the strength of the merging carriers. On the one hand, mergers of weak carriers might produce significant gains from reduction of excess capacity and redundant facilities (although the Milwaukee Road, through bankruptcy reorganization, had done that before its proposed merger). On the other hand, mergers of strong carriers may generate substantial increases in market power, with lesser potential for cost savings.

In a comparison of the change in ROI from 1978 to 1983, the merged carriers did considerably better than the nonmerging carriers. Although the latter experienced a 62 percent decline in ROI, four of the five merging carriers had a lesser decline or, in the case of BN, a substantial improvement in ROI. A somewhat more mixed picture emerges from the ROE indicator, because three of the five merging carriers did better than the control group. There are pronounced differences in financial performance across carriers, with BN:SLSF significantly improving in this time span whereas GTW:DTI greatly declined. The disparity can perhaps be best explained by differences in the two firms' traffic bases. BN:SLSF is the nation's largest coal railroad and benefitted from increased demand for coal between 1978 and 1983. On the other hand, GTW:DTI, which depends heavily on automobile traffic, was greatly affected by the decline in U.S. automobile demand during this period. Overall, the evidence strongly suggests that recent consolidations have had a positive impact on financial performance.

As shown in Figure 3, changes in MR reflect the fact that the mergers involved strong carriers with less excess capacity and were, for the large part, vertical mergers. Accordingly, the nonmerging carriers have been abandoning route miles at a significantly faster rate than the merged carriers.

In the ST comparison (Figure 4), three of the merged carriers have actually increased trackage, whereas that of nonmerging carriers has declined slightly. It is possible that the vertical mergers

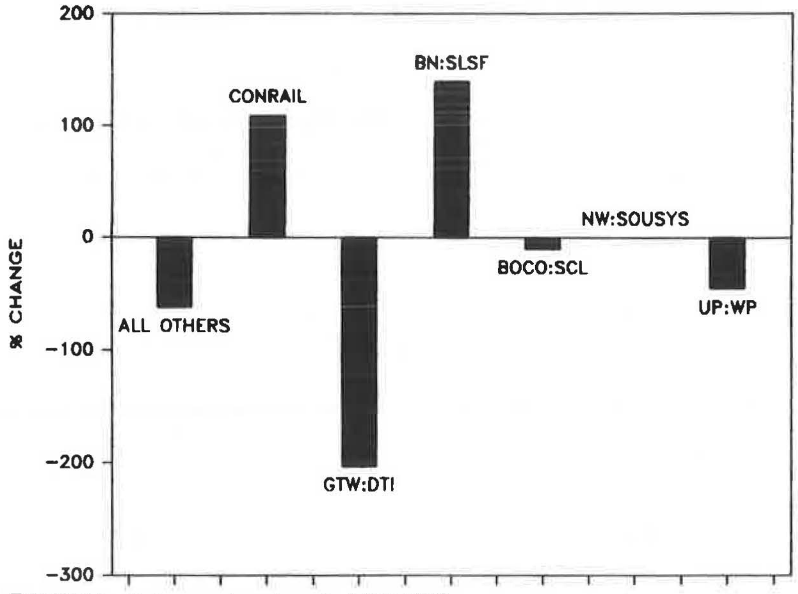

FIGURE 1 Return on investment: 1978-1983.

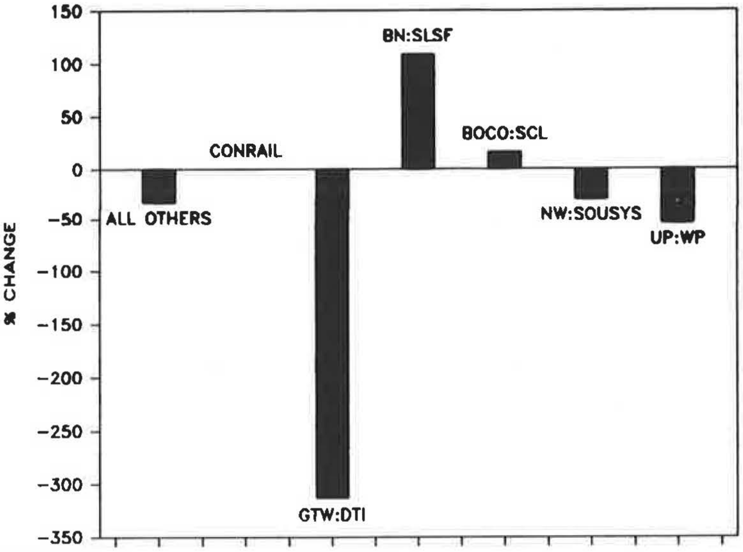

FIGURE 2 Return on equity: 1978-1983.

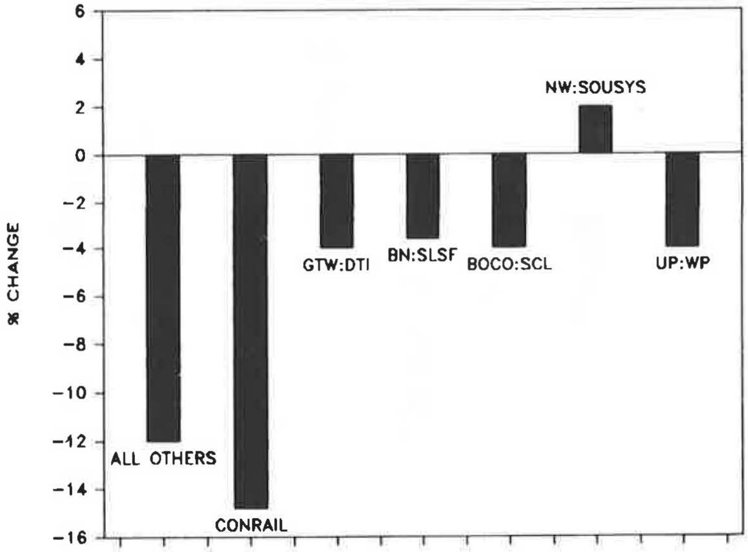

FIGURE 3 Miles of road: 1978-1983.

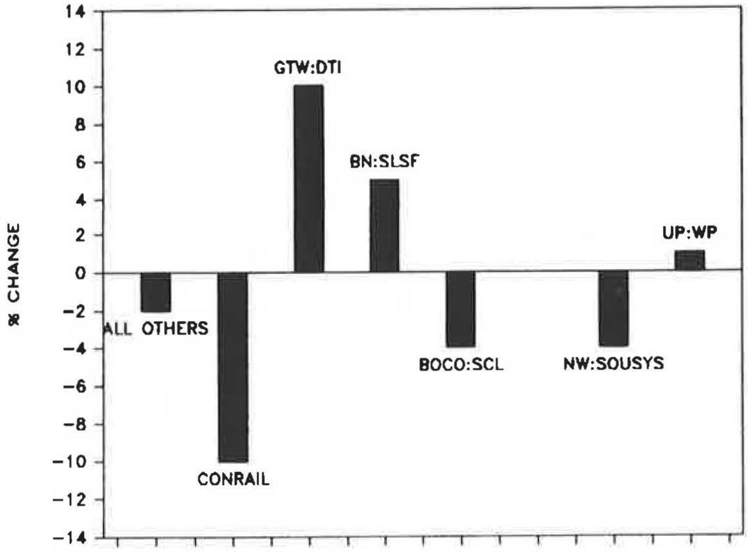

FIGURE 4 Switching track: 1978-1983.

have increased traffic sufficiently to offset any operating efficiencies, thereby necessitating an expansion of switching capacity. To test for that possibility, CLOT/ST utilization (Figure 5) was examined and it was found that, in fact, the merged carriers did relatively better on that score than did the nonmerging carriers. The NW:SOUSYS carriers, for example, increased ST by 2.2 percent, but their utilization declined by only 1.1 percent, versus an 11 percent decline in CLOT/ST for the control group.

The results in utilization of line-haul capacity (CM/MR, Figure 6) are also mixed but not inconsistent with expectations. Although the BN:SLSF and NW:SOUSYS did significantly better and the BOCO:SCL slightly better than the nonmerging carriers, UP:MP:WP and GTW:DTI did somewhat worse. As noted earlier, however, it would be expected that horizontal mergers would have a greater effect on traffic density than vertical mergers, so these results are not surprising.

One of the chief benefits of vertical mergers should be reflected in train length, and here (Figure 7) the results are unambiguous. Although nonmerging carriers experienced a slight decline from 1977-1979 to 1981-1983, all of the merging carriers except UP:MP:WP showed increases, from 5 to 19 percent. Presumably, these longer trains have reduced locomotive, crew, and fuel costs for the merged carriers.

Changes in net gross tons are shown in Figure 8. Two of the mergers (VP:MP:WP and BN:SLSF) have generated substantial gains, whereas the other three have not. The mergers do not appear to be beneficial on this count, though dramatic changes in car rules and supply practices may be influencing the results.

Finally, changes in operating costs are shown in Figures 9-11. Four of the five merged firms reduced their costs more than the control roads in at least two of the three categories, with the BN:SLSF and NW:SOUSYS consolidations experiencing the sharpest reductions. The UP:MP:WP was an outlier in this regard, with higher costs likely due to initial additional expenditure customary in the early period of merger consummation. Overall, the data provide some evidence that the recent mergers have resulted in operating cost savings. These differences are not

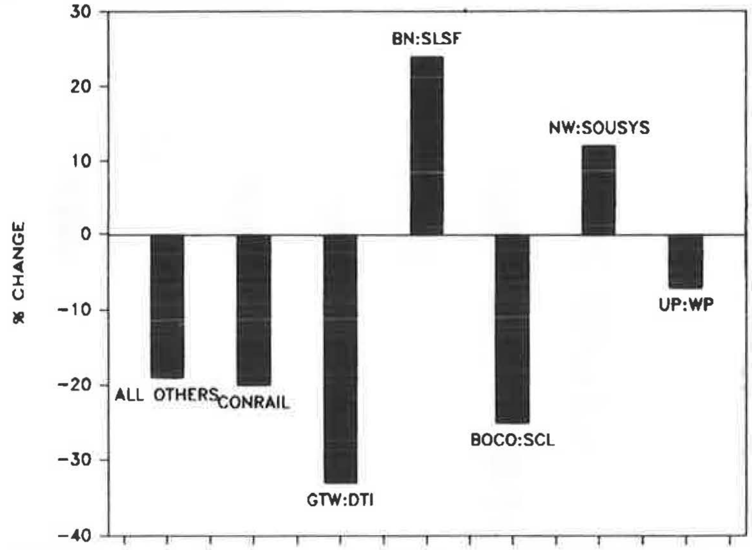

FIGURE 5 Carloads originated or terminated per mile of switching track: 1978-1983.

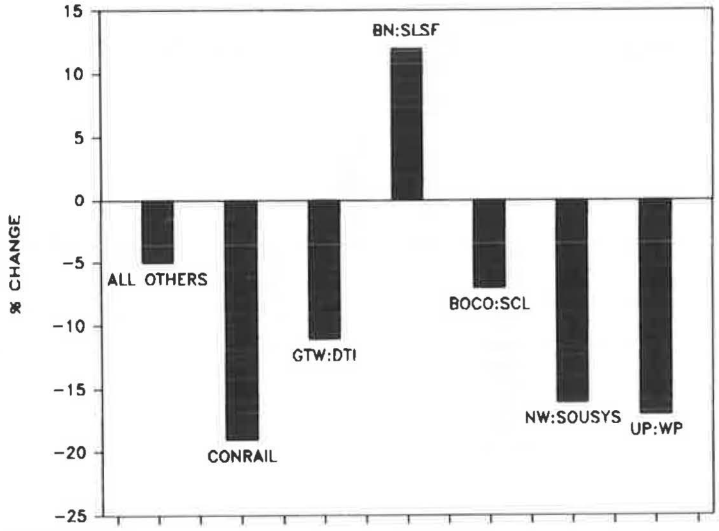

FIGURE 6 Car miles per mile of road: 1978-1983.

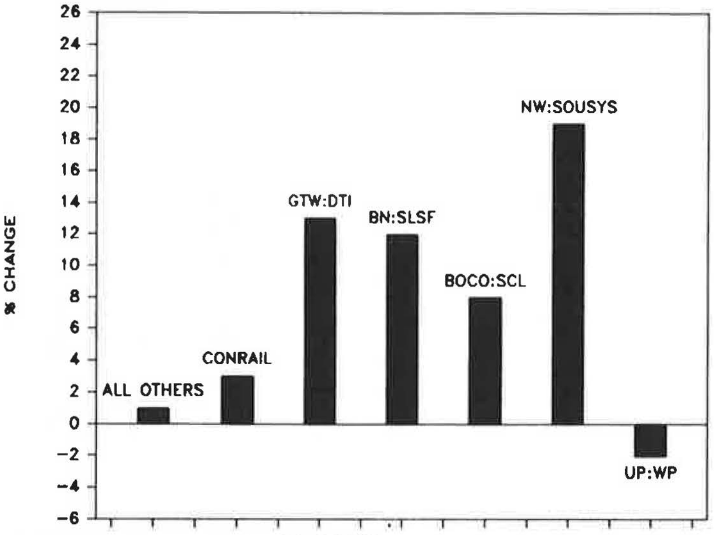

FIGURE 7 Cars per train: 1978-1983.

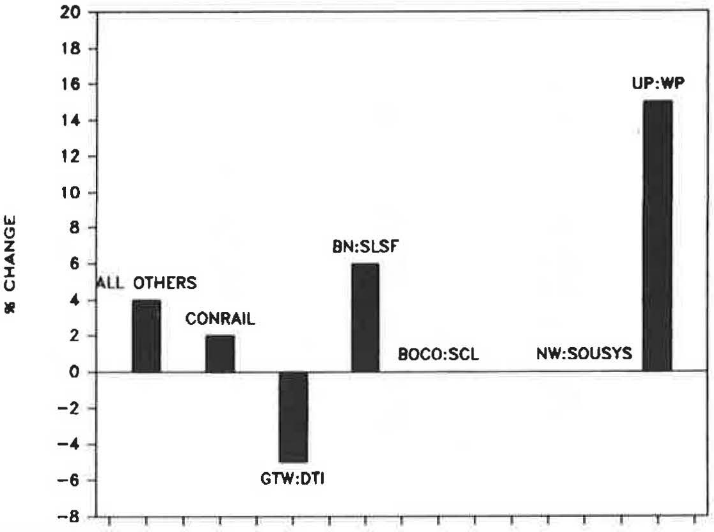

FIGURE 8 Net ton-miles per gross ton-mile: 1978-1983.

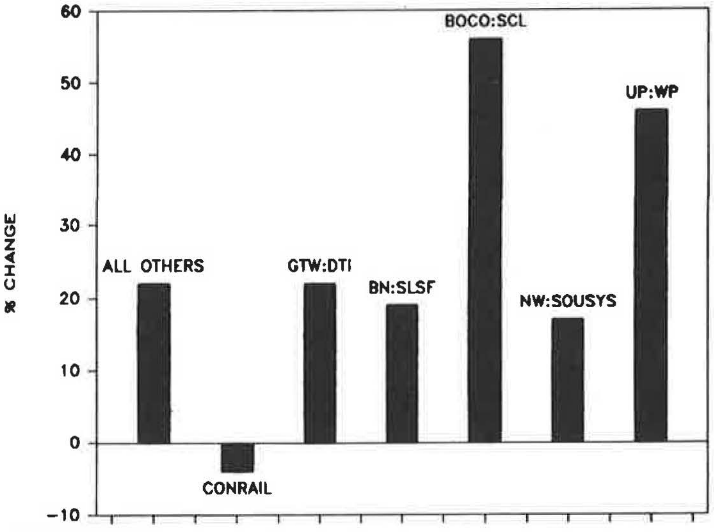

FIGURE 9 Maintenance-of-way and structure expense per 1,000 net ton-miles: 1978-1983.

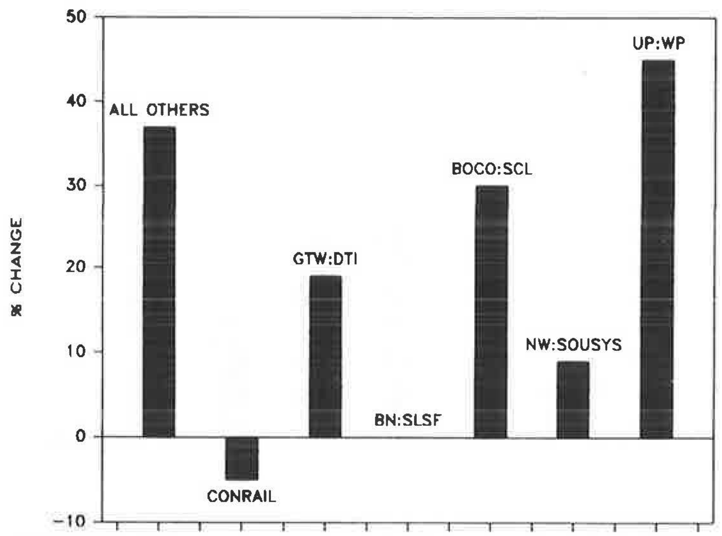

FIGURE 10 Maintenance expense per 1,000 net ton-miles: 1978-1983.

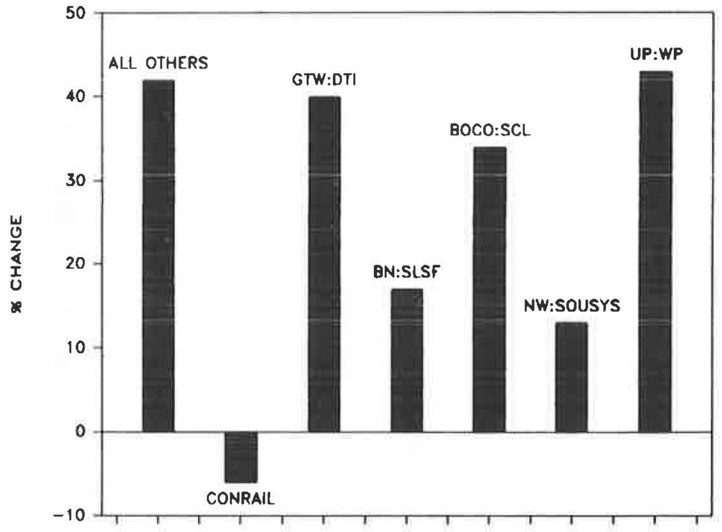

FIGURE 11 Transportation expense per 1,000 net ton-miles: 1978-1983.

TABLE 2 Difference-of-Means Test

	MWS	ME	TE
Nonmerged carriers			
Mean (%)	21	29	60
Standard deviation	0.003118	0.002653	0.007527
N	16	16	16
Merged carriers			
Mean (%)	15	19	43
Standard deviation	0.001285	0.000956	0.002032
N	11	11	11
t-Statistic	0.607742	1.125167	0.708393
t-Value[a]	1.7081	1.7081	1.7081
Rejection of hypothesis[b]	No	No	No

Note: MWS = maintenance of way and structure; ME = maintenance expense; TE = transportation expense.

[a] Significance = 0.10; 25 degrees of freedom.

[b] Rejection of hypothesis that means of nonmerged carriers equal means of merged carriers.

statistically significant, however, as shown in Table 2.

The recent mergers of major rail carriers have changed the structure of the industry rather dramatically. Although too little time has elapsed to draw any firm conclusions, mergers appear to have produced some benefits, particularly in improved financial performance and reduced operating costs. Future research should extend this retrospective merger analysis as data from additional years become available. In particular, 1984 and 1985 data should allow a more accurate assessment of the GTW:DTI merger, because demand for U.S. automobiles has rebounded during this period. These data will also be crucial for evaluation of the UP:MP:WP merger when more time has elapsed since this relatively recent consolidation.

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Interface Between Passenger and Freight Operations

DONALD O. EISELE

ABSTRACT

The fundamental conflicts between trains with different speed profiles and stopping patterns are outlined. The operation of the Northeast Corridor of the National Rail Passenger Corporation (Amtrak) is presented as an extreme example, with 13 classes of service over the same tracks. Various methods of handling this problem are discussed with specific applications of the concepts cited. Additional track is the first concept reviewed; both addition of lines to existing routes and construction of new separate right-of-way are considered. Examples of the various methods of increasing the permissible speed of passenger trains on the existing infrastructure through the use of pendular suspension and of interactive systems are explored. The changing nature of freight service in North America is examined and the suggestion is made that the scheduling problems to be faced in operating this service will be very similar to the interface between passenger and freight service today. The role of timetable planning and careful scheduling of trains is explored. The relationship between schedules and track configuration, particularly at line stations, is discussed. The nature of the role of the train dispatcher and his capability is explored. The potential role of the modern computer to convert the time spent on clerical tasks to more useful time resolving transportation problems is outlined. The use of computers to handle actual routine decisions is explored. The development of computer simulation techniques from simple train performance calculators to a planning tool capable of handling extremely complex diagrams is discussed. These tools are now being developed to the point of being able to estimate arrival times, conflict points, and other situations on a real-time basis. Alternative courses of action can be tested quickly on the basis of accurate current information. These tools will be available soon and give the dispatchers the ability to handle increasingly complex traffic situations.

Although the title of this paper includes the word "passenger" and the questions and areas of concern are now most pronounced for passenger trains, the fundamental problems discussed are very much applicable to an increasing number of railroads that carry only freight. In fact, one of the most rapidly changing areas, that of computer-aided dispatching (CAD), has been developed and is now in actual use on several railroads in this country that haul freight only.

The sound effects on the radio commercials for the National Rail Passenger Corporation (Amtrak)

Metroliner service succeed in giving the impression of speed. The impression of speed is even more pronounced when the morning New York-Pittsburgh train is receiving passengers at Princeton Junction and the Washington-bound Metroliner roars by at full maximum authorized speed. And this event illustrates the problem of differing speeds dramatically. The solution in this case is the tried and true civil engineering answer--an additional track. This quickly sets the stage for the present discussion.

Some time ago when jackets with patches on the elbows were very much in fashion, I was chided by some as needing the patches as a result of all the work I was doing on schedules. One wag told me that if I didn't have all these different zone trains--just had all the trains make all of the stops--it would make my life simpler. However, if the Metroliner made all the stops of the Trenton local across New Jersey, I suspect that Amtrak's marketing department would fold their tent very quickly. There are many different markets to be served over the same route.

This quickly introduces a second variable, stopping patterns. The nonstop New York-Washington Super Metroliner would be the extreme example in a discussion of the New York-Washington Corridor. The Metroliner Express with only one stop in each state is more common. Let us call the next class of train the "regular" Metroliner with two additional stops (though not necessarily the same stops). All of these can cruise along at a comfortable maximum of 120 mph. Just within this speed classification there are three distinctly different "paths." Each type requires different track occupancy within the same speed range.

To detour a moment, what has just been described is not too different from the operation between Tokyo and Osaka on the Japanese National Railways (JNR) famous bullet trains, which brings up the issue of track productivity. Although the JNR high-speed line is essentially a double-track line, many of the intermediate stations have four tracks in order to allow the superbullets to pass the slower bullets. The civil engineer is ever ready with his solution to the problem.

To return to the Northeast Corridor, consider this list of train types:

1. Metroliner
   a. Nonstop
   b. Express (four intermediate stops)
   c. Regular (six intermediate stops)
2. Standard train
   a. Regular (eight intermediate stops)
   b. Local (many more intermediate stops)
3. Suburban (New Jersey Transit)
   a. Zone express (two intermediate stops in New Jersey)
   b. Local or express (six intermediate stops in New Jersey)
   c. Local (11 intermediate stops in New Jersey)
4. Suburban (Southeastern Pennsylvania Transportation Authority)
   a. Local or express (six intermediate stops in Pennsylvania)
   b. Local (14 intermediate stops in Pennsylvania)
5. Suburban local (stops in Maryland)
6. Freight
   a. Trailer on freight car (TOFC) (Trailvan maximum speed, 60 mph)
   b. Merchandise (preferred maximum speed, 50 mph)
   c. Maximum tonnage (typical speed, 40 mph)
   d. Coal or ore (maximum speed, 30 mph)
   e. Local (serves sidings along route)

And as this outline is developed, it can readily be seen that the parallels in freight service could be detailed into many more types, each with its own path. However, the variety is far greater than this, as any dispatcher will readily attest. The actual track occupancy of a specific freight train is a function of the number and type of cars in the train, weight of the train, characteristics and mechanical condition of the locomotive configuration, track conditions, interference of other trains in the system, and expertise, and, on really difficult portions of railroad, the finesse of the locomotive engineman.

CIVIL ENGINEERING SOLUTION: ADDITIONAL TRACK

The most obvious answer to the problem of different types of traffic can be additional track. Indeed, in Great Britain, the tracks on a four-tracked line are usually labeled Up Fast, Down Fast, Up Slow, and Down Slow. The two center tracks of many four-track routes were maintained to a markedly different standard; the term "high iron" was visually obvious to the casual bystander.

Though seemingly inefficient from the viewpoints of both capital required and repetitive maintenance costs, having separate tracks for each class of service solves a number of problems. The problem of the markedly different curve elevation required for smooth operation of extremely high-speed passenger trains at one end of the spectrum compared with a slow-moving freight train at the other is solved by separating the services. On the new French Railways Tres Grande Vitesse (TGV), grades of 3.5 percent are common. The extremely high-speed TGV trainsets have no problem at all with this, but the dispatcher ordering out a 130-car freight train over that railroad would.

This is probably the point to introduce another issue, namely, maintenance standards. It is difficult to maintain track geometry for the extremely high speeds now common on the JNR bullet train, the French TGV, and the Amtrak Metroliner. However, Amtrak is unique in being required to maintain the track for high speed and at the same time operate heavy freight tonnage over the same track. As more freight traffic is scheduled for higher speed, many more railroads will face this same problem between different classes of freight trains.

Additional track or controlled sidings immediately add another element of cost, that of switches, signals, and controls. The maintenance itself introduces the next problem, that of track out-of-service time for maintenance. Consider a multitrack railroad with different classes of tracks. When the "higher"-speed track is required for engineering work, a whole series of problems follows. The high-speed trains lose time on the slow-speed track as well as requiring decelerating time before the restriction and accelerating time after the restriction. If a heavy tonnage freight train must be slowed or stopped, much time is lost. Service reliability of both classes of service is hurt. And if local or suburban commuter trains are involved and schedule connections are broken, many lives are disrupted.

When the total volume of traffic of all types requires additional trackage, the completely or partially separate line can yield important advantages. For example, the quadrupling of track on the existing route between Paris and Dijon would have been complex and expensive. Not only was the new line less expensive to build but it was only 426 km long as compared with 525 km for the existing line. This is reflected positively in reduced capital expense, reduced maintenance expense, reduced operating expense, and of course improved marketability.

The additional-track solution is under active consideration in the United States. At a recent meeting of parties interested in the continued growth of passenger service across New York State it was revealed that serious consideration is being given to constructing a third track within the existing right-of-way but separate from the two existing tracks in order to allow passenger trains to regularly operate at 110 mph. Several studies are under way for completely new high-speed railroads in various locations in order to attain the higher speeds and greater degree of reliability.

MECHANICAL ENGINEERING SOLUTIONS

Pendular Suspension

Some of the civil engineering problems posed by the operation of widely different types of trains (the extreme example of high-speed passenger service and low-speed heavy freight trains) can be alleviated by new equipment design. The Talgo pendular suspension as developed in the United States some 40 years ago has been tested at 143 mph and operates regularly at 88 mph in Spain and at 100 mph in France.

Lest this be considered an unusual or experimental service, note that the Talgo service has accumulated over 38 million car miles and carried over 471 million passenger miles. In the discussion of reliability, consider that 97 percent of the fleet is available during peak season.

The Talgo trains consist of a series of single-axle cars. One end of each intermediate car is supported on the damped air springs under the top of the car. The springs provide vertical and lateral suspension, and because they are well above the center of gravity of the car, the correct pendular effect is achieved on every curve. The result is a smooth and comfortable ride.

Incidentally, just to make the operation interesting, some of these trains operate between France and Spain. The track gauge in France is 4 ft 8.5 in. but in Spain it is 5 ft 6 in. The trainsets used in this service employ an adjustable-gauge truck, permitting the necessary gauge change to take place with passengers aboard (at a very slow speed).

On the opposite side of the globe, in Japan, a fleet of 277 electric multiple-unit cars equipped with a roller-type natural tilting system has been in regular service since 1973. The car tilts naturally by centrifugal force while running on curved track, cancelling the excessive centrifugal acceleration caused by the shortage of superelevation. These trains of the 381 series are reported to operate at a speed of "standard" plus 15 to 20 km/hr without any feeling of discomfort for the passengers.

Active Tilting System

One factor limiting the maximum speed of a passenger train around curves is the level of comfort of the passengers. Tests conducted in 1983 by British Rail refined the problem even more specifically; the comfort of the standing passengers will be a critical problem. In theory it would appear possible that engineers could design a system that would determine the lateral acceleration as the forward part of the train entered a curve and transmit this information to a mechanism that would tilt the body of the train at just the right degree to cancel out the unpleasant lateral accelerations.

British Rail has gone through the Mark I, Mark II, and Mark III carbody tilting systems and is now developing the Mark IV. The program is an example of the difficulty of converting theory into reality. In the earlier models the sensing accelerometers were mounted locally on each vehicle, and although this should have allowed satisfactory response, it was not actually achieved. Feedback systems, stability margins, desired response time characteristics--all are theoretically possible but the result was delayed tilting on transition curves and a jerky ride. Furthermore, because of the close relationship between tilt performance and lateral ride quality, the total ride quality was poor. Mounting the accelerometers on the preceding vehicle achieved better results.

After many years of trials, British Rail is said to have finally achieved the desired effect, only to have the poor riding quality of the articulated train cause discomfort. It has been reported that British Rail has decided that future high-speed coaches will not be articulated, at least partly because of the poor riding quality of the bogies.

As the development has proceeded, the testing procedure itself has become more sophisticated. A new ride meter (the Jacobmeter) was devised to measure ride quality as perceived by passengers. But there is still far more to the problem because a passenger's comfort is affected by vibration, noise levels, temperature, ventilation, visual environment, expectations of ride quality, and so on.

For example, consider for a moment the visual effects. In order to reduce the effects of claustrophobia, the trend in new equipment is to large windows. However, with tilting equipment, the horizon rises and falls without corresponding cornering sensations. The problem is worse for on-board staff who are standing, and much of their time is spent facing the windows. Motion sickness is a potential problem, as it is also on the Japanese class 381 equipment.

Meanwhile, since 1973, the Swedish State Railways and their vehicle supplier ASEA have jointly carried out their own development project, X-15, concerning the design and testing of a new vehicle concept. This effort appears to be closest to reality and bids have been requested for three prototype cars with an option for 50 production trainsets. The Norwegian State Railways plans to install tilting equipment in one batch of 24 cars to be delivered in February 1986 for trials. Judging by the tediously slow results elsewhere, it would be pleasantly surprising to see actual regular service by this type of equipment before 1990.

In Japan there is a program to develop a system to increase the speed limit on the narrow-gauge lines on curves to a standard plus 25 km/hr. The system uses an air cylinder that increases the tilt beyond that achieved by the roller system of the 381 series cars. The existing wayside devices of the automatic train stop (ATS) system are used as a base for the tilting system. The distance from each curve to the nearest ATS device is known, as is the diameter of the wheels. This information is calculated and stored in the controller. Depending on the direction of the curve, length of the transition curve, length of the curve itself, radius of curvature, and superelevation of the curve, the precise amount and duration of required tilt are calculated and applied to the car body. Tests have indicated that the initial transition at the beginning of the curve and at the end of the curve are important in obtaining an acceptable ride.

RESTRUCTURE OF RAIL FREIGHT MARKET

Although the title of this paper was first set out to be the problems between freight and passenger operations, and it might appear that the topic would not be of interest to railroads that carry only freight, it is suggested that operators of these lines take careful note. The highest speed at which freight trains operate today is 70 mph. It was not too many years ago that this speed was called "passenger train" speed. A glance at the list at the beginning of this paper indicates five types of freight trains with very different characteristics. In terms of dispatching, the highest-speed piggyback freight trains appear similar to the faster passenger trains. The slower maximum-tonnage trains may well take no more track time than a commuter local making all the stops. The peddler freight "dogs" along from siding to siding and does as much damage to a dispatcher's use of a high-speed freight railroad as it does to the dispatcher in the Amtrak Northeast Corridor.

The historic patterns followed by the railroads are undergoing dramatic changes. Even those railroaders not close to the marketing problems must be aware of thousands (actually hundreds of thousands) of boxcars that stand idle in sidings, yards, branch lines, short lines--seemingly everywhere.

The amount, type, and speed of traffic and the degree of schedule dependability required to retain this traffic are worlds apart from those characteristics just a few years ago. Consider one industry that everyone will agree is a vital component of intercity freight traffic--the automobile. Look at the changes in the components used in construction of each automobile:

	Avg Weight per Automobile (lb)	
Material	1977	1985
Hot-rolled steel	1,419	760
Cold-rolled steel	820	490
Cast iron	620	315
High-strength steel	105	225
Plastics	165	225
Total	3,129	2,015

This type of change in production hits the railroads in at least three ways. First, the reduction of weight of the components reduces ton-miles required. Second, the size and weight of the final product lead to reduced revenue from completed automobiles. Thus, as the components become smaller and lighter, they are more likely to be candidates for movement by truck.

This last point is critical. The railroads will have to meet the speed and dependability of the truck lines in order to retain revenue. As railroads revamp their freight patterns and schedules, the results look much like the passenger train schedules of a few decades ago. There are locations today where relatively new classification yards are operating at only a fraction of their installed capacity and the adjacent TOFC and container-on-flatcar (COFC) terminal is so busy that the capacity of the facility is strained.

If the trends of the Speedlink Service in Great Britain and the restructuring of freight service in West Germany move to the United States, a passenger timetable of a few years ago, complete with cars moving forward on connecting trains within a few minutes of arrival, may be mistaken for the new freight service folder. The problems of "passenger-type" dispatching will be regular occurrences on freight railroads. At the same time the heavy-mineral train and other classes of freight trains will still be plodding along at their traditional speeds. The complexity of scheduling and dispatching will increase accordingly.

OVERTIME AND CAR-HIRE COSTS

The conquest of the problem of efficiently handling trains that traverse widely differing paths creates costs savings for freight railroads that management can really relish. In one of the examples shown in the following, one railroad is realizing savings of two-thirds of a million dollars on just one division with a CAD system. In addition to this reduction in overtime and car-hire costs, it appears that substantial capital costs can be prevented by not building a planned siding. When the capital, maintenance, and direct operating savings from all aspects of this problem on freight railroads are detailed, many people will truly be amazed.

TIMETABLE PLANNING AND TRAIN SCHEDULING

It is a fortunate railroad that faces the problem of increasing throughput. Certainly such problems would indicate no lack of revenue. How this problem is handled will be an important factor in determining how much of this gross revenue is brought down to become net revenue. Both the civil engineer's solution and the mechanical engineer's solutions require substantial additional funds. The role of the planner and scheduler is usually to work within both sets of physical constraints--roadway and rolling stock--and achieve the best possible solution.

Ideal Railroad

It might appear that the ideal railroad would consist of trains all running at the same speed, much like a conveyor belt. This works fine until the first stop is scheduled. As soon as the train decelerates, the problem begins. The traffic signal designer copes with this problem by changing block lengths, increasing the number of blocks, and even increasing the number of signal aspects.

The solution may well be that the ideal railroad line would expand into two tracks as the route approached each station, at a distance to allow safe deceleration without adversely affecting the following train; have separate loading facilities for each track in the station; and then return to one line (in that direction) after a distance sufficient to accelerate to maximum line speed. As mentioned earlier, this is not unlike the plan of the JNR bullet trains. In the suburban service sphere, the Société Nationale des Chemins de Fer Francais (SNCF) achieves amazing throughput on its B line through Paris by just such a scheme.

Real Railroad

These are rare examples, however. Realistically the timetable planner is always trying to increase the number of train movements, handle longer and heavier trains, increase the speeds of all classes of service, and at the same time improve the dependability of the entire matrix.

The marketing manager wants the "name" train handled with priority over everything else. The yardmaster simply wants the tonnage freight to leave the yard as soon as possible and honestly is not concerned whether the dispatcher has any railroad on which to run it. The commuter wants to get home exactly as scheduled, even though the schedule is slow, and before his supper goes up in smoke.

One of the basic problems in scheduling is knowing with a high degree of accuracy exactly how long a given train with a specific locomotive, a specific consist, and a specific crew will require to traverse a given portion of line under given circumstances. Until recently this was all left to the experience of dispatchers and schedule planners. Even the most thorough hand calculations left much to be desired. The problem could be approached by starting with horsepower and tractive effort curves, track charts with grades and curves, the Davis formula, and everything else one could find. A different approach is to review the actual results of day-to-day operation of a given type of train over a sustained period of time and by introducing probability predict a reliable schedule. With these building blocks, the schedule planner balances the needs of all the requests noted earlier.

The use of high-speed computers has brought some degree of sanity to this problem. Computer simulation of all types of trains with many variables can predict train performance with great accuracy. More complex simulations that include the interaction between the trains and signal system, and in turn all other trains in the system, are now the backbone of timetable planning. However, the choice of stopping patterns is still a "given" or "input." Simulation will provide what has been suggested, but there is still a substantial leap from this statement of fact to the choice of which train goes first.

One effective method of increasing throughput is the technique of "fleeting" a series of trains over a portion of line as a group. In cases where densities are really high, some of the running patterns of the fastest trains may have to be relaxed slightly. Immediately the battle is engaged to balance the need to obtain high theoretical speed and also attain a high degree of schedule reliability. It is at this point also that some of the high-speed freight trains (TOFC and COFC) look much like passenger trains on the train graphs of many railroads. The Northeast Corridor with its maximum authorized speed of 120 mph is the obvious exception.

The next development from the fleeting concept is a zonal operating strategy. This method starts with fleeting the trains that are destined for the farthest points first and then scheduling the others by their first station stop, working backwards from the originating location. The technique works best when the headway between the movements is kept to an absolute minimum and time is allowed between the first fleet and the next fleet in order to provide for recovery.

Because one set of schedules determined from one origin is overlaid on the set of schedules from the next major load point, and this process is repeated again and again, the result is complex. Although the initiation of computer simulation of any railroad itself is a complex and demanding task, once it has been developed and used, it enables this sort of scheduling problem to be handled without massive effort.

THE DISPATCHER AND CAD

Clerical Work

It has been stated that the role of an airplane pilot is 99 percent boredom and 1 percent sheer terror. If this is accurate, it is somewhat analogous to the dispatcher on a busy railroad. An unfamiliar observer might come to the conclusion that most of a dispatcher's time is spent simply filling in on-schedule times on large and extremely unwieldy yellow charts. Indeed, in some sense he would be correct because federal law requires that complete records of every train be maintained. This information includes

1. Crew information--names of conductor and engineman, time on and off duty, and amount of rest time between assignments;
2. Locomotive information--specific numbers of locomotives;
3. Train equipment information--the amount of cars (separated between loaded and empty) at the beginning and end of the trip;
4. Details of time of train movement--departure time, intermediate passing times, meeting points and times, final arrival times;
5. Details of train delays; and
6. Record of all unusual occurrences.

A tremendous portion of a dispatcher's time is spent on record keeping and related clerical work. On some railroads it would appear that so much of the decision making is taking place at block towers that the dispatcher is really just following the show and not really controlling it. Some studies indicate that the proportion of the time spent on these clerical-type functions is about 80 percent.

It is in this area that CAD efforts have had their initial impact. There are several different approaches, but once the basic data are entered into the system, the computer does much of the clerical work. This frees the dispatcher for the real problems.

Needed Information

The other part of the picture of a dispatcher's work would be apparent if the observer walked into the dispatcher's office at the more exciting times. At these moments, as instructions are flying back and forth, one wonders how anybody can really remember all of the facts needed to make good decisions. Will a particular train fit in a certain siding? When will a portion of track be released by the engineering department? Exactly where in the interlocking is the troubled train? Which crew will "outlaw" (reach the mandatory maximum hours of time on duty) first?

The second impact of CAD is the ability to bring a great deal of (accurate) information to the dispatcher quickly. There is always a degree of judgement in every situation, but all too often guesses are made based on erroneous information. The facts are caught somewhere between the trains involved and the point of decision, but they are not available in a form that is understandable to the decision maker. The initial impact of the computer is not to replace the dispatcher but to put much more of the information he wants and needs at his fingertips exactly when he needs it. The result is to reduce the size of the leap of judgment. This gives the dispatcher much better odds at making the correct decision.

In some systems the data show up on a visual display unit. The last three arrivals shown on the CRT unit allow the dispatcher both to know the locations of the trains and to have a feel for actual progress. In more advanced systems the train number appears on a central traffic control board. On yet another system, a time-distance graph appears and the trains appear as colored lines showing their progress. In each case, however, the result is to give the dispatcher, or his superiors when the situation requires their involvement, a complete picture of as many of the variables as can be determined.

In the system being developed for the Amtrak Northeast Corridor the complete track diagram from Washington, D.C., to Wilmington, Delaware, will be projected on a large screen spanning the full length of the control center located on the top of the 30th Street Station in Philadelphia. As plans now stand, the actual train numbers will move across the board continuously, indicating the precise location of each train.

Routine Operations

An honest analysis of a great many things that we do each day will reveal the degree of routine in our society. Most of the dispatcher's decisions are in fact routine procedures. Analysis of the 20 percent of dispatching time left for controlling train operation (after the clerical functions are subtracted) indicates that 85 percent is routine. This degree of routine operation sets the stage for utilization of computers to aid dispatching.

The simplification of train orders by using a blank form on the CRT and then transmitting them electronically cuts through the traditional train order book and all that goes with it. The next step is the automatic clearing of trains from sidings. Clearing signals automatically in front of advancing trains prevents trains from having to reduce speed without real reason. On a high-speed operation like the Northeast Corridor this ability is immediately transformed into highly on-time performance. When heavy freight trains are involved, this ability is seen in reduced fuel consumption and brake wear.

Simulation of Train Performance

The use of the computer to grind through the details of train performance calculation, including the horsepower available, the traction characteristics of the particular locomotives (or multiple-unit cars), the grades and curves of a particular route, the Davis formula, specific local speed limits, and other factors, is known. It is a useful tool in determining new locomotive requirements, economics of line changes, and operating decisions and especially in timetable planning.

The more complex simulation of an entire schedule of trains--each with different operating characteristics and different stopping patterns, including the reaction between trains and the signal system, and in turn the signal system with following and opposing movements on single track and with parallel movements of trains with differing speeds and characteristics in the same direction on multiple track and a series of complex interlockings--has been an essential part of regular timetable planning on the Long Island Rail Road for over a decade.

However, "planning" is a relative term. The computer programs of a decade ago were so laborious that they could only be used for planning of schedule changes targeted for months ahead. In a railroad operating dispatcher's office the term "long-range planning" means tomorrow or perhaps (on the Amtrak Northeast Corridor, for example) even a few hours from now. The planner's computer models were certainly no help to the dispatcher when the "unusual occurrence" portion of his train sheet was overflowing with remarks.

Real-Time Simulation

The modern microcomputer has brought the possibility of rapid and timely simulation of train performance of a number of trains and their effect on other trains in the area into reality. In the simplest systems CAD predicts the estimated time of arrival (ETA) of trains for the dispatcher. If the train is delayed, or if it does not perform as anticipated, the ETA is changed accordingly. Potential conflicts are highlighted in time for corrective action to be taken.

Could the automation of the time-honored "string chart" be far behind? A visit to the Atlanta headquarters of the Norfolk Southern's Alabama and Georgia Divisions will reveal a CRT at the dispatcher's elbow displaying a time-distance graph that shows the actual and projected courses of trains on these divisions. The dispatchers regularly follow the plan developed by computer program that has determined the combination of meets and delays that will result in the lowest-cost operation. However, if the dispatcher wants to investigate an alternative plan, the system can test it quickly. If crews are nearing the 12-hr limit, the dispatcher is alerted. If power is needed for a connection, the CAD system flashes a warning.

The present planning for the Amtrak Northeast Corridor includes train identification, train status, track and track power monitor, and the control and validation of commands to interlockings. The system is designed to be expanded to include traffic management techniques including train graphs, meet-pass planning, conflict prediction, and other features as funds for implementation are made available.

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Railway Electrification and Railway Productivity: A Study Report

S. R. DITMEYER, J. R. MARTIN, P. E. OLSON, M. F. RISTER, B. A. ROSS,
J. J. SCHMIDT, and E. H. SJOKVIST

ABSTRACT

Various aspects of railroad productivity that might be influenced by the adoption of electrified railroad operation are evaluated. Productivity is considered from the viewpoint of motive power, transportation economics, signaling and train control, and railway operations.

The results of a productivity study undertaken by a subcommittee of the TRB Committee on Rail Electrification Systems are presented. This seven-member group evaluated various aspects of railroad productivity that might be influenced by the adoption of electrified operation. Primary emphasis has been placed on productivity improvements that might be anticipated with electrification of heavy-density main-line freight railroad operations.

Each member of the subcommittee has been involved in one or more North American main-line railroad electrification studies in the United States or Canada. In addition, each member of the subcommittee has been actively engaged in studies of electrification economics and is familiar with both North American and foreign electrification developments. A compilation is presented of recent U.S. and foreign electrification study results and experiences that relate to specific aspects of railroad productivity of diesel and electrified railroad operations and economics.

Railroad productivity is addressed from the point of view of motive power, transportation economics, signaling and train control, and railway operations.

BACKGROUND

During the four decades since World War II, while the major railroad administrations of Europe and other continents undertook to convert their rail lines to electrification, the United States has in fact steadily reduced the number of miles of freight operations conducted under electrification. The only new freight railway electrifications in North America have been either on short-line captive railroads or, just recently, on the somewhat special Tumbler Ridge Project in British Columbia, Canada. This last project, which connects directly with existing rail lines, does not have sufficient operating experience to provide any useful answers to the serious questions of the effect of railway electrification on operations and economics. Further, the short-line captive electrified railroads are too limited in the scope of their operations to serve as models for drawing valid conclusions about the effects of electrification on the subject being considered.

The dilemma facing the railway planner is that he must study the overseas experience, identify those aspects of such electrified lines that differ from diesel operation solely because of electrification, and then construct hypothetical models of known railroad operations in North America, incorporating the operating concepts gathered from this overseas study. At best, the result is a mental simulation of a railroad operation to which untested principles are applied and for which no opportunity exists to validate any part of the so-called model. When the model results are evaluated, it is necessary to distinguish carefully between true effects of electrification and consequential effects that are brought about primarily because a new, unconstrained look is taken at the railroad operations. In recognition of the lack of U.S. experience in new main-line railroad electrifications, with the exception of commuter and passenger operations, this paper is generally based on foreign operating experience, principally in western Europe, South Africa, and the Soviet Union, and on U.S. railroad electrification studies that have been carried out during the past two decades. In some instances even though the subject studies may initially have been performed in the late 1960s or early 1970s, they have been continually updated to reflect changes in equipment characteristics and improvements in electrification technology.

For purposes of this evaluation the term "railway productivity" has been defined in a broad sense to include effective utilization of capital, reductions in operating costs, savings in manpower, reductions in environmental impacts, and improvements in railway operations.

MOTIVE POWER CHARACTERISTICS AND COSTS

The electric locomotive and the diesel-electric locomotive have provided the subject matter for countless technical papers comparing their characteristics, capabilities, and economics (just as decades ago the electric locomotive and the steam locomotive did). A review of these comparison papers quickly establishes in the reader's mind the fact that published material presents in most instances an advocacy of one of the motive power alternatives rather than a comparison. A further complication in the appraisal of motive power characteristics, performance, and costs is the widespread adoption of the electric locomotive for high-traffic-density lines in western Europe, the eastern European countries, Asia, and South Africa and its almost universal rejection for such service in North America.

Locomotive Unit Horsepower and Tractive Effort

The most notable of the electric locomotive characteristics is that, rather than being a converter of new energy--in the form of diesel fuel or coal--to mechanical energy at the wheel-rail interface as are the diesel and the steam locomotive, the electric locomotive is a converter of externally supplied electric energy to mechanical energy. This permits an electric locomotive to develop much higher horsepower for a given size or weight than a comparable diesel-electric locomotive. When electric and diesel-electric locomotives are compared, it is important to have a clear understanding of tractive effort and power capabilities. An electric locomotive has no capability of providing higher maximum tractive effort than a diesel-electric locomotive of equivalent weight on drivers. An electric locomotive's maximum tractive effort is limited by adhesion between the locomotive wheels and the track. This assumes that both types of locomotives have good wheel-slip systems, and experience has shown that acceptable wheel-slip control can be achieved on both electric and diesel-electric locomotives.

The electric locomotive's ability to draw high horsepower from the catenary system (in some instances up to twice as much per unit for short periods) may be a significant asset in certain operating circumstances. In effect when a train is started or when a train is accelerated after a speed reduction or when an existing speed is maintained as grade increases, the electric locomotive can deliver outputs substantially in excess of its nominal horsepower rating. The diesel locomotive cannot match this short-time performance because of the lack of such horsepower overload capability in its diesel engine.

Further, the electric locomotive can be designed, as a general rule, to deliver for the same weight and size unit from 50 to 100 percent greater nominal horsepower than a comparable diesel-electric. In certain operating circumstances, such as very long grades, this can be a valuable asset.

How can this greater unit horsepower characteristic of the electric locomotive be exploited to contribute to railway productivity? In subsequent sections of this paper the advantages of high unit horsepower will be considered from the viewpoint of locomotive cost, railway operations, and overall railway economics. In each of these areas higher unit horsepower should, in many instances, be able to enhance railway productivity.

Motive Power Unit Initial Cost

Locomotive unit cost comparisons must be considered from the viewpoint of both unit tractive effort and unit horsepower. When cost is considered, it should be recognized that current North American electric locomotive costs are based on a limited number of deliveries. It seems reasonable to anticipate some reduction in electric unit costs as electric motive power comes into common use, spreading production and research costs over a larger product base.

Current North American costs for the same continuous tractive effort unit indicate that the cost of the electric locomotive (based on recent sales and quotations) may be estimated at 1.5 to 1.7 times the cost of a comparable diesel-electric unit. On the basis of nominal horsepower unit ratings, the electric unit is estimated to cost 50 to 80 percent as much as a comparable diesel-electric unit.

It must be realized that actual locomotive prices may be materially influenced by specific customer requirements with respect to locomotive characteristics, numbers ordered, and prospects for future orders. These cost comparisons, however, should provide input to the question whether electric locomotive units initially cost more or less than comparable diesel-electric units.

Maintenance Costs

For several reasons, it has always been difficult to get a fair comparison between the specific maintenance costs (cost per year per locomotive, cost per unit mile, or cost per ton-mile) of diesel-electric and electric locomotives. Railroad administrations in various countries use different accounting systems. Costs of material and, in particular, labor vary considerably between different countries. The productivity of maintenance personnel depends on the facilities used, and the investment that can be justified for these facilities is very much a function of the number of locomotives to be maintained and the degree of standardization of locomotive models and their main components. The impact of changes in design on maintenance cost of electric locomotives in France has been shown by Gautier and Blanc (1) and by Nouvion (2). The utilization of the locomotive in different types of service also has a great impact on the maintenance cost. Finally, the quality achieved by the locomotive manufacturer plays a significant role.

For these and other reasons, no fair comparison can be made directly between maintenance costs obtained from different countries. Second, a comparison between diesel-electric and electric locomotives in one specific country is likely to be less reliable if the number of diesel-electrics is very small compared with the number of electrics, or vice versa. Therefore, the following countries have been excluded from a direct comparison: United States (very few electric locomotives), Canada (very few electric locomotives), Germany (diesel locomotives mainly diesel-hydraulic), and Switzerland (very few diesel-electric locomotives). Countries that, at least to a degree, meet the requirement of operating a sufficient number of both diesel-electric and electric locomotives include the USSR, South Africa, France, and Sweden.

Statistics related to specific maintenance cost are usually expressed in one of the following ways:

1. Cost per locomotive unit mile in a year,
2. Cost per unit of transportation work (e.g., gross ton-miles in a year), or
3. Cost per unit of rated output, for example, engine rating (gross or available for traction) or output at rail.

It is extremely important to compare maintenance costs only as they are related to the same definition. Because diesel-electric and electric locomotives generally do not use the same power output definition, the third type of statistics should be disregarded. Maintenance costs related to the first type are common but do not take into account the actual transportation work produced. Therefore, only the second type of statistics gives a fair comparison.

Various publications (1,3-7) describe in some detail the maintenance procedures for electric locomotives in Great Britain, France, Sweden, and Switzerland without comparing them with diesel-electric locomotives. Horine (8) attempts to show how the maintenance cost of rather old American locomotives varies with the age of the locomotive. The rest of the references may be classified into two groups:

(a) studies based on certain assumptions and (b) statistics from experience on railroads.

Category a includes the following. In 1974, Cogswell et al. (9) reported to the American Railway Engineering Association (AREA) that the maintenance cost for an electric locomotive per gross ton-mile hauled would be about 30.2 percent of the corresponding cost for a diesel-electric locomotive as an average. The range would be between 25.8 and 48.1 percent depending on a number of site-specific factors. Ephraim (10) estimated in 1977 that the ratio would be about 60 percent per annum in heavy-duty freight service but might be 30 percent or less in lighter freight operations. For the electrification of the main railroad on the Italian island of Sardinia, Mayer (11) estimated in 1982 that the ratio per ton-mile would be 20.2 percent.

Statistics from actual operations of diesel-electric and electric locomotives include the following. In the Soviet Union a report by Rakov in 1975 (12) gave statistics for 16 years of operation showing that the ratio for diesel-electric/electric locomotive maintenance per ton-mile had varied for individual years between 35.6 and 49.4 percent with an average of 43.1 percent. In 1976, Serdinov (13) reported that the ratio per unit mile was 55.6 percent. If only labor maintenance cost was considered, the ratio was 57.4 percent.

For South Africa, Wade in 1968-1969 (14) and Gosling in 1977 (15) have both reported that the ratio per unit mile was 25.6 percent and per ton-mile it was less (no figure quoted).

In France, Nouvion reported in 1971 (2) a ratio of 55.6 percent per unit mile and 33.3 percent per ton-mile. Three years later he gave a ratio of 32.7 percent per ton-mile (16).

Harley et al. reported in 1973 (17) for Sweden that the ratio was 42 percent per unit mile and 18 percent per ton-mile, and Salomonsson in 1982 quoted 25.4 percent per unit mile and 14.0 percent per ton-mile (unpublished data).

Although Great Britain and Japan do not meet the requirements for a fair comparison specified at the beginning of this section, the following statistics may be of some interest. Wade stated in 1968-1969 (14) that in Great Britain the ratio per unit mile was 28.9 percent, whereas Calder in 1977 (18) said that it could vary between 32.8 and 45.5 percent depending on what locomotive models were compared.

For Japan, Wade's ratio (14) was 48.8 percent per unit mile, whereas Mizuno in 1982 (19) quoted a ratio of 37 percent per unit mile.

In conclusion, experience has shown that the ratios for maintenance costs (electric/diesel-electric) fall within the following ranges: 25 to 56 percent on a unit-mile basis and 14 to 43 percent on a ton-mile basis.

Availability

It is a recognized characteristic of electric locomotives that they can be turned for dispatching more quickly than diesels because they require less servicing. There is no need to move to a fuel station for refueling. No lubricating oil must be added; no oil samples need be taken to evaluate diesel engine condition; no cooling water is required. The only periodic servicing necessary is to refill sanding bins and to check brake shoes. These last two items are shared with all diesel locomotives.

If the time needed for heavy overhaul is subtracted from the theoretical 100 percent availability of maintenance-free locomotives, the actual availability of diesel-electric locomotives in North America is about 84 percent; that is, they are not available 16 percent of the time. If the regular servicing (mainly refueling) takes 6 percent of the time, some 10 percent is needed for some kind of maintenance work on a diesel-electric locomotive. For an electric locomotive, the 6 percent for refueling disappears, and a conservative estimate of the time spent on maintenance work would reduce the 10 percent for the diesel-electric to about 6 percent for the electric locomotive. It is estimated that maintenance- and servicing-related availabilities are approximately 84 percent for diesel-electric locomotives and 94 percent for electric locomotives.

In specific cases--and this will be true of most rail operations able to justify electrification--the reduced terminal-to-terminal times possible with electric motive power can make a further contribution to electric motive power availability. If a train can be moved over the railroad in reduced running time, it follows that its locomotive is available for reassignment more frequently in a given length of time. However, because this availability factor improvement is specifically related to railway operations, it is not possible to estimate its effect on a generalized basis.

Shutdown Capability

Some expense and reduced wear benefits may be anticipated from the ability to shut down either the entire electric locomotive or a major portion of its overall system during periods of no demand, waiting, servicing, maintenance, or train delay. This shutdown capability translates into a not inconsequential reduction in energy consumption and engine running hours, which the diesel locomotive normally experiences during its long periods of engine idling operation.

LOCOMOTIVE MAINTENANCE AND FUELING FACILITIES

Electrification has the potential to reduce the number of units operated, reduce maintenance cost per unit operated, and reduce costs associated with locomotive fueling and servicing facilities. Savings may be realized in locomotive maintenance and fueling facilities and related manpower when a high percentage of traffic is electrified and a considerable amount of electrified route mileage has been attained. This saving will be a function of the percentage of diesel-electric-related facilities that have to be retained to meet the requirements of switching and light-traffic-density line-service motive power. In most instances electrification of such operations is not feasible.

Locomotive electrical maintenance force and facility requirements are comparable for electric and diesel motive power fleet operations. The traction motors are similar and require similar shop skills and machinery. Control systems are comparable in complexity as are power conditioning systems. The main generator-alternator of the diesel locomotive is replaced by a transformer, which requires very little shop maintenance. Auxiliaries in many cases are identical, but in overall count the advantage lies with the electric locomotive; there are fewer and less complex cooling systems, pumps, blowers, and filters.

With respect to locomotive mechanical system-related maintenance facility and manpower requirements, the diesel engine, associated fuel tank, lubricating oil system, and engine cooling system are completely eliminated. This implies that a considerable reduction may be possible in the number of shop craftsmen, such as machinists and skilled engine mechanics. Also, the requirements for major diesel engine rebuild facilities will be significantly reduced, although travel mileage to and from rebuild facilities may increase unless diesels are worked en route.

To the dieselized railroad, capital costs and operating expenses associated with locomotive fueling stations are not inconsequential. Among these costs are such elements as the cost of the fueling facility itself, including fuel storage tanks, pumps, nozzles, filters, and meters; fuel inventory costs; spilled fuel and waste water collection and treating facilities; engine cooling water treatment and dispensing facilities; lubricating oil storage and dispensing facilities; and transportation of fuel and lubricating oil to fueling facilities. To the extent that electrified operation permits the elimination or reduction in size of fueling facilities, some savings may be anticipated.

The saving in maintenance and fueling facility investments and operations will be very much route specific and will be materially influenced by the percentage of rail operations that may be electrified. Further, it must be recognized that these savings will be of a long-term nature and that these costs in the initial stages of electrification may actually increase because of the requirements for new electric-locomotive-related facilities before it is possible to reduce or eliminate diesel maintenance and servicing facilities.

ENERGY COST AND AVAILABILITY

The cost and availability of diesel fuel as compared with electric energy is a major factor in the decision to adopt electrified railway operation. Because the electrification decision is a long-term one influencing the manner of railway operation for many decades, current and assumed fuel conditions in most instances play a major part in the electrification decision. National concern over oil availability and prices has been a major factor in the decision of many railway administrators in western and eastern Europe, Asia, and Africa to adopt electrification.

Although diesel fuel prices have stabilized and actually declined during the 1980-1985 period, the basic long-term picture of oil resources versus supply remains unchanged. Also, it must be recognized that the world economic and market pressures that have stabilized and then reduced the price of oil-based fuels are subject to change because of international, economic, or political conditions.

Most energy economists anticipate that both electric energy and oil costs will increase at rates related to, but somewhat higher than, the overall inflation rate. Further, the rate of electric energy increase will be from 1 to 3 percent lower than that of oil. Although oil is today in oversupply, it is well known that the exploratory drilling and development of identified fields, both domestically and worldwide, is today at a very low level. Further, the members of the Organization of Petroleum Exporting Countries (OPEC) and probably other exporting nations will, to the extent that their economies permit, endeavor to change the current supply-demand situation.

Because of the indeterminate nature of future fuel availability and costs, North American railways face the problem of making a decision with, in many instances, the most important variable in the economic equation--the electric energy-diesel fuel price differential--for practical purposes almost indeterminate. This situation is further complicated by the lack of a clearly defined and legislated national energy policy in the United States.

Two recent North American main-line railway studies of the Southern Railway and the Missouri Kansas and Texas (MKT) Railroad have indicated substantial fuel cost savings even with present fuel price relationships--$16 million per year for Southern railway and a 25 percent reduction in fuel costs for MKT.

Although electrification in most instances will require substantial investments in signaling system modifications, these modifications, if an innovative approach is adopted, may present in themselves unique opportunities for increased railroad productivity.

In recent electrification studies, the cost of signal reconstruction and interference correction has been estimated at slightly greater than $100,000 per route mile, an amount equal to about 43 percent of the cost of the catenary alone, or 23 percent of the total cost of an electrification project. This reconstruction leaves the owner with a signal system that is no worse than the one before electrification but one that is no better.

A great deal of work is now taking place on new concepts in fully integrated railroad command, control, and communications systems (C^3 systems) to replace the current signaling and communications systems. The new C^3 systems are based on modern avionics technology and have sufficiently low costs and high benefits that it is extremely likely that they may substantially supplant conventional signaling and communications systems within the next 10 to 20 years.

All current systems are based on fixed blocks, which have been the standard since the first railroads were built 150 years ago. Telegraph wire lines were first put into service 145 years ago, electric track circuits 115 years ago, electric wayside signals 80 years ago, and central traffic control (CTC) 50 years ago. Even the most modern CTC system still uses wire line and cabling to send control instructions to wayside cabinets that contain the relays to control the wayside signals that control the movement of trains over the fixed blocks. All those elements--wire line and cabling, wayside cabinets, wayside signal, fixed block track circuits--require expensive modification and shielding if they are to be used on an electrified line.

The new C^3 systems will do away with all those elements. Train control instructions can be sent directly to locomotive cabs via digital data links instead of wayside signals. The instructions will appear on a CRT or as hard copy from a small printer. Precise train location and speed will be determined with a receiver set on the locomotive that receives signals from navigation satellites, and the location information can be sent to the dispatcher and other trains via the data links. The trains will no longer require spacing at fixed block intervals; instead, moving or dynamic blocks surrounding each train will permit a significant improvement in route capacity. The data links and satellite receiver sets will operate at frequencies far removed from that of the electrification and thus will be compatible without major reconstruction costs.

Because the new C^3 systems will have no wayside signals or wayside cabling, their costs will not vary with mileage but rather with the number of trains being operated. However, for comparison purposes, a new C^3 system on a moderately trafficked line with signals is estimated to cost less than half that of a new CTC system.

The benefits of a new C^3 system--improved safety, increased route capacity, lower capital and maintenance costs, potentials for fuel savings, and so on--will occur whether or not a line is electrified. However, once a C^3 system is installed, the cost of electrification could be reduced by nearly one-fourth because many components of the train control protection system would no longer have to be reconstructed or shielded to be compatible with electrification.

ELECTRIFIED RAILWAY SUBSTATION AND CATENARY SYSTEM

The electrified power delivery system must be included in any balanced appraisal of electrified railway productivity. The substation and catenary system represent a capital investment of from $150,000 to $200,000 per electrified track mile, the carrying charges on which must be paid from savings due to electrified operations. Further, the catenary system and substation facilities (if substations are railway owned) will require the organization of a dedicated maintenance force with dedicated depots, vehicles, and other necessary equipment, owned by either the railroad or a contractor.

On foreign electrified railway operations, annual catenary maintenance costs have been in the range of 2 to 4 percent of capital investment. It does not appear unreasonable to anticipate a comparable cost for North American operations.

RAILWAY OPERATIONS AND ECONOMICS

Although, as stated in the introduction, this paper places primary emphasis on main-line freight railroad electrification, the operational and economic benefits to commuter and passenger service productivity will also be addressed. The analysis of each operation includes references to the previously cited motive power and facility characteristics as they may apply to the overall railway operations.

Passenger Service

The greatest single implication of electrification for passenger train operations is attributable to the characteristics of the electric locomotive. The full-time and short-time high horsepower ratings possible in a single electric locomotive greatly surpass what is probably attainable in a single diesel locomotive of comparable weight. It is highly unlikely that a lightweight four-axle locomotive can be built in the United States with a diesel engine rated at more than 4,000 hp. On essentially the same chassis, an electric locomotive can easily be rated at 7,000 hp for continuous duty and at approximately 10,000 hp for short-time duty, as when accelerating after a station stop or following a track slow order or other speed restriction.

This ability to accelerate a passenger train to top track speed is very important in reducing overall running time. It is much more cost-effective and easier to achieve a reduction in total running time by such means than to make track modifications that would permit a higher maximum speed. To a great extent, this short-time power rating can partially offset the need for permanent track realignments that would serve only to reduce some permanent speed restrictions.

The stream of economic and productivity benefits that flows from this characteristic may be summarized as follows: better utilization of passenger cars and locomotives; higher track capacity; higher top speed capability and shorter travel time, thus improving marketing appeal; reduced track maintenance for a given top speed because of lighter-weight locomotives; and faster turnaround time for electric locomotives, leading to a smaller locomotive fleet.

Commuter Service

The principal productivity improvement in commuter rail operations attributable to electrification lies with the high, short-time, power-overload capability of electric traction. Because the traction horsepower is not limited by any on-board prime mover, the power available to accelerate the commuter train after a station stop is limited by the thermal capacity of the traction motors and related electric power conditioning apparatus. The power supplied by the catenary can readily support a temporary 50 percent increase in electric traction horsepower drawn by a commuter train during acceleration.

In many instances, the electrified multiple-unit train may offer the most economical alternative for frequent-stop, high-traffic-density commuter operations. The multiple-unit train, having distributed traction power, can achieve great operating flexibility with respect to the size of the train. The length of the train can be readily converted from two to six cars, for example, with no loss in performance with regard to top speed or acceleration. This flexibility might not be available as readily and economically if a given electric locomotive were assigned to various consist lengths of trailer cars.

Freight Service

If railroad electrification is to develop on a significant scale in North America, it must provide measurable productivity improvements in freight operations on heavy-traffic-density main lines. Experience in Europe and South Africa indicates that train weights and speeds comparable with those of North America can be handled economically and efficiently by electric motive power. Numerous examples of such operations can be cited in the USSR, Poland, Sweden, Germany (both East and West), South Africa, and other countries. An application of the previously cited electrification productivity factors to an actual railway operation, comparing electric versus diesel operation, follows.

Railway Characteristics

To consider the economics of straight electric versus diesel-electric in a freight service operation, some assumptions must be made about the operating environment, type of service operated, and physical characteristics. Any saving (i.e., productivity improvements) incurred results from certain combinations of these factors.

First, the line must have high traffic density. This is a necessity because the basic property of an electrified operation is that of a high initial capital cost, which is recovered by future savings or improvements in motive power costs, fuel expense, and rail operations. In order to recover these expenses, the saving per train mile operated must be at least equal to all electrification-related costs and investment carrying charges.

Next, the line must allow a relatively high rate of speed to be maintained. In this regard, the curvature must be light enough to allow minimal reductions from timetable speed. Gradient is of less importance than curvature reduction, and in this respect, Southern Railway's Cincinnati-Chattanooga-Atlanta line is a prime example. Most sharp curves and some major grades were both eased and relocated in the 1960s. Today, this line permits freight train speeds of 50 mph and TOFC train speeds of 60 mph.

The blend of traffic, especially a mixture of freight and passenger traffic, can provide opportunities for high locomotive utilization, assuming that servicing and turnaround times are rapid enough to fit frequent schedules. Also of prime importance is the requirement for a balanced, two-way operation. If locomotives must be deadheaded back to be in place for a mostly one-way operation, then operating and investment savings are rapidly lost.

Assuming a major trunk line with these characteristics running through mountainous terrain with the modern curvature alignment that is becoming prevalent as 100-year-old roadbeds are improved, economic results in terms of operating productivity will be examined.

The fundamental benefit would be in fuel cost savings per train mile operated. An evaluation at each individual substation location to determine the price per delivered kilowatt-hour may not be possible in a generalized study, but it is assumed that the rate to be paid for electricity will be relatively constant and vary with time of demand. If electricity rates are higher during peak periods, railroads may find frequent scheduling in peak power demand (and thus peak rate) periods unavoidable.

Further, assuming that sufficient tonnage is available to be moved in both directions, with a reasonable mix of foreign, originated, and terminated loads, the amount of electric energy used (in lieu of diesel fuel) will return a significant saving to the railroad, based on the Southern Railway and MKT Railroad studies. Unless utility rates become appreciably higher (or diesel fuel costs substantially lower), it must be assumed that electric locomotives will haul the same tonnage at a lower variable cost per mile. Where grades require a higher ratio of horsepower per ton, electric locomotives will cost less in fuel and variable maintenance expense at all traffic-density levels. When the cited conditions exist, the saving will increase directly in proportion to ton-miles hauled.

Electric locomotive costs now average about 1.66 times those of comparable diesel units. The cost differential may be reduced as electric motive power comes into common use, spreading production and research costs over a larger product base. Even if there is little change in this cost differential in the near future, the available horsepower--nominal and short-time--of the electric unit is greater than that of diesel with the advantage that fewer units are required. A factor that may mitigate this advantage is that the diesel-electric has made great progress in increasing rail adhesion up to 24 percent, and state-of-the-art electric units may be losing the unit-for-unit tractive effort advantage. North American electric locomotives are also rated currently at 24 percent adhesion. However, the electric units can be concentrated in fast, main-line through freight or limited pick-up and set-out service, where their higher unit horsepower and lower energy and variable costs can provide maximum savings.

Considering a moderate reduction in through locomotive units, a second source of savings can come from faster turnaround due to minimal servicing and inspection time requirements. Because there is no fueling and no internal power plant to adjust and monitor, minor cleaning, sanding, and inspection will allow the units to return to service sooner. This will allow them to remain in revenue service a greater number of hours each year and could reduce the total number of locomotives required in the fleet.

Fewer road failures because of the inherently simpler electric motive power will be another benefit. If this is coupled with improved over-the-road time (depending on the gradient and speed restrictions on the line), an additional reduction in the number of units required can be effected. This benefit will exist mainly where service is frequent enough to require motive power as soon as it is available.

Future energy source reliability, both in availability and price, must be a consideration. Currently, the unstable Middle East situation could cut off a major source of world oil supply with one adverse move. Even with North American oil reserves and a deregulated market, there is no guarantee of a constant diesel fuel supply for rail transportation. Further, it appears safe to assume significant diesel fuel price increases during any oil crisis. The supply of electric power tends to be more stable, and although the price is steadily rising, it is probably more predictable for long-range planning. On the average, it is concluded that the fuel cost per train mile will be more favorable with electricity. The Southern Railway estimated in 1983 a fuel saving of $16,000,000 per year if they electrified the Cincinnati-Atlanta route. This figure was based on a 4.10¢/kW·hr and a 90¢/gal energy price. It is reasonable to use the kilowatt-hour fuel bill as constant with cost increases related to general inflation in planning for 5 years or more, whereas there will be more fluctuation and thus another element of risk when future diesel fuel expense is estimated.

Freight Train Operating Productivity Improvements

The relationship between the revenue earned and the amount expended to earn that revenue is the basic operating efficiency measurement that is generally monitored in rail operations. This measurement, known as the operating ratio, is extremely sensitive to variations in train movement expenses, rate changes (and thus revenue changes), or any combination of the two. Fuel and locomotive costs to move a train have increased to the point where they represent more than half the total cost of moving a train. The size of the train crew will generally not be affected by electrification. Railway planners and managers must continue to make strenuous efforts to hold the line on increasing motive power costs.

The maintenance of a locomotive fleet for moving trains represents a significant fixed cost. Although much of this cost is examined under shop and field handling considerations, the ability to reduce servicing and inspection time with electric units will contribute to a higher locomotive availability rate. Because freight cars also incur costs as a function of time, any incurred car cost attributable to locomotive servicing can be reduced with electric locomotives because of reduced unit turnaround or servicing time. In a prior assumption it was stated that the line segment has a sufficiently high traffic density to require fast locomotive turnaround with crews in place and ready for duty.

Reliability is related to locomotive servicing, both in terminals and on the road. Electric locomotives have fewer moving parts to wear and to require lubrication and therefore will inherently incur less down time than diesels. Car-hire costs in and between terminals decrease as delay is reduced, and train crew costs likewise drop with fewer on-road breakdowns. Beyond this direct savings, train delay has a domino effect on the line segment operation because other trains are delayed awaiting these locomotives or connecting cars. Further, trains meeting the delayed train are likewise delayed. Southern Railway currently averages a $260/hr cost for through freight train delay, so it is evident that these costs can represent a significant portion of the operating expense.

On certain line segments, speed restrictions and grades slow the operation of diesel-powered trains. Electric locomotives have an ability to accelerate more rapidly following a speed restriction and can maintain a relatively more constant speed over grades because of their higher short-time and nominal horsepower ratings. This advantage may be reduced if the line segment is basically level without speed restrictions, but in much of the terrain having potential for electrification, this advantage may exist to varying degrees.

This improved train-handling capability will be especially important when there is a mixture of freight and passenger trains. Improvements in freight train accelerating capability can contribute significantly to reducing potential conflicts with the shorter, faster passenger fleet or with high-speed freight trains.

In instances where electrification makes possible a faster, more reliable over-the-road operation, the potential exists for tapping previously hard-to-reach markets. Although much rail traffic is in the bulk-commodity category related to the "smokestack" industries, recent years have seen a decline in this transportation market. If railroads can reach other markets, they can retain a high degree of plant utilization. However, much of this new traffic is highly competitive, and service must be reliable because shippers are now leaning toward "just-in-time" delivery. Considering the narrow profit margins available, railroads will secure this market only through increased reliability, lower operating cost, and competitive door-to-door delivery times. Although electric locomotives are not the sole answer, they can, in selected locations, contribute to reduced locomotive costs, increased on-time ratios, and decreased over-the-road times needed to compete for this traffic.

Operations will also benefit from better train control and handling with electric locomotives. Possibly greater tractive effort at the rail and higher horsepower available to the engineer, together with reliable regenerative braking, make consistency of train operation easier to obtain. This can make progress toward more balanced trains in opposing directions. Currently, track superelevation on curves must compromise between the highest train speed and that of the slowest train, generally upgrade. Any ability to speed up the slower trains will reduce this imbalance and could possibly allow somewhat higher speeds in some locations where the tonnage or upgrade train speed can be significantly increased. This more constant train speed can significantly benefit track maintenance. Where train speed imbalances on curves exist, the slower trains tend to stress the inside rail because the high center of gravity of today's cars transfers the majority of car weight to the inside wheel. Further, where track and train speeds are inconsistent, the potential for derailment due to track deterioration is much higher. The outside rail on these curves is subjected to high wheel wear on the gauge side, which could be reduced if a better match between superelevation and train speed were possible. Needless to say, more consistent train speed will lead to longer rail life, which considering the present price of premium or hardened rail, can represent a significant indirect cost saving.

Mentioned earlier was the high cost of car hire. Although much of this cost is mileage related and will remain constant regardless of a 5-mph or 50-mph train speed, roughly one-third of this cost may relate to time. In that case, the railroad operation must be scrutinized to determine any savings. Passenger operation generally has captive cars that remain within a fixed-charge category based on the trip more than on the hours. In freight operation, many routes may concentrate only home road and privately owned cars, and thus no saving is possible, but in other cases, the hourly charge paid to foreign car owners can be reduced with faster transit times and more reliable schedules made possible through use of electric locomotives.

The potential to handle traffic increases with little additional investment is present with the electric locomotive alternative. Shorter track occupancy times due to faster turnaround times, more reliable locomotives, and faster over-the-road schedules (where possible) can allow the handling of traffic increases without additional locomotive purchases or the construction of additional tracks. This characteristic is railroad specific, but in many instances where the line segment is near saturation, an improvement in train service can be an alternative to increasing the physical size of the plant.

Fuel Handling, Shop Facilities, and Environmental Impacts

In the days of steam locomotives, railroads established fueling and watering points where needed along their route, as well as both minor and major repair facilities. This is still true for the diesel-electric, although these points are not nearly so numerous. Fueling points remain every 100 to 150 mi, although through trains ran 300 to 500 mi between fueling. Electric locomotives do not require refueling facilities nor the handling of lubricants, and if an all-electric operation is contemplated, the potential exists for significant servicing area savings.

Activities related to the purchasing and shipping of lubricants and fuels can be reduced, as can the ownership of fuel cars along with their associated switching and handling costs. Storage tanks can be eliminated and personnel reduced to that required to comply with Federal Railroad Administration (FRA) inspection laws and the minor repairs required by electric locomotives. Locomotives would not have to be cut off from their trains and run to the fuel racks, which in turn could eliminate unnecessary yarding of the train. Southern Railway has this problem on continuous unit coal trains and has had to construct main-line fueling facilities solely for these trains.

Inventories of fuel and lube oil can be greatly reduced. Significant funds could be tied up in the large inventories of these supplies. Further risks related to the speculative nature of purchasing an item subject to such price fluctuations can be reduced. Metering and control of diesel fuel can be eliminated along with the possibility of theft.

These savings will accrue to a maximum extent only in the case of 100 percent electrification with total elimination of diesel locomotives. Most Class I railroads will never do this and will want to have the flexibility of running local and certain other trains with diesel power even though they operate in electrified territory. This decision will mean that some diesel fueling facilities will still be necessary. Selective studies may identify those facilities that may be eliminated, but the major savings will only come about through reduction in size, staffing, and supplying of the remaining locations.

Any reduction in the use of fuel oil will reduce risk of both pollution and penalty fines. Sources of oil spills are attributable to locomotives in derailments, damage to company oil tank cars in transit, spillage during refueling, and loss of fuel from storage tanks or transfer lines. All fueling facilities today must have elaborate containment systems to control any spills. To quantify these savings would require in each case a determination of the level of remaining diesel operation to identify the reduction in fueling apparatus, tanks, personnel, and fuel handling.

Electric locomotives have a repair expense estimated to be 40 to 80 percent (depending on the U.S. railroad considered) of the repair costs of a diesel unit. The possibility also exists to lower fixed expenses through the reduction of major repair installations brought about through the reduced maintenance requirements of the electric locomotives. The greatest benefit would accrue to the 100 percent electrified railroad, whereas rail systems maintaining a percentage of diesel operation still would need some diesel-related facilities.

Southern Railway, in its 1983 study to electrify the line from Cincinnati to Atlanta, estimated that no shops would be closed because of numerous diesel-operated intersecting lines and that initially one shop for electric units would have to be constructed at a cost of $16.5 million. Each railroad operation appears to be case specific, with the major savings incurring to railroads achieving near 100 percent electrification.

CONCLUSION

Electrification offers an opportunity to substantially improve the productivity and transport capability of North American heavy-traffic-density, high-speed main-line railways. Electrification has compiled a worldwide record in meeting rail transportation requirements efficiently and economically. The electric locomotive's higher per-unit horsepower, greater availability, longer life, lower maintenance costs, and lack of dependence on petroleum fuels enable electrification to provide railway planners and managers with a proven technology for improving current and future railroad productivity.

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Principles of Unit-Train Productivity

A. T. LEWIS

ABSTRACT

The premise that the railroad industry must increase both quality and productivity of the railroad transportation product forms the basis of this paper. This increase is brought about by the emerging "just-in-time" manufacturing environment and increasing emphasis on productivity in the U.S. industrial climate. It is argued that knowledge of unit-train principles is important as a method to increase both quality and productivity. Statistics are presented from crew cost and car movement records to show the contrast between controlled service and random or mixed service. Although somewhat theoretical in nature, the discussion calls for setting operating goals to approach unit-train ideals in an effort to control operating costs (crew and fuel), reduce assets employed (locomotives, cars, trackage), and produce marketable, high-quality transportation. The statistical results presented are important in all operations whether they consist of true unit trains or only partly of unit trains.

The future opportunity of railroad operations is likely to lie in the area of precision or "just-in-time" freight service. Although unit-train-type operations have been a major cost control mechanism in the past, it is important to also see them as a precision revenue-gathering mechanism in the future. To this end, familiarity with unit-train characteristics and their control must be gained so that marketable, cost-effective precision freight services can be produced.

In this paper unit-train principles are emphasized, that is, what the underlying operational and delivery system characteristics of unit-train operations are. Once these are clearly seen, the opportunity exists to organize and manage many operations, unit train or not, to produce these valuable characteristics, valuable because they allow increased cost control and the ability to market precision transportation products.

The strong point of railway operations has always been train operations--the ability to move large amounts of goods and materials across the face of the globe with a bare minimum of direct labor and direct energy costs. All other railway operations detract from this singular strong point. Unit trains capitalize on this strength by minimizing support operations while offering to simplify and strengthen the key operation in a railway's economic makeup--trains. To the extent possible, unit-train principles must be understood and applied to other railway operations. The long-distance-freight (LDF) train is a good example. Both the classic unit train and other operations that mimic its characteristics must now become precision freight operations in the new industrial economy forming in the United States.

PRODUCTIVITY DEFINED

Productivity may be defined as the joint productivity of the set of resources employed. Note that the word "productivity" implies that something is to be produced. Now in railway operations, it is often concluded that the product is gross ton-miles. Therefore, productivity might be gross ton-miles (GTM) produced per unit of resource expended. But the equation is complicated because a composite or joint resource employed must be sought instead of a single oversimplified resource such as GTM per gallon of fuel. The concept of a joint resource is not easily understood.

A joint resource is an abstract idea, but an important abstract idea whose formulation is subject to debate. As much as one would like to simplify the problem by restricting its inputs to the individual areas of responsibility, formulation of the joint resource can be simplified only at the risk of misunderstanding the true economics of the corporate product.

But what are these GTMs? GTMs have been a useful statistical reference point in the industry for a long time but could a GTM be sold to a customer? GTMs are only a useful measure, not the real goal of productivity. How about net ton-miles? Maybe railroads' productivity goal is net ton-miles per unit of joint resource used. One can feel a little better about that. How much will you pay for a net ton-mile? How much will a net ton-mile cost?

Both questions are stated with a common denominator--dollars. Therefore, the productivity that must be controlled and improved with unit-train-like operations is a ratio:

$$\frac{\$\text{Revenue produced}}{\$\text{Joint resources expended}} = \text{Productivity} \qquad (1)$$

If this ratio is not greater than 1.0, the job is not worth doing.

Now for a look at unit-train productivity. To do this, a set of joint resources must be identified. These are as follows:

1. Above-rail resources
   a. Crews
   b. Fuel
   c. Locomotives
   d. Cars
2. Supporting resources
   a. Main tracks
   b. Sidings or second main track
   c. Auxiliary tracks
   d. Service or shop facilities

But resources do not stop at corporate boundary lines and control transportation productivity as experienced by the customer. The customer also has resources directly tied to the transportation operation, which cannot be ignored. They are

1. Inventory in transit,
2. Inventory to prevent stock-out (buffer),
3. Warehouse or stockpile space (buffer), and
4. Excess work force to overcome variability (buffer).

An understanding of productivity at this level of joint resource expenditure is needed in today's transportation environment. The relationships among the joint resources must be understood and workable management control to optimize the resource set must be gained. Unit-train knowledge can help do this.

UNIT-TRAIN OPERATIONS

To dwell a moment on details of unit-train operations, the nice thing about unit trains is that they are predictable--they have a uniformity about their character and performance that allows different management. Some of the buffers from the system can be removed.

What buffers might there be? To start with the above-rail costs, the buffers or hidden inefficiencies in the system may be as follows:

- Short crew districts
- Excess crew members
- Excess fuel
- Excess locomotives
- Excess cars

A plot of crew cost per train mile operated versus length of crew district is shown in Figure 1. This plot simply takes payroll by crew pool, divides by train miles produced, and categorizes by crew district length. This plot is taken from actual records and describes total dollar payout. Logical arguments, such as whether "long pools" really pay, aside, the relationship is quite clear: long pools produce lower-cost train operations and furthermore unit-train type operations are conducive to long pools.

Along with giving the unit-train crew a singular "unit" responsibility to move the train over the road, the need for excess crew population goes away. Three-man crews are common practice these days and two-man crews are clearly practical. Although the one-man crew is not advocated here, tonnage ore trains in some parts of Europe are operated with only a mechanic or engineer. Unit trains having no work en route lend themselves to these minimum crew populations.

Figure 2 describes the "hurry and wait" characteristics of railroading. The area under the curve is train miles produced (mph x hours = miles). One plot shows a train hurrying at 50 mph and then waiting for a meet or an unplanned event. The long wait is where a set of cars is disassembled or switched before movement can continue to destination. The net effect of this movement system is an average movement represented by a straight horizontal line. This is the ideal that is sought and unit trains with their uniformity and simplicity of organization can help do that. Uniformity is important for the following three reasons:

1. The uniform operation can be produced with less fuel. Energy is not lost up the stack in high-speed windage losses or wasted with only the braking system to reaccelerate. For example, the difference between 40-mph and 50-mph operations on a railroad system in flat or rolling country is in the magnitude of a 9 percent reduction in road fuel cost.
2. If one does not need bursts of speed because of the environment for uniform operation, one does not need a high horsepower-ton ratio to move trains. The unit-train philosophy can reduce the number of locomotives needed to produce a given amount of GTMs. These locomotives currently cost in the vicinity of $1.3 million apiece and generate approximately $25,000/year average in fixed or nonvariable maintenance costs. The railroad should determine how many locomotives can be reduced from its operations.
3. Unit-train philosophy need not be limited to a slow-speed coal operation. Trailvan (TV) or container trains are unit trains, and here unit-train uniformity is important to capture markets. Uniformity is needed to guarantee a reduced transit time. Figure 3 shows this possibility by dependably compressing the time axis to produce the same ton-miles as the variable mixed-freight operations.

Before freight car savings are added to this presentation, one needs to spend a moment on the understanding of how variability destroys a transportation product. Figure 4 is a plot of frequency versus transit time that shows how cars move in

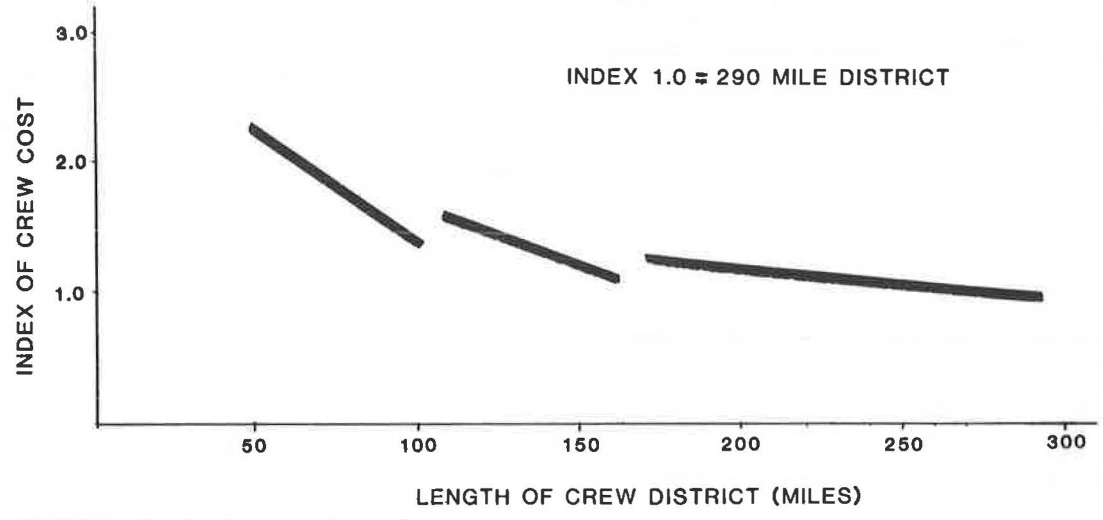

FIGURE 1 Variation in crew cost per mile.

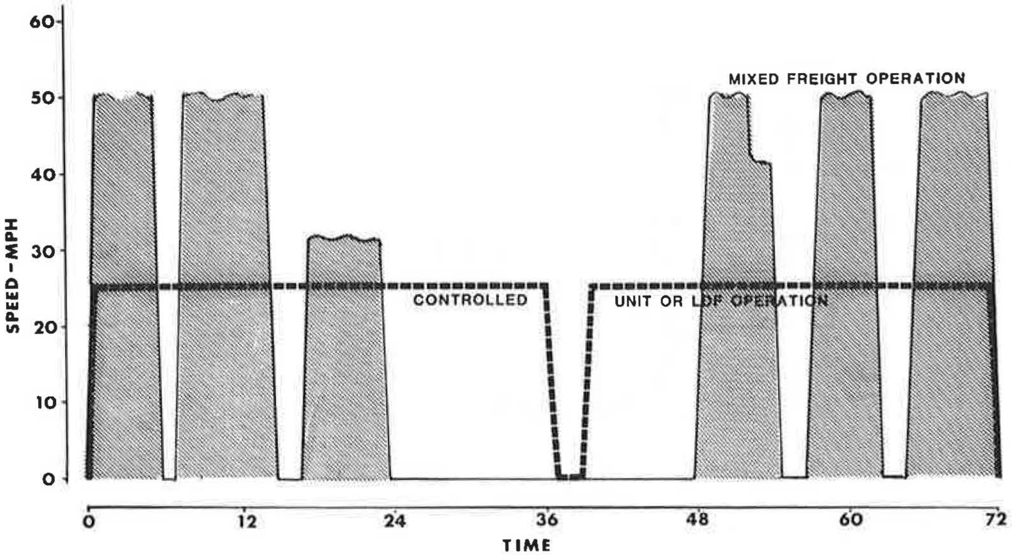

FIGURE 2 Controlled operation to reduce cost.

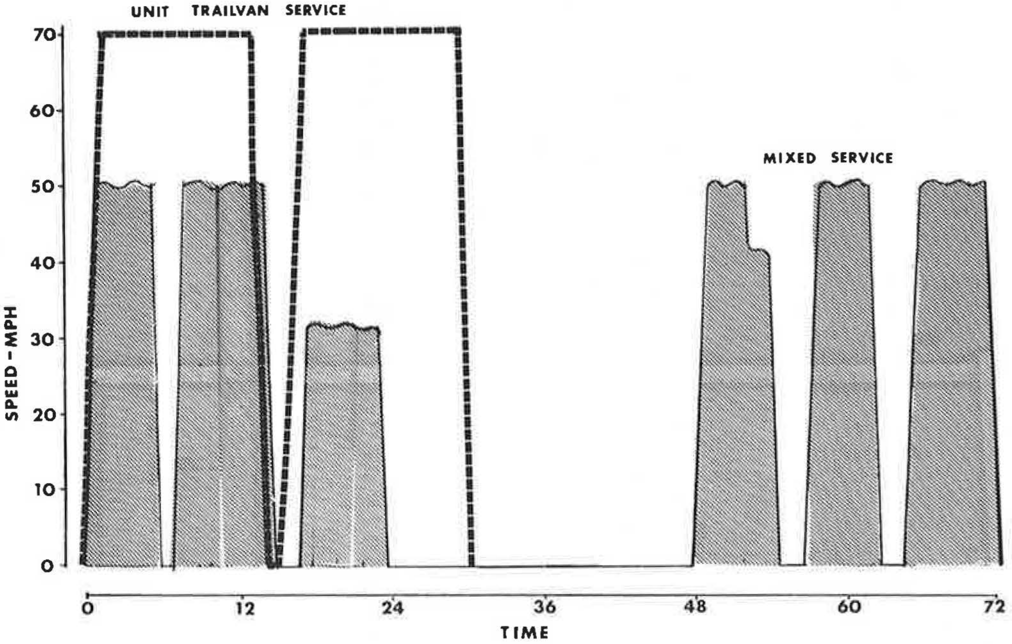

FIGURE 3 Controlled operation to gain market.

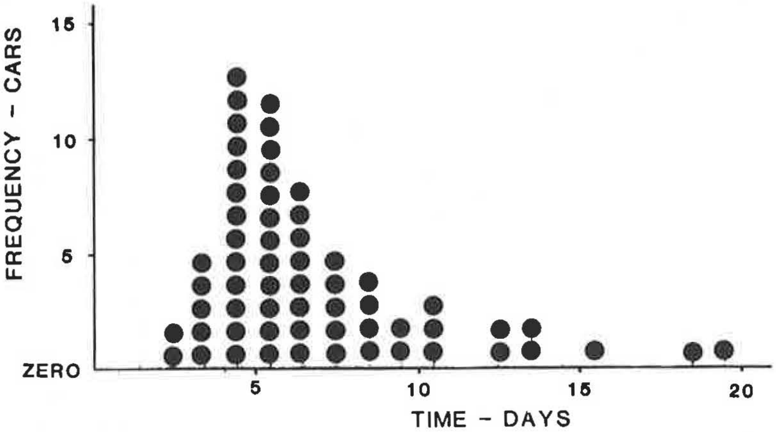

FIGURE 4 Sample dock-to-dock time in mixed-freight service.

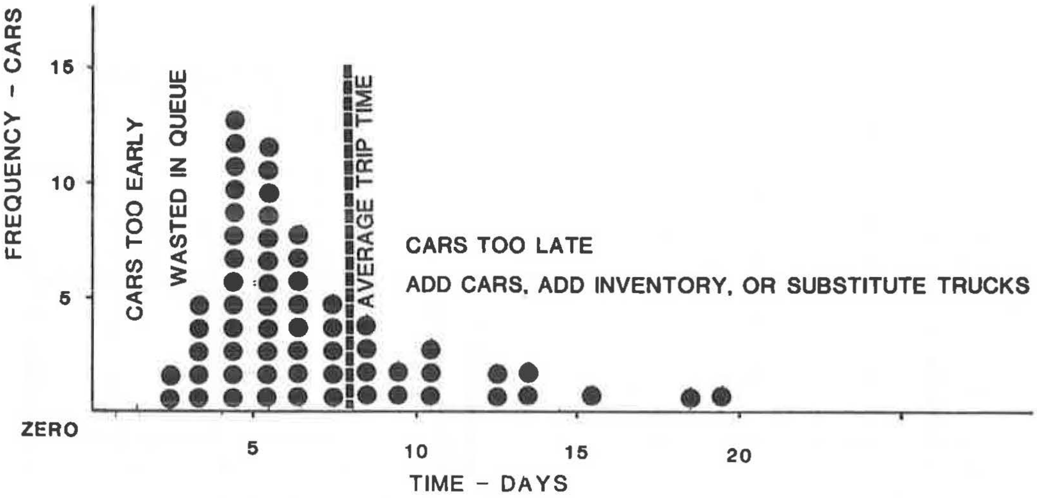

FIGURE 5 Wasted assets in variable service.

mixed-freight service. It is difficult to see how the railroad industry, to say nothing of the customer, tolerates it.

To look at this illustration in another manner (Figure 5), the question is how many freight cars are needed to commit to this service in order to command 100 percent of this customer's business. The average transit time in the sample is 8.4 days. Adding a similar 8.4 days for return, 3 days to load, and 3 days to unload, there is a 23-day car cycle or a yield of 16 loads per year.

But some of these cars have arrived 1 or 2 days too early and their crews are due for a paid vacation in terms of per diem or excess investment before they will do useful work again. The cars to the right of the dashed line are excess cars that one must have available to catch the next load because the slow movers cannot be depended on to get back to the loading zone. But this is ridiculous, so car management reduces the car days committed to this service. This, in fact, is done by playing statistical roulette with a badly variable transportation product. The result is that all railroads have owned too many cars (excess assets) and the companion transportation performance produced has pushed customers one by one toward use of trucks. Unit-train operations have the potential to simplify and attack this area of railroad inefficiency and market loss.

A contrast is provided by two plots of car performance in unit-train service. The first (Figure 6) shows a closely controlled unit coal operation. The second (Figure 7) shows a TV train service. Again use of resources is controlled and assets required can be reduced. An illustration of this efficiency can be found in piggyback car miles per day, which is a considerably higher multiple than the various increments of the general service fleet.

The lesson is that unit-train operations control the car cycle and, by controlling the car cycle, control excess resources. The benefits of precision freight service begin to appear when the car cycle is dealt with.

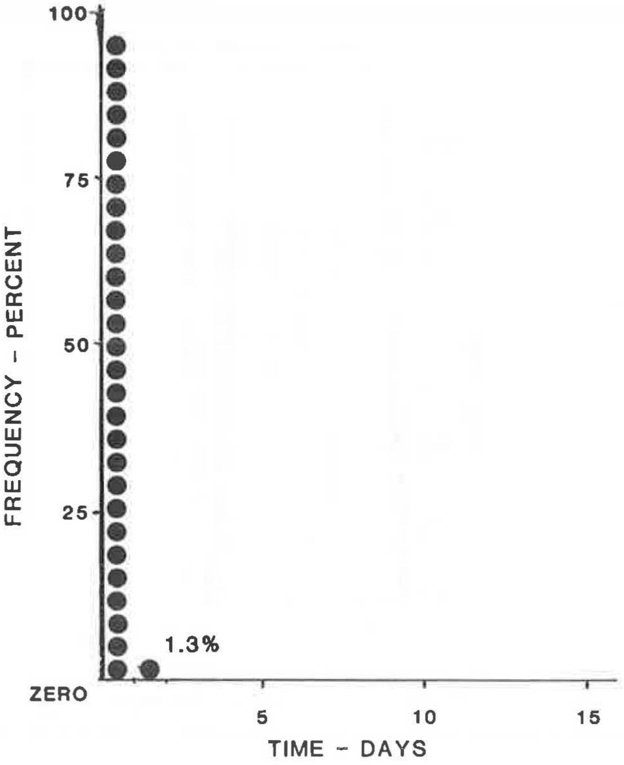

FIGURE 6 Sample elapsed time in unit coal service.

PHYSICAL PLANT PRODUCTIVITY

The productivity of the physical plant may be thought of as ton-miles or loaded car miles produced per mile of track. The point here is to use as little track as possible to produce marketable services. What this means is that double track should be used or retained only when really needed; sidings should be minimized, leaving them only where trains commonly meet; auxiliary tracks should be reduced as close to zero as they can be brought. Figure 8 shows variations in track productivity in different railroad systems. There is a need to be concerned about the productivity of physical plant assets.

It is hard to get the ball rolling in track reduction, but the uniformity of unit-train or LDF operations can provide an opening to attack unproductive physical plant. The railroad should look at its double track and determine where opposing fleets of trains meet day after day and where on this network the traffic is really one way day after day. The occasional train or uncontrolled conflict point

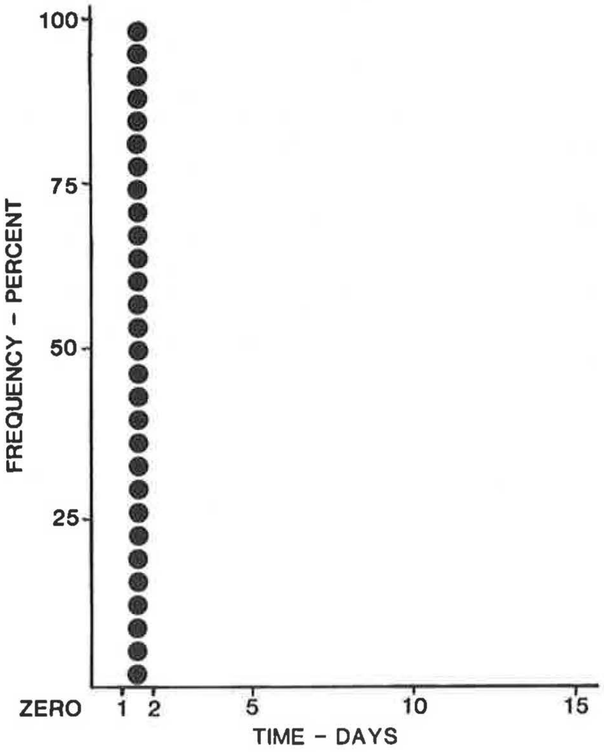

FIGURE 7 Sample elapsed time in TV service.

cannot justify underutilized tracks at today's replacement costs of $0.33 million per mile.

The uniformity of planned unit-train operations becomes doubly important in single-track territories. If one can maintain a planned and controlled operation, sidings need to be maintained only at the locations required for common meetings of trains. Sidings to support random operation are no longer needed.

Another facet of unit-train cost-reduction opportunities lies in reducing auxiliary tracks to zero. If auxiliary tracks are going to be reduced, first the ideal--a regular, 7-day operation that loads and unloads on the main track at each destination--should be visualized. The only additional tracks required are a handful of shop tracks. No switching or sorting, no car storage requirements. Coal, ore, grain, potash, containers, trailers, and tank trains can all operate in this fashion. From a practical standpoint in territories with high-density main tracks, an unloading siding and storage tracks for traffic surges will have to be provided, but classification yards, industrial yards, and low-productivity spur tracks drop out of such a system. Productivity per main track mile and productivity per auxiliary track mile must be part of the railroad equation and unit-train operations can help bring this about.

CUSTOMER-OWNED RESOURCES

Although so far only railroad-owned resources have been discussed, the picture is not yet complete. The customer-owned resources are a part of the economic productivity equation that one ignores only at his peril. The customer resources employed in the transportation operation were mentioned earlier.

Unit trains can address these costs by controlling transit time and variability. Consider the case of the automobile manufacturing plant today. It is not like it used to be. The automobile industry's money is no longer tied up in inventory in transit, buffer stocks, and warehouse space. The traffic manager knows how many hours' worth of inventory he has on the floor--commonly 4 hr. The traffic manager knows the precise transit time and variability that

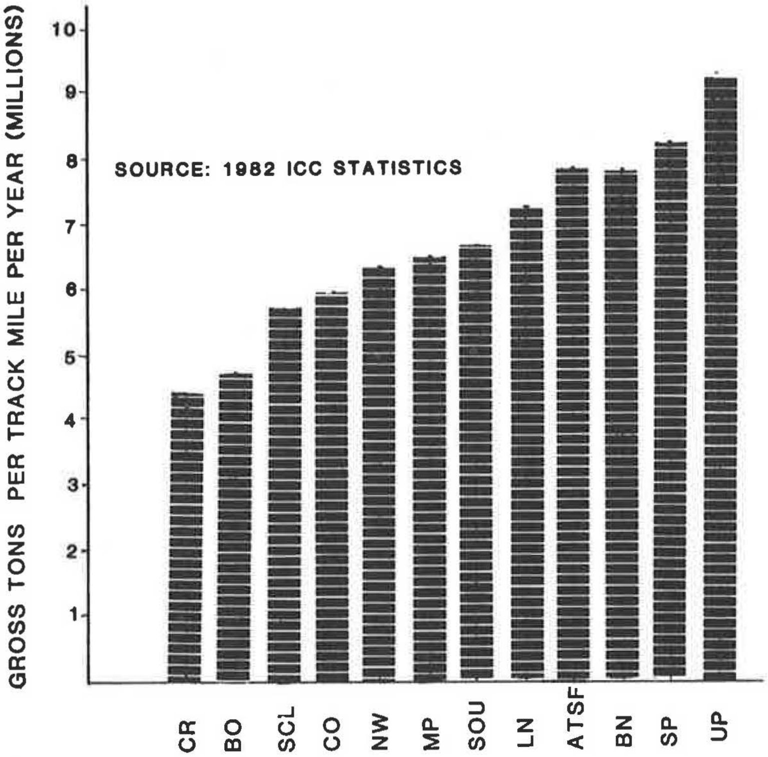

FIGURE 8 Productivity of trackage for various roads.

describe each supply line coming into his plant, for example, 22.5 hr ± ___ hr.

This is the way in which modern industrial America is thinking. And to participate in this renaissance, the railroads must consider the customer resource cost in the productivity equation. It may appear that this has little to do with unit trains but that is not so--the unit-train principles have to be understood. These provide a uniformity of operation that allows the cost elements and service criteria to be controlled. The uniformity allows precision production with reduced crew cost, reduced fuel, reduced horsepower, reduced car fleets (controlled car cycles), reduced support forces, and minimum trackage. These all stem from controlling variability so that resources are not wasted on buffers to isolate uncoordinated operations of labor, plant, equipment, and customer inventories.

Excellent examples of this step forward in the industry can be found. The interplant automobile trains of the Consolidated Rail Corporation, which have three-man run-through crews, operate on utterly reliable schedules between parts plants and assembly plants. Other emerging potentials can be found in the operations of steel distribution centers and lumber drop points. Some of these ideas are still emerging, but the unit-train potential is there.

The problem is not just productivity; it is productivity in a precision freight system. Unit-train operations and operations that mimic unit-train principles stand a strong chance of providing the industry the productivity and precision that it needs. Last, it must not be forgotten that the productivity sought is a ratio (Equation 1) and that productivity times volume leads to profits. Although one likes to think in physical units, the worth of what is done will be measured in dollars by the productivity equation.

Publication of this paper sponsored by Committee on Intermodal Freight Terminal Design.

Optimal Use of Classification Yards

JAMES A. WETZEL

ABSTRACT

Railroad classification yards are an integral part of a railroad network. At these yards cars are classified, assembled or reassembled, and dispatched in trains from origin to destination. The objective of the classification yard is to eliminate reclassification of cars at intermediate yards between origin and destination. The efficiency of the classification yard is determined by its location, design, and operation. The design and productivity of flat and hump yards are discussed as well as a proposed method for upgrading hump-yard analog control systems.

The optimum railroad operating system provides transportation service between traffic origin and destination in the shortest time and at the least cost.

In general, freight traffic is consolidated at a yard located at or near its origin for movement in trains to its destination. The nature and volume of traffic moving between origin and destination pairs govern the frequency of operation and the physical facilities required for providing optimum service. The geometry of the yard design is a function of these volume requirements and the nature of the business. An analysis of traffic flow between origin-destination (OD) pairs will help to determine the optimum location, size, and design of a yard.

Although it is desirable to transport traffic in unit trains directly from origin to destination, it is unlikely--except for the movement of coal, ore, grain, and containers--to find a sufficient traffic volume from a single source to a single destination to operate unit-train service. On the Consolidated Rail Corporation (Conrail) 20 percent of the traffic moves in unit grain, coal, or ore trains, 19 percent in Trailvan (TV) trains, and the remainder (61 percent) in symbol trains that must be classified through yards. Therefore, it is necessary to emulate unit trains by creating through trains between the major gateways of the system. These gateways are identified as freight traffic centers at major industrial locations, intersecting railroad routes, and junctions with other railroads.

The evolution of the large automatic hump yard, which is the key to the optimum rail network, began in 1924 when the first retarder was installed at Gibson Yard on the Indiana Harbor Belt Railroad.

The improved efficiency of the hump yard attracted more traffic, and as motive power increased in size and trains grew longer and heavier, classification yards were required to handle more cars. In the 1950s and 1960s the modern analog computer-controlled retarder yard provided a tool for consolidating more traffic in a single hump yard and eliminating numerous flat and rider hump yards. Railroad mergers of the 1960s and 1970s, deregulation, contract service, and increased competition have resulted in new traffic patterns. Many of the older yards are no longer needed for classifying cars and are being converted to handle intermodal traffic. Some of the remaining yards are therefore required to classify more traffic than they were originally designed to handle and may need restructuring.

Recent trends in modal-choice decisions by shippers could have significant implications on classification yards in future years. There is more of a tendency in the shipping community to reduce in-transit inventories, placing a premium on faster deliveries. The extreme example is the "just-in-time" inventory system being adopted by automobile manufacturers. This places rail boxcar traffic under extreme pressure. For example, between 1977 and 1984, plain boxcar loadings in the U.S. rail industry declined by 69 percent. Similarly, rail piggyback traffic during that period increased 60 percent. The time lost in classification yards is becoming more critical to the railroad industry, and railroads are opting to completely bypass intermediate classification yards wherever possible.

Optimum use of the remaining classification yards may require design modifications to meet the demands imposed by changing traffic patterns.

YARD CAPACITY AND DESIGN

In this paper yard capacity and the design characteristics of both flat and hump yards are discussed and no attempt is made to address the subject of network models such as the Princeton model or the Southwest Research Institute (SRI) CAPACITY model. These computer-based models, however, are useful tools for determining optimum traffic flow. Their application can result in considerable man-hour savings in the necessary operations planning efforts before any major yard reconstruction project. Further proposed changes may become unnecessary when the effect of scheduling or blocking modifications on yard efficiency is illustrated.

Flat Yard: Need, Location, and Design

Flat yards are often required to hold cars in support of major industries and are essential as gathering points for assembling blocks of cars between through trains at intersections of principal routes.

An efficient flat yard can be designed to handle and classify as many as 1,000 to 1,200 cars per day. The former New York Central Suspension Bridge Yard (Niagara Falls, New York), now operated by Conrail, is a good example of a high-production flat yard (Figure 1). Before the construction of Suspension Bridge Yard, inspection trips to several new and older flat yards throughout the country were made to observe the operations at these facilities. The Illinois Central Landers Yard and Indiana Harbor Belt Norpaul Yard at Chicago as well as the Kansas City Southern Facility at Shreveport, Louisiana, were visited and analyzed to determine the most efficient size and geometry for a flat yard. Any design selected was a compromise to accommodate the variation in car characteristics; however, the following profile appears to provide the best solution.

In general, the proposed yard grade (Figure 1) of the ladder was -0.27 percent (normally an accelerating grade) and -0.15 percent throughout the body. Velocity head calculation for an average car with a rolling resistance of 4.4 lb/ton and a variance of 2 lb/ton for the easy-rolling car and 6 lb/ton for the hard roller appeared reasonable. (Head loss from curve resistance was selected at -0.025 ft per degree of central angle.) The track design employed a tandem ladder configuration using number 8 turnouts and a ladder angle of 19.5 degrees. The use of the tandem ladder for Suspension Bridge Yard had the advantage of a shorter ladder, resulting in less walking for the switchman and a shorter distance for the cars to travel to the clearance point, thus reducing catch-ups. The disadvantage of the tandem ladder is the length of curve from the switch point to the clearance point. Accelerating grades of -0.5

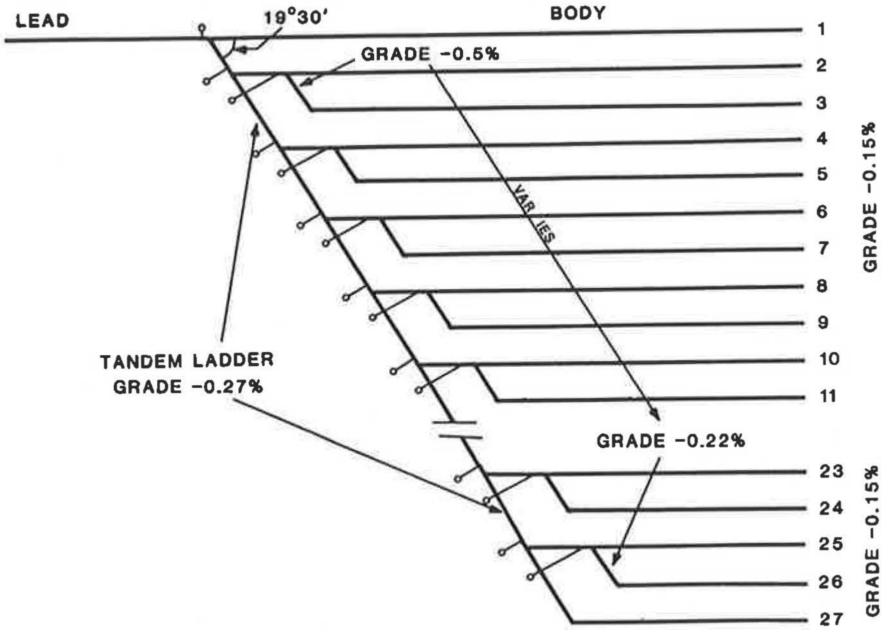

FIGURE 1 Suspension Bridge Yard, Niagara Falls, N.Y.: ladder configuration and grades.

to -0.2 percent were designed through the curve section.

Suspension Bridge and other flat yards constructed to these specifications have proven successful in cases where traffic density does not demand or justify the expense of a complex computer-controlled hump yard.

Hump Yard: Need, Location, and Design

Hump yards are needed for consolidating and classifying large volumes of traffic within a short time schedule for movement to destination. Location is governed by origin or destination volume or both. The optimum use of the hump yard is based on the economics of consolidating traffic for movement between origin and destination utilizing new or existing yards and facilities. New traffic patterns demand higher productivity from existing hump yards.

Hump-yard productivity is generally governed by the design and operation of the facility. The operation includes arrival and departure train schedules, total number of trains, and car volume and classification distribution. The design includes not only physical configuration but the sophistication of the yard retarder control system as well. The function of a hump yard can be analyzed in two steps--the humping or sorting operation and the pulling or train-makeup operation.

Hump productivity is measured by the number of cars humped per day and is generally governed by the number of cars available for switching. Productivity is usually less than the capacity of the hump. The hump capacity is limited by the facility design and the ability to obtain maximum utilization of the hump and humping speed. Time between trains and time spent "trimming" (shoving track or reswitching cars routed to the wrong track) decreases the hump utilization. A good yard design will provide a facility for minimizing this lost time between trains and the amount of trimming necessary. Trimming is usually caused by stalling of cars before they reach coupling or by catch-up (when cars enter retarders or the switch protection circuits before the preceding cars clear). Catch-ups are caused by cars with wide variance in rolling resistance (usually an easy-rolling car requiring heavy retardation followed by a hard-rolling car requiring no retardation). The humping rate (cars per minute over the hump or miles per hour of humping) is controlled by the catch-up problem.

High-production yards are designed to separate cars as quickly as possible by providing a steep accelerating grade (5 percent) from the crest of the hump. The hump crest should be on a 100-ft vertical curve. Most of today's modern yards use a two-point retarding system--automatic speed control and switch operation. Some of the older yards built in the late 1920s to early 1950s have master, intermediate, and group retarders. These yards were operated from a series of retarder towers where speed was manually controlled to maintain car spacing for manually lined routes. A few of the new high-production yards of the 1980s are equipped with a three-point retarder system. The third retarder in these yards is located on each classification track at the tangent point.

The use of this system permits higher velocity of cars from the group retarder through the "fan" (switch system for routing cars into the classification tracks), thus reducing the potential for catch-up. Use of tangent-point retarders will increase the humping rate from between 2 and 2.7 mph to between 3 and 3.5 mph. (Two pinpullers are required to maintain this high-speed humping rate.) Although the humping rate can be increased and car control improved through the use of tangent-point retarders, the additional cost of this equipment is difficult to justify.

Most modern yards utilize a two-point control system--master and group retarders. The yard may have two master retarders, depending on the total tracks in the yard, and one group retarder for each 6 to 10 tracks.

The first modern retarder control systems were introduced in the early 1950s. These systems included remote-control switch machines using relay logic for establishing routes from the hump crest to the classification tracks and an analog computer to automatically control the car speed through the retarders. These systems are now obsolete and are candidates for replacement with microprocessors programmed to route cars to their preassigned classification track, control speed for damage-free coupling, maintain performance records, control locomotive humping speed, and furnish a perpetual inventory of cars within the yard. Most of the old clerical functions of keeping the car records in the yard are absorbed within the microprocessor system.

MICROPROCESSOR SYSTEM

At Conrail, plans are being finalized to upgrade the five obsolete analog-controlled yards to a modular microprocessor system. Expectations from the modular approach using microprocessors are as follows:

- Reduce computer hardware costs,
- Reduce maintenance costs (replacement of smaller computers when required),
- Reduce cost of redundant back-up equipment,
- Interface with present field equipment,
- Expansion to include additional controls and track design changes,
- Adjustment for automatic fine-tuning speed control,
- Ability to be installed to operate in parallel with the analog system (avoidance of shutdown for conversion),
- Installation and testing of each module separately before "cut-in,"
- Interface with the management information system (MIS), and
- Upgrading of older manual retarder yards by selected modules.

Although the final design of the analog conversion has not been selected, the preliminary proposal subdivides the control system into six principal functions. Each function is programmed to operate independently and, through interconnected circuits, to relay data to the succeeding modules. The six principal modules include

1. Operating data link,
2. Automatic route and switch control,
3. Classification-track and distance-to-coupling measure,
4. Rolling-resistance measure and retarder exit speed calculation,
5. Retarder control, and
6. System testing and diagnostics.

Module 1 (operating data link) is designed to receive information directly from Conrail's MIS. It will have the capacity to store all trains and cars en route, trains and cars in the receiving yard, cars in the classification yard and the car repair facility, and cars and trains in the departure yard. As the switching operation progresses and additional data or data corrections are received, this module will continue to be updated, transferring information from the en-route file to the receiving-yard file, to the classification-yard file, to the departure-yard file, and to Module 2.

Module 2 (automatic route and switch control) is designed to receive data from Module 1 and, in parallel with Module 1, to receive data from the yardmaster or operator (or from both) governing the yard operation, that is, swings, add car, missing car, catch-up, switch failure. Module 2 is programmed to automatically route trains from the road to the assigned receiving yard track and to the hump and cars from the hump crest to the classification yard. Module 2 is designed to control the hump locomotive operating speed. Updated switching data are automatically transferred back to Module 1. After switching has been completed and corrections identified, Module 1 will be updated and an as-hump list printed.

During the humping process car identification and classification information will be transferred from Module 2 to Modules 3 and 4.

Module 3 (classification-track distance-to-coupling measure) is designed to provide continuous surveillance of the classification track distance from the clearance point of the group switch to the last car and to transfer this information to Module 1 for the track capacity table and to Module 4 for calculating retarder exit speed. Module 3 is also programmed to measure car rolling resistance on tangent track and to relay this data to Module 4, where a performance table will be maintained for actual rolling resistance measured on each track and for each prescribed weight and general car type.

Module 4 (rolling-resistance measure and retarder exit speed calculation) is designed to receive velocity measurements of cars rolling over the test section and to correlate the acceleration, car weight, distance to coupling, curve resistance, and car characteristics with the actual performance table to compute the desired retarder release speed for the master and group retarders. The equation will also recognize ambient temperature, wind velocity and direction, moisture, and car surface area and will modify the release speed calculation accordingly. Information derived from Module 4 is transferred to Module 5 and back to Module 1 to be tabulated with performance data used in Module 6.

Module 5 (retarder control) receives the information from Module 4 and also receives the weight rail and radar speed measurement for applying retarder pressure to reduce the car speed to the predicted release from the master and group retarders. The actual release speed from the master and group retarders is transferred to Module 4 along with the initial tangent-point velocity for calculating the curve component used in the retarder release speed equation. Performance data from Module 5 are transferred to Modules 1 and 6.

Module 6 (system testing and diagnostics) is the testing module designed to simulate the entire sequence of operation and to test each function of mechanical and electrical performance, identifying all malfunctions.

TRAIN MAKEUP

The second step in the general yard design deals with the track configuration and the train makeup abilities of the yard. There are three basic components in all hump yards--the receiving yard, the classification yard, and the departure yard. The configuration of these components can range from a straight in-line style to a totally parallel style, or any combination of in line and parallel (Figure 2). For example, the straight in-line yard has a receiving yard in line with the classification yard and the classification yard in line with a departure yard. This configuration provides for one-direction movement from the entrance of the receiving yard to the exit from the departure yard. The early hump yards were in-line designs. The main problem with this design is congestion at the makeup end of the yard caused by doubling or coupling blocks of cars from separate classification tracks while trains are being assembled.

Most modern hump yards and all of Conrail's major hump yards built since 1954 have departure yards parallel to the classification yard. Frontier yard at Buffalo, Big Four Yard at Indianapolis, and Buckeye Yard at Columbus, Ohio, have both the receiving and departure yards parallel to the classification yard. At high-volume yards, such as Elkhart and Selkirk, where the predominant traffic volume arrives and departs in long road trains, the departure yard tracks are located on each side of the classification yard and the receiving yard is in line with the classification yard.

The critical areas of a major high-productivity hump yard are

- Entrance to and exit from the receiving and departure yards,
- The area between the receiving yard and the hump crest,
- The area between the hump crest and tangent point of the classification tracks, and
- The area between the classification tracks, pull-out leads, and the departure yard.

These areas should be designed to eliminate congestion and interference.

CONCLUSIONS

Advantages of parallel receiving and departure yards, as listed by the Union Pacific Yard Design Group, are as follows:

- Outbound trains can be made by handling 25 to 40 cars each move, thereby enabling switch engines to move at a faster rate.
- The classification yard is supplemented. Larger blocks are allowed to be set out, thereby reducing congestion in the classification yard.
- Clerical personnel are allowed to perform a portion of the clerical work before the train is called.
- Mechanical personnel can perform light repair before the train is called.
- Bad orders can sometimes be detected before the train is called.
- They can be designed to serve as receiving yards in emergency situations.
- Company road crossings are never blocked for long periods of time.
- All operations can be viewed from one strategic location, enabling reduction in overtime by yard crews and terminal time by road crews and improving efficiency of the entire terminal.
- All departure tracks can be utilized for train makeup.
- It is not necessary to hold the departure track clear for returning trim engines.
- It eliminates the hazards of yard engines moving back and forth through the departure yard, endangering mechanical employees who are working the trains.
- Outbound road engines can be hosteled to departure tracks ahead of the actual call time, reduc-

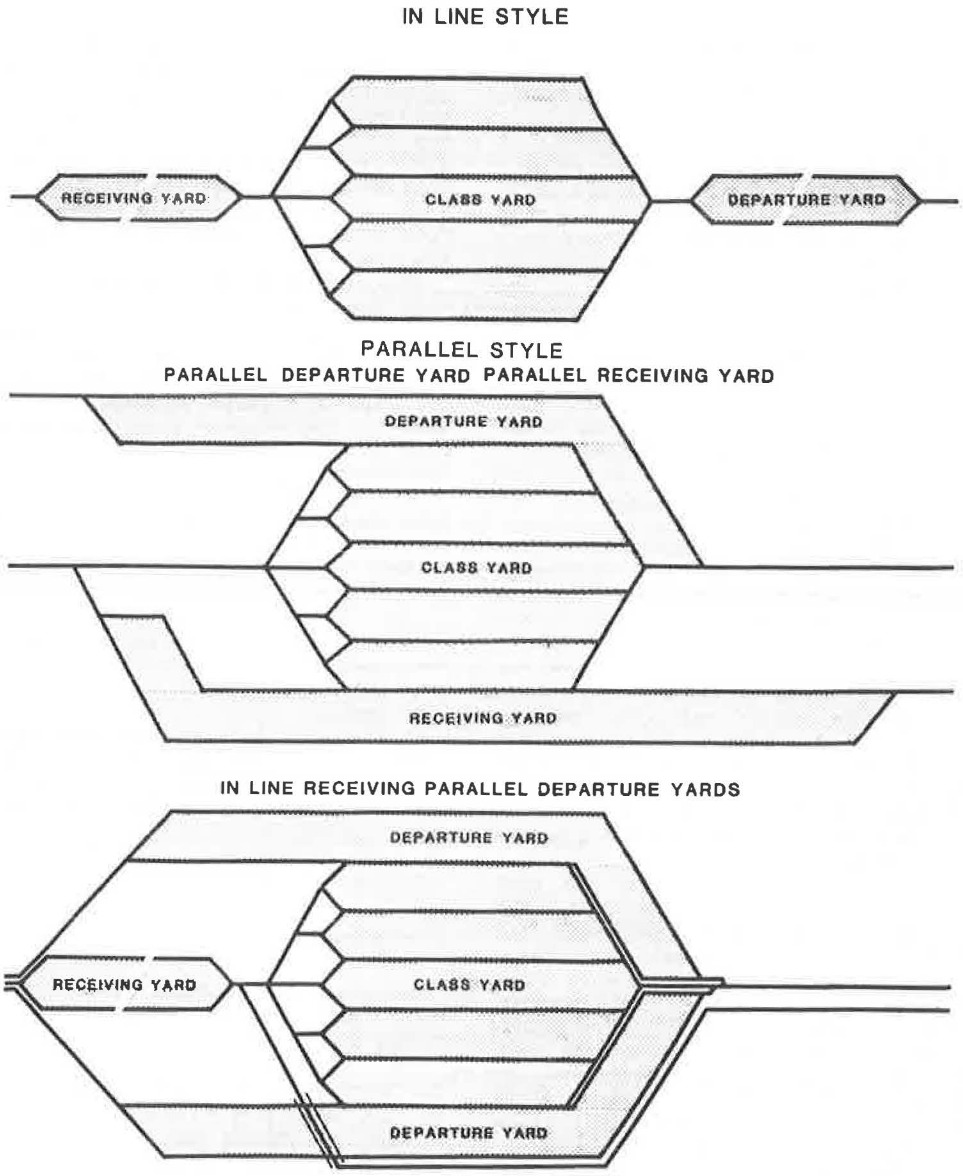

FIGURE 2 Hump yard types.

ing congestion in the shop area as well as terminal time for the outbound crew.

- A parallel departure yard reduces the length of the entire yard, which in turn reduces the terminal time.

The general design specifications of an efficient hump yard are as follows:

- The yard should be designed to maintain the shortest distance between entrance and exit within the critical areas of the yard.
- The length of the receiving yard and departure yard should be sufficient to hold the longest train.
- The track length in the classification yard should be a minimum of 30-car capacity, with the longest track in the center (teardrop design).
- The ladder on the pull-out end of the yard should provide for parallel-simultaneous pull-out crew operation for transferring cars from the classification yard to the departure yard.
- The pull-out ladders should be tandem design with twice the frog angle construction.
- The pull-out leads should be on a zero grade and extend 10 car lengths longer than the longest classification track.
- Power-operated switches should be provided for automatic, programmed route control between the classification yard and departure yard.
- The classification track fan switch configuration should be designed for 10 track groups.
- The classification tracks should be constructed with a maximum curvature in the fan of 12 degrees 30 min.
- Inert or skate retarders should be installed on a plus grade of 0.3 percent starting 300 ft from the clearance point of the pull-out ladder.
- The hump lead should be as short as possible with a maximum curvature at the base not to exceed 820-ft radius.
- The vertical curve at the crest should be 100 ft with the lead on a +3 percent grade and the grade between the crest and master -5 percent.

- The pin puller walkway should be constructed on the right side of the hump lead.
- Wide track centers (19 ft) should be designed between the receiving yard tracks and between departure yard tracks.
- The departure and receiving yards should have a maximum grade of ±0.15 percent.
- The car repair facility should be located parallel to and between the classification yard and departure yard.
- The locomotive service facility should be located between the departure yard and receiving yard.

Publication of this paper sponsored by Committee on Rail Freight Classification Terminal Design.

Burlington Northern Railroad's View of Intermodal Hub Centers and Their Impact on Productivity and Customer Service

WILLIAM E. GREENWOOD

ABSTRACT

Burlington Northern Railroad (BN) has almost completed the establishment of its network of intermodal hub centers. Since 1982, BN has consolidated 140 rail ramps into 20 hub centers and 21 satellites (some rail, some highway) while expanding the geographic scope of service. BN's hub centers are the key component in implementing two additional strategies: (a) new-technology rail and trailer equipment operating between hub centers on dedicated trains and (b) customer-responsive products and charges. BN hub centers are organized and used as marketing units rather than just as operating entities. Each hub center is regarded as an entrepreneurial joint venture, responsible for sales and pricing as well as operating and administrative functions. Hub center management teams make their own decisions to balance revenues and costs to improve the value of service to the customer and enhance the common profitability. Hub centers are demonstrably more productive than traditional ramps in equipment utilization and cost containment while simultaneously improving service to the customer. Hub centers not only have increased total traffic volume for BN, but also have made possible partnerships with motor carriers to produce new intermodal traffic that formerly moved only by highway. BN's hub centers are proving to be the type of decentralized, customer-responsive organizational structures needed to compete effectively in a deregulated environment, and they have produced a corporate culture conducive to manageability and commitment.

Burlington Northern (BN) began its intermodal hub center program in October 1982 with two pilot hubs at Minneapolis-St. Paul (Midway), Minnesota, and Portland, Oregon. During a 6-month test period, the intermodal growth rate for Midway was 40 percent and for Portland 60 percent.

This improved growth rate, gains in productivity, and better customer service were the primary reasons for BN's expansion of its hub center program. To date, BN has consolidated 140 rail ramps into 20 hub centers and 21 satellites (some rail, some highway) operating under the supervision of hubs and expanded the geographic area served by BN Intermodal.

BN hub centers consolidate high-cost, low-volume rail ramps into efficient shipping and receiving depots for intermodal service. Because they are specialized and have new-technology rail and trailer equipment, BN hub centers generate enough traffic to justify dedicated train service connecting them.

Organized as marketing units under the leadership of managers with motor-carrier experience, BN hub center management teams are responsible for sales and pricing functions as well as operations and administration. This helps each manager and his team create customer-responsive products and charges while managing his business on a profit-and-loss basis. As a result, hub center management teams control most costs and revenues and are able to make trade-offs necessary to meet customer needs profitably and in an entrepreneurial manner.

OPERATIONS

The basic operating functions of the hub center are ramping and deramping trailers, equipment maintenance, and dock pickup or delivery within the hub market area as needed. BN hub centers have used the highway networks to expand their operations up to a 250-mi radius and reach customers never before served by the railroads. This expansion of market area allows BN to compete for a share of the more than 90 percent of all the trailer loads that move exclusively over highways and that otherwise would never consider using rail service.

It is important to note, however, that BN seeks to work in partnership with motor carriers. The key is to find situations where intermodal transportation simultaneously benefits BN, the motor carrier, and the customer. For example, many regional truck lines have 48-state operating authority but no effective way to exercise it. BN can arrange either to pick up the load at the shipper's door or to deliver it to the receiver's door in cooperation with a regional motor carrier who completes one portion of the haul.

Another example in which BN works together with motor carriers is trailer utilization. By finding situations that are backhauls for BN and headhauls for the motor carrier, equipment and rate packages can be fashioned that benefit both the transporters and the customer as well. This type of situation works within the confines of the hub center's 250-mi radius or between hub centers. In either case, it produces a system where trailers rarely run empty and tractors rarely bobtail.

SALES

Each hub center has a sales manager to assist the hub manager in assessing and meeting customer needs. The sales manager

- Develops and implements profitable sales plans,
- Has direct responsibility for key accounts,
- Supports other sales personnel with accounts within the hub center's radius, and
- Establishes programs and product packages to develop new business.

PRICING AND ACCOUNT MANAGEMENT

Hub center management teams are empowered to negotiate rates and custom-tailored packages of options and prices with individual customers (noncontract patrons). Although sales teams are provided with floor rates for both rail and highway movements under which they may not quote without consultation with BN Intermodal, each team is essentially free to tailor packages of options and pricing without corporate-office ratification.

This decentralized marketing structure is vital to BN's efforts to provide customer-responsive products and charges. Experience has shown that consultations with BN Intermodal are rarely needed and that monthly profit-and-loss statements and other indicators provide adequate monitoring of the system.

In addition to the sales force operating in the hub centers, BN continues to have account managers at both regional and system locations for those customers who need them. Also, BN currently is implementing a ZIP-code pricing structure to make it more convenient for customers to use BN Intermodal.

ADMINISTRATION

All clerical functions, including reporting and billing, are consolidated in the hub centers. This provides optimum response to customer needs as well as improved teamwork and overall business cohesiveness. Clerical functions are being automated as quickly as possible to free administrative personnel to work on solving potential customer service problems before they actually occur.

ASSESSING PROFITABILITY

Because the hub center management team has direct responsibility for both structuring the product and pricing it, a monthly profit-and-loss (P&L) statement is used to measure cost and revenue at each hub center. The P&L statement

- Is computer-generated;
- Is done on a marginal cost basis;
- Portrays revenue to and from each hub center, with attendant expenses (both line-haul and hub-center-specific), so that each hub center management team can gauge the effectiveness of product and pricing decisions; and
- Provides an accurate picture of cost containment, quality of revenue, and return on assets to hub center management teams closest to customers and best able to react to market needs and changes.

HUB CENTER RESULTS

BN's hub centers have played the key role envisioned for them in implementing the new-technology and dedicated-train and customer-responsive strategies. Their combination is producing a synergism in which each strategy enhances the others' effectiveness and growth.

For example, BN currently is running 10 dedicated trains, compared with four 2 years ago. More than 300 new-generation rail platforms and 1,500 new trailers (102 in. by 45 ft) equipped with BN's new innovative floor tie-down device have been acquired.

Significant rates of growth have been achieved, thanks largely to hub center operations. Between 1982 and 1984, hub center strategies and the intermodal team produced a 40 percent growth in volume. In 1984 alone, volume was up 25 percent. It is important to note that the large portion of this growth is from new intermodal traffic that was converted from what was previously all highway movement through partnerships with motor carriers.

The hub centers have contributed to better and more reliable service by BN Intermodal by providing mechanized lift capability (including the ability to lift privately owned trailers not equipped with lift pads), plus reduced potential for loss and damage due to the reduced slack action of the new equipment and dedicated intermodal train operations that avoid classification yards.

In the area of equipment utilization, the hub centers have increased BN's hitch utilization ratio 15 percent, despite the complexities of matching varying trailer lengths and destinations. As a result, fewer railcars are handling more units, with commensurate per diem expenditure reductions. Also, BN's trailer fleet utilization rate has improved.

The hub centers also have helped control and contain BN's costs of improving customer service. The substitution of highway for rail-feeder service within the 250-mi opportunity radius surrounding each hub center has produced equipment per diem savings that more than offset the increased highway drayage costs. Using a competitive bid process for drayage and ramping services has controlled the cost of providing these services, thereby expanding BN's competitive range.

Finally, the hub centers have helped BN to improve its corporate culture both organizationally and philosophically. Each hub center is very much an individual entrepreneurial joint venture, responsible for its product and profit. Line personnel have a high degree of autonomy in their tasks. Basically, they are asked only to do their best and to produce a product that works and is profitable.

Hub center team members have responded in very positive ways. For example,

- Hub center personnel helped design BN's new floor tie-down system for trailers;
- Hub center personnel invented lift shoe adapters that permit older lift devices to handle wider trailers plus enable all BN lift equipment to safely handle privately owned trailers that do not have lift pads;
- Hub center personnel adapted weight scales from the logging industry to intermodal use, so that each unit is weighed as it is lifted;
- Hub center personnel have absorbed a near doubling of business volume without requiring additional help; and
- Quality personnel are trying to be transferred into the hub centers, not out of them.

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New Concepts in the Control of Train Movement

PETER J. DETMOLD

ABSTRACT

The concepts on which the Advanced Train Control Systems project is founded are described. These are of two kinds; there are the technical concepts on which the systems will be based and the organizational principles that permit the North American railroad industry to initiate a quantum improvement in this specialized technology. Both are described. The Advanced Train Control Systems project is a cooperative endeavor on the part of the railroad industry to control the use of their resources in a more cost-effective manner. The substantial increases in the productivity of labor and capital to be expected from their use will include savings in fuel, maintenance of rolling stock and track, and savings from the better utilization of motive power and cars as well as from the increase in route capacity obtainable at any level of investment in track. The project constitutes a step in the direction of automation.

The concepts described in this paper may be new, but the notion that productivity in industrial countries should follow a long-term rising trend--albeit an intermittent one--is as old as the Industrial Revolution. It is as old as the idea that the progressive advance in science should enable the industrial work load to be accomplished with a decreasing proportion of the time of the work force and increase leisure time and free labor to make new products.

The history of transport in general and of railroads in particular is one of increase in the productive use of labor, material, and resources. The railroads of the United States and Canada have already achieved a high level of efficiency in these areas and this observation extends to the central train control (CTC) signaling that is in general use. On the two major Canadian railways, for example, the productivity of labor in all trades involved in transportation in man-hours per gross ton-mile moved has grown at an average rate in excess of 6 percent per year since 1968. It must be added that increasing lengths of haul and the proportion of traffic made up of large unit trains of bulk freight have contributed to this surprising statistic.

However, some are concerned that many of the sources of technical advance that have served well over many years are nearly fully exploited. By the end of the decade, a technical plateau may well have been reached from which further progress in these areas would be both costly and difficult to achieve.

During the last decade the Track Train Dynamics program of the Association of American Railroads (AAR) has thoroughly explored the means of squeezing the last modicum of reduction in specific resistance to traction through improved metallurgy, track lubrication, and train stability, among other measures. Aerodynamic improvements and the use of the radial truck offer further savings.

Similarly, the High Productivity Integral Train project is encouraging the supply industry to pare down the tare weight of freight cars and, incidentally, to eliminate some of the causes of high cost in locomotive and freight car maintenance. Also, recent advances in the design of motive power have achieved substantial improvements in fuel consumption and an increase in haulage capacity in freight service of around 35 percent compared with the designs of the mid-1970s. And train information systems have started the caboose on its journey into folklore.

But once the benefits from these important developments have been exploited in revenue freight service, further advance must await the development of improved materials, less costly manufacturing techniques, or some major innovation. By 1990 scientific analysis and engineering technique may well have exploited to the full the design of the freight train and its track as currently envisaged.

Progress has not been confined to trains. Hump yards have been automated. Track re-laying has been highly mechanized. Workshop procedures have been streamlined. Computerized information systems abound. And computerized dispatchers' aids already predict the most favorable "meets" (passing places on single-track routes).

Substantial though these fields for improvement may be, it is doubtful whether collectively they would be sufficient for the productivity of railroads to continue to keep pace with the growth in the productivity of labor in all U.S. industry, which has averaged a rate of about 3 percent since 1980. Research and development expenditure in the United States has been rising year by year since 1977, suggesting that further increases in productivity are in store. Should railroads not continue to keep pace with this general progress, inevitably the scale of their operations will decline.

How should it be made certain that the rate of productivity increase in railroading equals and hopefully surpasses North American averages? The best prospects appear to be through the more efficient use of resources, that is, by controlling operations more efficiently so that the maximum possible output is achieved per unit of investment in track, motive power, freight cars, terminals, and workshops and per unit of expenditure on labor, fuel, and other materials.

ADVANCED TRAIN CONTROL SYSTEMS PROJECT

The Advanced Train Control Systems project results from this basic premise that the principal area for technological advance in railroading is likely to come from the improved means of controlling operations. This prospect results from the enormous advance in the state of the art in microelectronic technology that has taken place during the last two decades in the aerospace, defense, and computer industries. All through history, railways have often borrowed the means of major technological advance from other industries. The steam engine, for example, was originally designed for pumping water from mines; the diesel was used in trucks long before its introduction to railroads on a substantial scale. Why not once again convert scientific developments from elsewhere to improve the economics of railroading?

With such thoughts as these in mind, the following seven railroads got together in September 1983 to write the operating requirements for these new systems:

- Algoma Central Railway
- British Columbia Railway Company
- Burlington Northern
- Canadian National Railways
- Canadian Pacific Limited
- Norfolk Southern Corporation
- Seaboard System Railroad

In the summer of 1984 they were joined by the Southern Pacific and the Union Pacific. And the Consolidated Rail Corporation (Conrail) and the Santa Fe are now supporting the project, which will be managed in a joint operation involving the Railway Association of Canada and the AAR and specialized personnel from participating railroads. First the basic concepts around which these systems are being designed will be described and then the organizational principles, which are certainly new to the railroad industry and novel in a number of respects.

The project involves a number of systems, extending from the simple to the complex. Not all the concepts described would necessarily be included in all the systems and few of them would be involved in the most simple. But for the sake of brevity and simplicity, all the concepts will be described together as if they were being applied to the most advanced system that any of the participating railroads might envisage.

THE CONCEPTS

The most fundamental concepts that underlie the most advanced system are as follows:

- All information that is relevant to train movement should be passed to a single point covering some large territorial area.
- The sequence and combination of decisions that use resources safely and in the most economical manner should be computed.
- These decisions should be conveyed in the form of continuously updatable instructions to enginemen and others concerned, track forces, for example. (As far as enginemen are concerned, all information pertinent to their immediate actions would be concentrated in an electronic display in the cab.)
- Instructions must be acknowledged and, to the extent that is possible, enforced if they have been overlooked.

These four operations may be viewed as a closed loop of information, computation, instruction, acknowledgment, and, if necessary, enforcement essential to an automated as distinct from a permissive system. Many of the components of this process (track circuits, for example) are far from new and only a small proportion of the functions called for in the operating requirements are wholly novel. It is in their use in a highly automated system controlled from a single point that the major significance of the project lies.

One possible layout involving control loops is shown in Figure 1, which shows some of the more important functions that will be described in the following paragraphs.

Information

The control of all facets of train movement at a single point requires that all physical characteris-

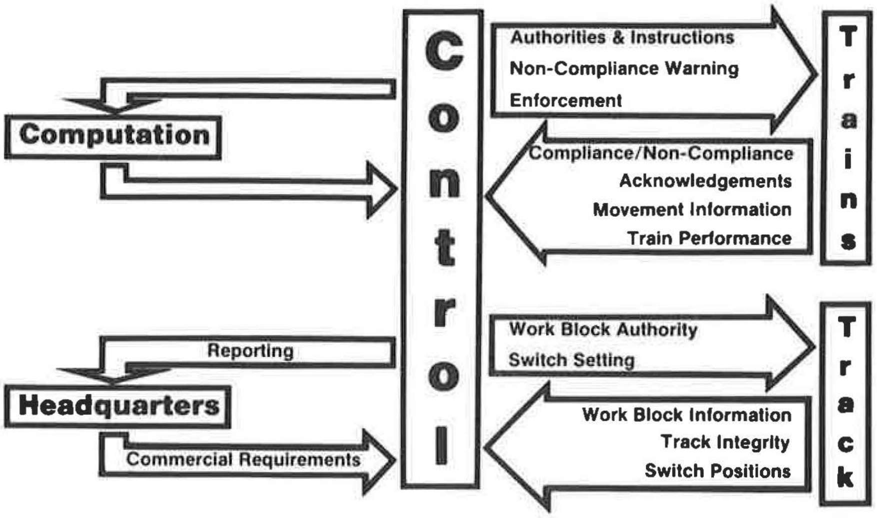

FIGURE 1 Control loops (one possible layout).

tics of the route network be represented in electronic form. The information needed at the control point to achieve these purposes falls into four discrete groups expressed in the following continually updated statements of

- The presence, identity, location, speed, and direction of movement of any train in the system;
- The position of all switches and the integrity of track and its freedom from excessive stresses and from obstructions, such as the presence of maintenance equipment or rock slides;
- Notice of any irregularity or defect on the train itself, such as the indications of defective equipment and monitoring systems for locomotive performance;
- The timetable together with statements of the last acceptable arrival times for the highest-priority traffic on each train.

Determination of the Decision Sequence

A major future task will be to develop the capability to compute the decision sequence with the best prospects for achieving commercial objectives at minimum cost consistent with high safety standards. The results of these computations will be conveyed to the dispatcher in the form of instructions for onward transmission if approved by him.

An essential component of the computing software will be a conflict-resolution module that will project, with continuous updating, the paths of all trains. It will detect such conflicts as might arise both between trains and with track vehicles and inform the dispatcher of them together with recommendations for their resolution. This function will require computation of all changes in speed of each train with regard to gradients, curvature, and speed restrictions, as well as the performance capability--including the braking capability--of the trains themselves at all points on the route. From this will be estimated the speed necessary for each train to maintain at every point on the route in order to reach its destination or next point of conflict in the most cost-effective manner consistent with safe operation and the achievement of commercial goals.

To this end, a movement cost model will simulate, perhaps every few minutes, the cost of the operation over the next several hours, searching for the most cost-effective decision sequence with regard to wage cost, fuel, wear and tear on trains and track, utilization of trains, and sufficient opportunities for track maintenance for the work to be done economically. For example, the energy consumption routines will search for the sequence of power settings on individual trains that meets the required timing with minimum fuel consumption and also for the timetable that achieves the commercial requirements of the traffic in the most energy-efficient manner.

There is no reason why the appropriate power setting should not be indicated to the engineer together with a continuous indication of the desired train speed. With microprocessor-equipped locomotives a further development objective would be to adjust the power automatically. There is, of course, the need to avoid differences in velocity along the train of a sufficient order to lead to run-ins and run-outs of unacceptable severity. The final step therefore would be to also automate train-handling techniques and thus avoid such occurrences.

Fuel savings will be achieved in the following principal ways:

- On single track, meets will be planned to occur at places where the total energy lost both by the unnecessary slowing of the main-line train and the stopping of the siding train would be minimized. They will, for example, be planned to occur at those points such as the summit of a grade where the train stopped would have been running at low speed rather than at the foot of a grade where it would be running at high speed before climbing another.
- The train to be stopped would be paced so as not to enter the siding much before the last moment that would avoid slowing the train taking the main line.
- Trains would not use high power to accelerate to a high speed when this could not be maintained for more than some short distance.
- The timetable (as already implied) would be adjusted to facilitate an energy-efficient movement.
- On double track (including that with bidirectional movement) and on routes with alternate lengths of double and single track, train speed would be adjusted continuously to minimize braking.

These examples will suffice to illustrate the point that there will be extensive demand for movement control software of increasing sophistication and complexity. Whereas the hardware for Advanced Train

Control Systems, once engineered effectively, may be expected to remain unchanged for a number of years, the software will be subject to ongoing development into higher levels of power as railroads advance into the age of automation during the remainder of this century and beyond.

Instruction, Acknowledgment, and Enforcement

The most favorable decision sequence must be transmitted both to train crews and field forces in the form of instructions and to others, such as terminal managers, in the form of information. Before this is done, however, powered switches must be moved to and locked in the correct position and it must be verified that hand switches are correctly set.

In all probability, an electronic display in the cab will convey to the crew the authority to proceed, the desirable speed, and other pertinent information such as the next permanent speed restriction or slow order, work block limits, hot box indications, and work to be performed en route. It is desirable that the authority to proceed be printable for the engineman's retention, possibly as part of the procedure by which the instruction is acknowledged to the control point.

The existence of a core store of all pertinent information will be useful for other purposes. For example, the maintenance-of-way officer could apply a slow order when track work is complete by the use of a portable terminal capable of printing out the controller's acknowledgment of the revised instruction.

The enforcement of speed restrictions is not new. Swedish National Railways has employed a system for some years capable of applying the brakes if the train speed exceeds the maximum permissible, including both permanent and temporary restrictions at specific locations. But until the automation of train handling is complete, such applications will only be used as an emergency measure.

In summary, the advanced systems will provide a powerful new tool for controlling the traffic across the entire network. Whereas present control systems are permissive in the sense that they combine the maintenance and safe separation between trains and the enforcement of maximum speeds, primarily through signal indications, operating rules, and written instructions, these new systems will be automated in that they will also be capable of enforcing instructions and maintaining train speeds at levels computed as the most desirable from a systems standpoint. Every aspect of train movement will be part of a single system under unified control and in which the loop of instruction and compliance is verifiable and complete.

ORGANIZATIONAL PRINCIPLES

The principles on which the project has been organized differ in some important respects from customary railroad practice, drawing partly on that used in space and military projects and in some other respects on procurement in the air transport industry.

The first principle was that railroads representing a substantial proportion of users should, as previously stated, write their requirements and that they should eschew expression of their technical preferences in so doing.

The second principle is that the project should be self-financing. To achieve this it will be necessary for suppliers to convince themselves that the market is sufficiently large and the economics of the project sufficiently favorable for them to design and manufacture the component parts with their own venture capital. Railroads in turn must be convinced that their own investment in meeting the cost of engineering the basic characteristics of the system can be justified.

A team of system engineers is currently estimating the cost of the project in some detail, and a team of economists drawn from major railroads is estimating the benefits in terms of the savings in labor and fuel; reductions in the cost of maintaining track, cars, and power; the near-elimination of accidents; together with increases in traffic capacity and equipment utilization. The return on investment is being estimated from these two studies. It is expected to be large.

The third principle is that the industrial base should include skills representing the state of the art in every technological field, including communications, computing, software, fail-safety, and human interface in addition to traditional forms of train control. To this end, a substantial advertising campaign drew representatives from around 140 companies to attend a presentation in Toronto in June 1984 concerning the purpose and organization of the project, supplementing the outstanding skills of the railroad signaling industry. About 100 are now involved in the project.

Last, a consortium of system engineers headed by ARINC Research Corporation of Annapolis, Maryland, and including Transportation and Distribution Associates, Inc., of Philadelphia, Pennsylvania, and Philip A. Lapp Limited of Ottawa, Ontario, began work in February 1985; they are currently identifying the technologies that could be used to perform each function in the 39 modules called for in the operating requirements, assessing how well each technology will perform each function, and determining their availability and their cost. They will also review existing train control technology and components already in service with the purpose of determining how much of what exists today can be adapted to meet these new requirements and estimating the need for the development of entirely new components, including both hardware and software.

By combining the results of this initial survey with the railways' own estimates of benefits to them, it will be possible to plan a work schedule to accord the highest priority to producing the performance specifications for those subsystems and modules shown to have the highest rates of return and the fastest payback periods.

The system engineers will then specify the interfacing and connections between modules and components in order to permit components of independent design to operate together, to ensure that when any equipped locomotive runs on any equipped track, any control function of which both locomotives and track are capable should be performable. They will also develop minimum performance standards required to meet railroad standards of safety and reliability. Last, they will identify the scope of the research needed, including a program that the AAR will carry out under the direction of W.J. Harris, Jr., and C.E. Taylor.

The marshalling of a massive industrial base to develop the products is the supply aspect of a supply and demand equation. The demand is represented by the collective efforts of the North American railroad industry. Railroad professions such as communications, signalling, locomotive and track engineering, computer systems, and railroad operating have set up task forces of experienced professionals to interface with the system engineers, who will receive advice from user and supplier alike.

From all this work will emerge the alternative layouts for the new systems in terms of equipment at control points, at trackside and on trains, together with assessments of the overall rates of return on investment that should be obtainable. However, this process will not prevent suppliers from showcasing their products by direct contact with railroads in the customary manner. The system engineers will enable all proprietary and competing products to conform to an orderly plan to develop a system with a common architecture. But who buys what from whom will be a matter for the free market process.

Apart from the inherent advantages of the market process, there are a number of other benefits from carrying out the work in this manner. First, it enables large numbers of specialist companies to contribute in much the manner as in the various U.S. aerospace programs. Second, the system is especially tolerant of new technologies that may emerge after the initial system has been engineered. There is no reason why some specific module should not be replaced by another, using some new technology to carry out its function. Third, and most important, with the system engineering approach, the initiation of a quantum advance in technical performance is more readily achievable than with development processes of an inherently evolutionary character.

Last, the Advanced Train Control Systems project has demonstrated both the feasibility and the advantages of international cooperation in large research projects involving not only railroads of the United States and Canada but a wide range of high-tech designing, engineering, and manufacturing organizations.

PROJECT TIMING

ARINC and their partner companies will complete their technology assessment by September 1985. By that time, each railway will be receiving proposals from the companies that want to build complete systems; indeed some have received proposals already. Before the end of 1985, the first of the performance specifications for the components of the systems will be available and all should be available by the end of the first quarter of 1986.

During 1986, the first trial installations that meet these specifications and comply with the system architecture will be taking shape. They will probably be some of the more simple versions of the system. Will they be based on transponders and radio, on satellites, on conventional track circuits and cables, or on some of them or on all of them? It is just too early to say.

What can be said is that every technology will have been evaluated and every aspect of the environment in which they will operate will have been taken into account. The choices will have been reviewed with all participating suppliers and their views will have been carefully considered. Appropriate test procedures and any research found necessary will be carried out before these choices are made.

During the period 1986-1990, Advanced Train Control Systems will be installed on a large scale, sometimes standing alone and sometimes overlaid on existing signals to extend the range of the functions that they currently perform. Expenditure is likely to exceed $5 billion U.S. and may well reach $10 billion U.S. by the early 1990s.

SOME FURTHER THOUGHTS

The significance of the Advanced Train Control Systems project extends far beyond a massive effort to procure new control equipment. It will engender the notion that every aspect of investment in control equipment, track, motive power, cars, and other plant will soon become part of a closely integrated strategy, to be evaluated only in terms of the overall stream of benefits for the overall stream of expenditures.

But Advanced Train Control Systems are not the last word in train management technique. Rather they are the first word--the first word in a new generation in which the vast knowledge and power of the microprocessor and communication industries will be brought to bear in applying a progression of new generations of higher-level control software.

The progressively more cost-effective deployment of the railroads' principal resources--of labor, capital equipment, and material--may well restore the high rates of productivity growth that followed the introduction of the second-generation diesels and the "100-ton car" in the early 1970s. This achievement can only be brought about by the massive cooperative effort that has been described.

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Track Lubrication: Its Application and Potential for Reducing Fuel Consumption

ROY A. ALLEN and RICHARD P. REIFF

ABSTRACT

Most railroads in North America control excessive wear of wheels and rails by lubricating the gauge face of the outside (high) rail of curves. In 1983 an experiment at the Transportation Test Center (TTC) indicated that effective lubrication also has an additional benefit of reducing train energy and fuel consumption. This resulted in considerable research activity with tests being conducted on railroad properties to quantify these savings. These earlier tests were all carried out on highly curved territory and have demonstrated that significant fuel savings are possible on curved routes. There are also definite indications that train resistance can be reduced by lubrication on tangent track. Two recent experiments, one on a long section of tangent track and one in the laboratory, have provided evidence to support this possibility. It is unlikely that trackside lubricators alone can realize the maximum potential energy savings, and a number of alternative vehicle-mounted lubrication systems have been tested at TTC. These tests have demonstrated the potential benefits and limitations of operating these systems in revenue service. Different methods of monitoring the effectiveness of lubrication have also been developed. All of the foregoing research is summarized.

Wayside lubricators are used quite extensively on curved track in North America to control excessive wear of wheels and rails. Lubrication is typically applied to the gauge face of the outside (high) rail of curves and in addition to reducing wheel and rail wear, it has been shown to reduce rail end batter and the rate of corrugation growth (1). Recent research, however, has demonstrated that effective lubrication has the added benefit of reducing energy and fuel consumption, which is causing many railroads to pay increased attention to their lubricating practices.

Research on the effects of wheel and rail lubrication has been carried out under the auspices of two research programs: the Association of American Railroads (AAR) Energy Research Program and the Facility for Accelerated Service Testing (FAST) Program. The AAR's involvement in energy consumption was expanded in 1983 to include studies aimed at identifying and quantifying the discrete elements associated with train resistance. Train resistance has previously been estimated by using empirically derived equations such as the familiar Davis equation, for which there is only a limited theoretical justification and limited knowledge of the detailed contributions of individual parameters to the overall train resistance. Thus, although improvements might be made in individual car components, for example, through the use of improved car or truck designs or both, it is difficult to evaluate the overall effect of these improvements on energy or fuel consumption.

Hence, efforts were made to develop an improved understanding of the individual parameters that collectively determine total train resistance. The projects are part of a multiyear program and include analyses of aerodynamics, vehicle-track interaction, and roadbed resistances. Data generated in this program are to be used to develop more accurate economic and train energy models for use by the industry in evaluating fuel conservation alternatives. A train energy model was made operational and will be improved as test data are generated in the program. A Rail Energy Cost Analysis Program (RECAP) is also operational and is designed to use data from the train energy model to evaluate the economic potential of various fuel conservation strategies.

Coincident with the initiation of the train resistance studies in 1983, experimentation in the FAST Program at the Transportation Test Center (TTC) in Pueblo, Colorado, indicated the potential for energy savings due to lubrication and resulted in increased activity in this area.

EARLY EXPERIMENTATION AT FAST

Wayside lubrication has been used at FAST in order to obtain wear information for different rail metallurgies under both lubricated and unlubricated conditions. Experience from revenue service has shown increases in rail life due to lubrication; rail life is typically 50 to 100 percent greater with lubrication than without. However, at FAST, where a high level of control is much easier to achieve than in revenue service, large increases in rail life with lubrication have been obtained.

The effect of various levels of lubrication on the gauge face wear rate of standard carbon rail is as follows (MGT = million gross tons):

Level of Enforcement	Wear Rate (in./MGT)	Avg Relative Improvement (%)
Dry rail (no lubrication)	0.005-0.007	1
Low	0.001	5
Medium	0.00029	17
High	0.000064	80

It can be seen that with high levels of enforcement, large improvements can be obtained, which almost eliminate gauge face wear as a problem. Under these conditions, fatigue of the rail gauge corner becomes the limiting factor (1), and this will be the subject of a future FAST experiment.

During the course of the lubricated-wear experiments at FAST, it had been noticed that train handling and throttle position were quite different between lubricated and unlubricated periods. As a result, locomotive fuel consumption was monitored quite closely by measuring the fuel that was required to top off the tank. From these measurements, it was determined that an average savings in fuel consumption of 32 percent was being obtained because of lubrication.

Subsequently, AAR personnel at TTC developed a system (2) designed to measure train resistance by characterization of locomotive tractive effort versus input power to each traction motor. The Roll Dynamics Unit (RDU) was utilized as a dynamometer to calibrate the measuring system. The locomotive, which was kindly loaned to the AAR by the Burlington Northern, is shown mounted on the RDU in Figure 1. The product of input voltage and current to each traction motor was compared with power at the dynamometer to determine the traction motor efficiency. This effort was accomplished for all throttle positions and speeds up to 60 mph. The RDU was utilized to power the locomotive to characterize the dynamic brake tractive effort relationship.

This instrumentation scheme was then used for an experiment (3,4) utilizing a six-car test train on a 4.8-mi FAST loop. This loop consists of 45 percent tangent track and 55 percent curved track ranging from 3 to 5 degrees. Grades of up to 2 percent are encountered.

For the six-car train operating on the FAST loop, an average of 414 kW of power was required at the wheel-rail interface to maintain a constant speed of 40 mph on unlubricated rail. The Davis equation approximation for the FAST loop is 442 kW.

These on-track tests were repeated for track generously lubricated by trackside lubricators, simulating a territory with a lubricator located every 2.5 mi. The average power consumed was measured at 270 kW. This represents a saving of 34 percent in energy required to move the identical train over the identical territory, which, of course, correlates well with the fuel saving mentioned previously. Breaking the FAST loop into individual sections yields the following relationships (energy consumed because of train acceleration and track gradient over each section has been removed):

FAST Section	Energy Savings due to Lubrication (%)
Tangent	30
Curved	
Three degrees	36
Four degrees	39
Five degrees	51

The large savings on tangent track were surprising, and this phenomenon will be discussed later.

REVENUE SERVICE TESTS

As a result of the FAST test, the decision was made to conduct a number of tests on railroad properties to determine the magnitude of energy savings due to wheel-rail lubrication for different operating conditions in actual train service. The first of these tests was conducted jointly by the AAR and the Seaboard System Railroad in cooperation with the Norfolk Southern Corporation in October 1983 (5,6).

A loaded unit coal train consisting of four 3,000-hp six-axle locomotives, the Norfolk Southern Corporation rail lubrication car, the Seaboard System test car, 72 loaded coal cars, and a regular crew caboose was assembled at Corbin, Kentucky. The gross trailing weight of this train was 9,091 tons.

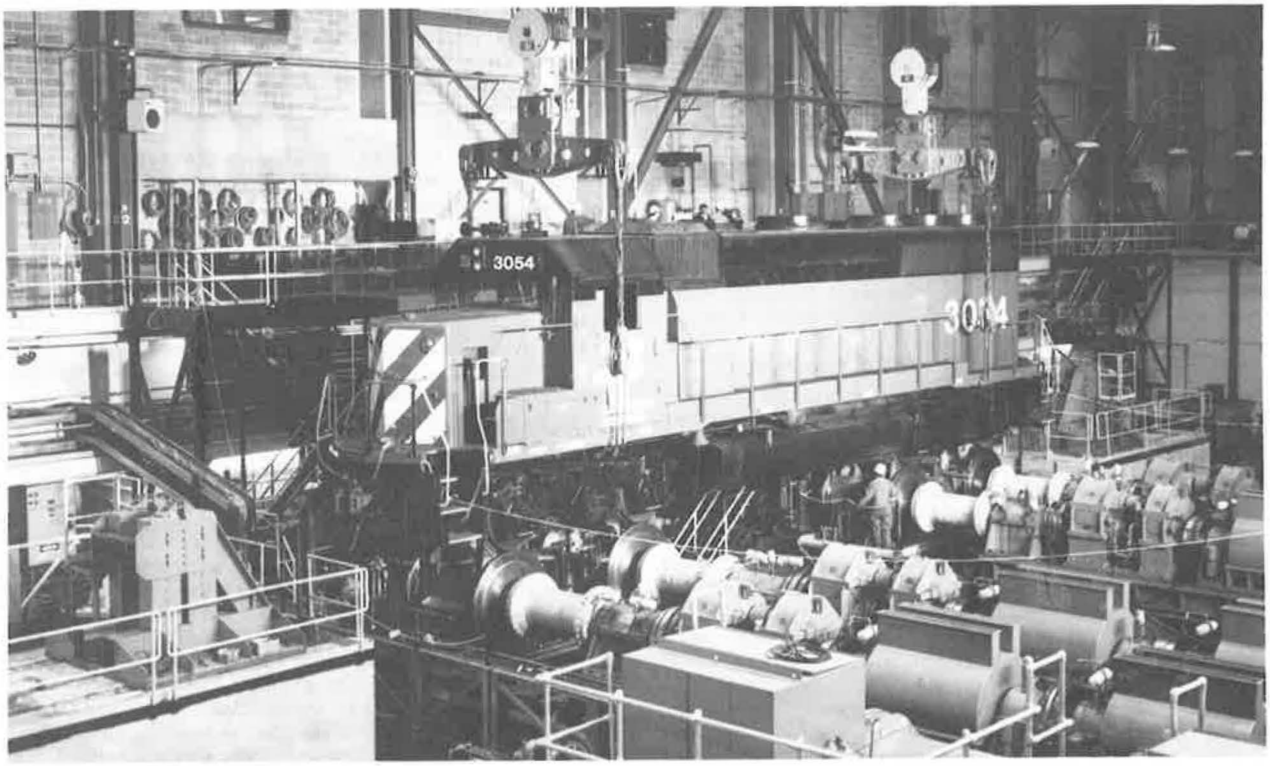

FIGURE 1 Locomotive mounted on RDU.

The locomotive units were instrumented to record train speed and main generator output voltage and amperage (power). The data were collected by a desk-top computer mounted in the cab of one of the locomotives. Coupler force and locomotive throttle position were also measured.

The test was conducted on the Seaboard System main line south of Corbin on a 14-mi segment that had an average grade of 0.568 percent. For the last 5 mi of the test route, the average grade was 0.9 percent and contained reverse curves of up to 10 degrees. Approximately 70 percent of this 14-mi segment was curved track.

Three days before the start of the test, all wayside lubrication devices in the area of the test were made inoperative in order to allow time for lubrication from these sources to be dissipated by passing trains. These devices were not operative during any part of the test.

The first three runs were made without lubrication from any source in order to establish base-line data for comparison with data from lubricated track. On the second day, three further runs were made on lubricated rail with the lubricant being applied from the Norfolk Southern lubrication car. During all test runs, the same speed profile as established during the first run was maintained as closely as possible by increasing or decreasing the locomotive throttle as necessary.

The energy savings on the lubricated runs as compared with the dry runs were immediately noticeable during the test by examination of the throttle notch position data as seen on the strip chart recorder. On dry rail, throttle position 8 was used 68 percent of the time but only 26 percent of the time on lubricated rail, and the average speed varied only 0.1 mph between the two runs.

The force data obtained by the computerized data acquisition system from the coupler were converted to horsepower-hours and are therefore expressed as energy consumed rather than pounds force. The locomotive alternator power measurements were similarly converted to energy consumed and both sets of data are as follows:

	Energy Consumption (hp-hr)	
Track Condition	Drawbar	Locomotive Alternator
Dry	5,143	6,756
Lubricated	4,370	5,744

Train acceleration effects have been removed from these calculations of energy consumption in order to minimize the difference between runs due to train handling. In these particular tests, however, the removal of acceleration energy is not a major factor, because train accelerations during the test were small and do not significantly affect the results.

The energy consumption as measured at the locomotive alternator is higher than the drawbar measurement because, of course, the latter is measuring only the energy required to pull the trailing consist whereas the locomotive data include the energy for the complete consist. However, both measurements indicate a 15 percent energy saving due to lubrication.

Subsequent to this test, Consolidated Rail Corporation (Conrail) ran tests (7) to measure the energy required to pull unit coal trains over a 200-mi section of railroad. Repeated tests were conducted with no lubrication at all, trackside lubricators, on-board lubricators, and combined trackside and on-board lubricators. Lubrication clearly reduced train resistance, and trackside lubricators produced better results than did on-board lubricators. Combining both types of lubrication reduced train resistance more than either type alone as follows (GTM = gross ton miles):

	GTM	
Lubrication Method	Per Kilowatt-Hour	Per Gallon of Fuel
None	156	1,999
On board only	183	2,294
Trackside only	194	2,498
On board and trackside	223	2,590

Conrail ran this test on a generally level but mostly curved route in central Pennsylvania. Sixty percent of the route is highly curved (up to 12 degrees) secondary track, and the other 40 percent is moderately curved main line. The train consisted of one SD40-2 and one SD50 locomotive, the Conrail instrument car, 125 to 130 loaded 100-ton hoppers, and a caboose. The train speed was less than 45 mph throughout the test. The 200-mi route has 44 well-maintained trackside lubricators.

A similar test run over curved territory by Norfolk Southern has indicated energy and fuel savings due to lubrication of the same order as those measured by Conrail.

TANGENT TRACK INVESTIGATIONS

Thus, there is ample evidence that effective lubrication has a dramatic effect on fuel and energy savings on curves. There is also some evidence that lubrication may reduce train resistance on tangent or straight track. The original FAST test with the six-car consist was conducted so that energy savings on individual sections of track could be identified, and 30 percent savings on tangent track were clearly measured. Although not measured directly, similar tangent track savings were noted from the Seaboard test data.

Both tests were conducted on track containing numerous curves with only small sections of tangent track in between. One hypothesis is that, in such a situation, the three-piece trucks, with all their inherent friction characteristics, do not have sufficient time to straighten out of the attitude assumed in the curves and consequently continue to run with misaligned axles, which results in flange contact on straight track.

It is also feasible that lubrication will have a beneficial effect on energy consumption even on long tangent track sections. It has been shown analytically (5) that relatively small misalignments of the axles on a three-piece truck can result in flange contact on tangent track and that reduction in the flange-rail contact patch through lubrication will decrease train resistance. The required misalignments are achievable in practice because of the longitudinal clearances that exist between the bearing adapters and the side frame pedestals.

To investigate tangent track resistance, two tests were carried out in 1984. In the first, the AAR participated in a joint test with the Atchison, Topeka and Santa Fe Railroad on a 5-mi-long section of tangent track in Kansas. The train consisted of eight open-tip gondolas pulled by one locomotive (Figure 2), which, as for the previous tests, was instrumented to measure alternator and traction motor power. The power required to pull this consist over the tangent track at constant speed was measured for speeds between 20 and 70 mph in nominal 10-mph increments. Lubrication was applied by means of a system mounted on the locomotive. The results are shown in Figure 3, where the average resistance of the whole train in pounds force is plotted as a function of the train speed for four test cases. It

FIGURE 2 Santa Fe consist used for the long tangent test in Kansas.

will be noted that for the cars loaded to their 100-ton capacity, the reduction in resistance due to lubrication is considerable, particularly at speeds below 60 mph. It will also be noted that the empty cars had more resistance above 50 mph than the loaded cars, indicating the crucial importance of aerodynamic drag at higher speeds.

A second experiment to investigate tangent track resistance was also carried out in 1984 on the RDU at TTC. A conventional three-piece truck was placed on a pair of rollers (Figure 4) and the measurement of torque in the rollers allowed calculation of the rolling resistance. The effect of different axle misalignments on tangent track operation was assessed. Tests were carried out with and without lubrication. At the time of this writing, the results had not been fully analyzed. However, for the misalignments tested, which were equivalent to yawing the axles to take up (a) half the clearance and (b) all the clearance between the bearing adapters and side frames, initial indications are that the resistance measured on dry rollers was significantly higher than that measured when the rollers were lubricated.

FAST LUBRICATION STUDY

Thus, the research into energy consumption aspects has produced exciting results, and the potential economic benefits (8) are considerable. However, overlubrication, especially when lubricant finds its way to the top of the rail, has a detrimental effect on rail life as well as train handling and rail forces. However, the railroad industry is inexperienced in measuring and quantifying lubrication effectiveness. In addition, a wide variety of methods are available to apply the lubricant, and these factors led the FAST program at the TTC to undertake a 10-month lubrication study. The major objectives of this study include

- Development of methods for measurement of lubrication effectiveness;
- Development of performance criteria for types of greases, location and methods of application, and alternative application systems;
- Development of reliability and maintenance history records of various trackside systems;
- Determination of energy savings potential of various lubrication systems; and
- Development of ideas for better lubricators for FAST.

The first objective was to develop a method of assessing the effectiveness of lubrication. Methods such as monitoring overall fuel consumption, train handling, or rail-wheel wear are accurate but do not provide an easy-to-use instant reading of lubrication effectiveness. Grease output meters, installed in the trackside lubricator hoses, have been used previously at FAST but with mixed results. Frequent clogging, cold weather freezing, and erratic readings led to abandonment of this system. The "goop gauge" (Figure 5) was used for several years to monitor and control the level of visible grease on the rail. When FAST rail wear data were collected during recent periods of lubrication, it was attempted to maintain the lubricant at least at a +0 level and no higher than a +10 level based on gauge values.

A trackman would periodically inspect curves and

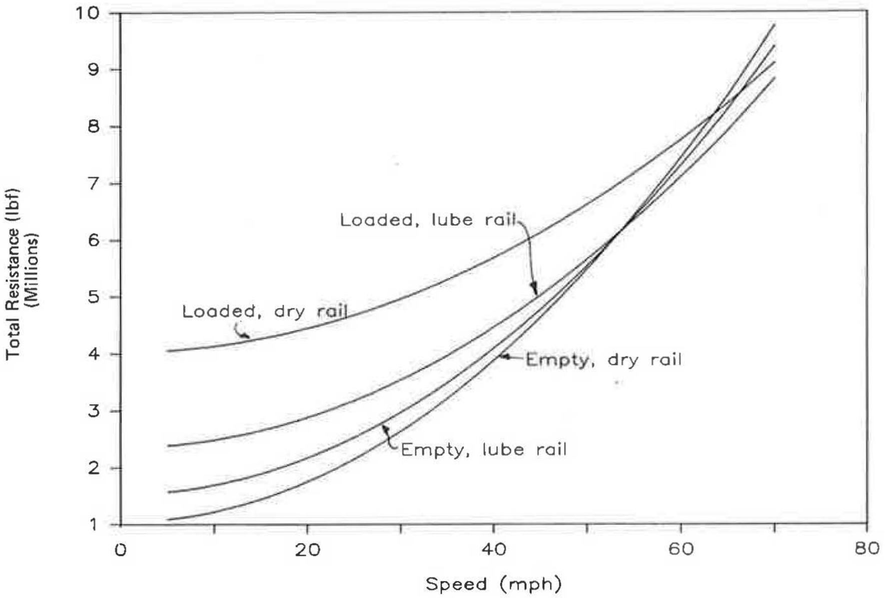

FIGURE 3 Resistance test results: low side mill gondolas.

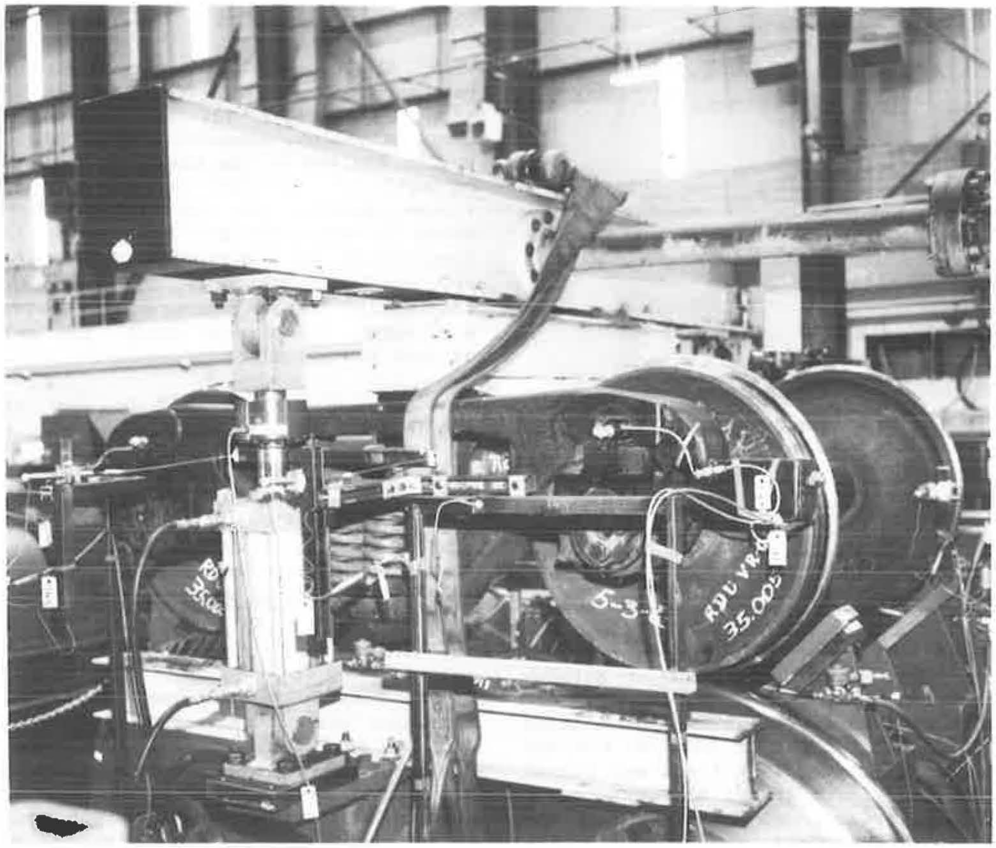

FIGURE 4 Three-piece-truck rolling resistance tests on RDU.

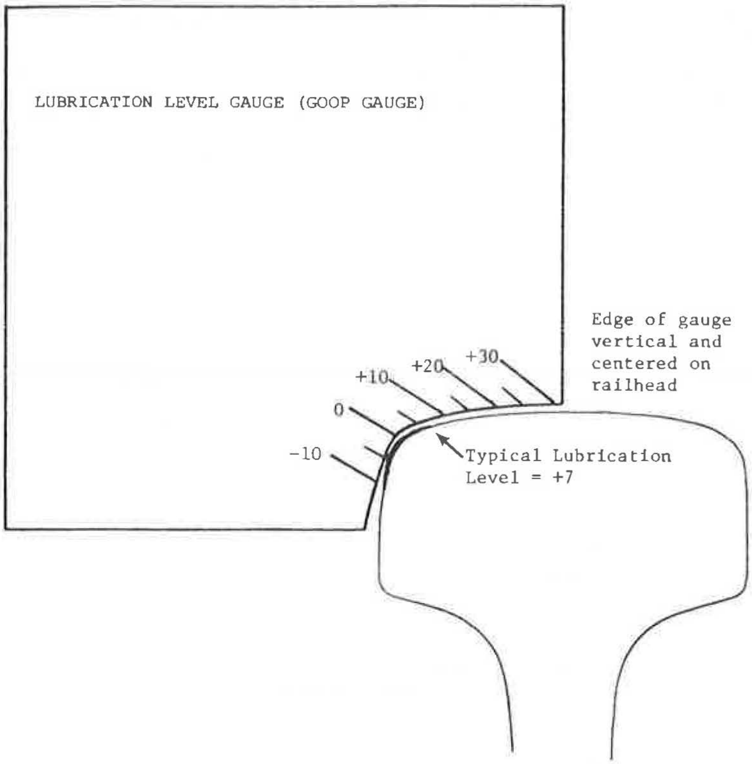

FIGURE 5 FAST lubricant level measurement (goop gauge).

adjust the lubricators to maintain grease at the desired level. The goop gauge is a useful tool for maintaining a constant level of lubricant, but it does not indicate effectiveness of the visible lubrication. The goop gauge is also useless when non-graphite-based greases are tested because the grease film is usually invisible.

Alternative methods of measuring lubrication effectiveness (9) were examined, and two were ultimately adopted for FAST tests. These are wheel-rail longitudinal force of a loaded hopper car (leading axle) and rise in rail-head temperature due to the passing of a train. The rail-head temperature rise measurement is being examined for potential everyday use by railroad field personnel.

Both techniques stem from the fact that during negotiation of sharp curves, flange contact occurs and substantial creep forces are generated in both the lateral and longitudinal directions. These forces and creepages cause considerable energy dissipation in the wheel-rail interface and result in a need for an increased drawbar force to pull the vehicle through the curve. Part of this energy is dissipated in the form of wheel and rail wear and part in the form of heat causing a rise in temperature of the rail, particularly of the high rail in a curve. When lubrication is applied to the contact area between the flange and the gauge face, the coefficient of friction is lowered and the magnitude of the longitudinal forces decreases dramatically. This reduces the energy dissipated in the wheel flange contact patch and hence reduces wheel and rail wear, drawbar force, and the temperature rise in the rail.

Longitudinal force is monitored by a specially instrumented wheelset, mounted in a conventional truck (leading axle) under a 100-ton loaded car and recorded by a data collection vehicle. (The axle is strain-gauged to measure torsion of the axle, which is a measure of wheel-rail longitudinal force.)

On Section 3 at FAST (Figure 6), which is a 5-degree curve with 4 in. of elevation, at a train speed of 45 mph longitudinal force provides a very uniform means of comparing dry and lubricated rail. A dry rail will result in longitudinal force values of 5,500 to 8,500 lb. On the same curve in a fully lubricated state, these forces decrease to 1,500 to 2,000 lb. Predictable values of force are observed between these two extremes at intermediate lubrication levels.

Longitudinal force measurements, although accurate and apparently very indicative of lubrication, would be costly to obtain and would not be practical for most railroads. An additional verification method was elected, that of rail-head temperature rise.

Creep forces, present during the flanging action as a train negotiates a curve, result in heat at the rail-flange interface. The amount of heat produced by a passing train is a function of many complicated actions, including curvature, speed, superelevation, truck characteristics, train weight, and lubrication. At FAST it is possible to control these variables, and during the lubrication experiment, all of these items (with the exception of lubrication) were kept constant; thus, the resulting temperature rises were an excellent indication of lubrication effectiveness. The field side of the high rail is used for temperature measurements because results obtained there would translate easily into applications by the railroad industry for portable systems.

Figure 7 shows the comparison of goop gauge, longitudinal force, and temperature rise under lubricated and dry rail conditions. The lower line on the graph indicates ambient rail temperature in FAST Section 3 monitored on a 4-ft segment of no. 136 rail adjacent to the track. The data for an 8,500-ton train on a 5-degree curve with 4-in. elevation at 45 mph are as follows:

	Dry	Lubricated
Longitudinal force (ft·kips)	15.0	2.0
Goop gauge level	-10	+10
Temperature rise at rail head (°F)	18	3

By monitoring both longitudinal force and rail-head temperatures as the FAST train negotiates a curve, the lubrication effectiveness of the system or product being tested can be assessed.

SELECTED LUBRICATION TEST DATA

Individual reports (10-13) on the alternative lubrication systems tested have been prepared and the following data have been selected from those reports.

The first alternative for applying lubrication at FAST was the lubricator car (Figure 8). This car is operated behind the last locomotive and applies lubrication to the rails from nozzles that spray conventional track grease onto one of the wheels of the car. The lubricator car was supplied courtesy of the Norfolk Southern.

Table 1 shows the lubrication effectiveness of the initial and the 1st, 5th, 10th, and 20th trains after a lubricator-car-equipped train. On the basis of these results, it was recommended that such a car, using conventional track grease, be operated in at least one train of every four in order to maintain an effective level of lubrication.

The Hyrailer lubricator vehicle test followed the lubricator car test. The Hyrailer vehicle was supplied by the Burlington Northern Railroad. This system utilized a conventional Hyrailer pickup truck to transport grease application equipment. Conventional track grease was sprayed directly onto the rail (Figure 9).

Trains operated after the passage of the Hyrailer vehicle spread grease along the rail surface. Figure 10 shows temperature and wheel force data for a simulation where the Hyrailer was operated every 10 trains, and Figure 11 represents a Hyrailer pass after almost 40 trains. In order to obtain significant lubricant on the rail, a large amount of track grease was applied, often resulting in wheel slip because the conventional grease migrated to the top of rail. An important observation during the Hyrailer test was made after a special drydown run. Under dry FAST loop conditions, approximately half the length of all tangents only was lubricated, and no grease was applied on curves. After the pass of one train, all curves were fully lubricated and remained effectively lubricated for at least 10 laps, gradually losing effectiveness in a fashion similar to those runs where only curves were lubricated. A subsequent series of test runs using an open-gear lubricant provided significantly better results. The lubricant was suspended in a carrier that evaporated within 10-15 min after application. The remaining lubricant film was very sticky and did not flow over the rail head as conventional track grease does.

The ability of grease to move from curves to tangent supported the conclusions made during the lubricator car test. Effective lubrication must be present on both tangents and curves to obtain the greatest fuel savings. If only curves are lubricated, the flanging effect of trucks will rapidly dry off wheels on long tangents and it will be impossible to

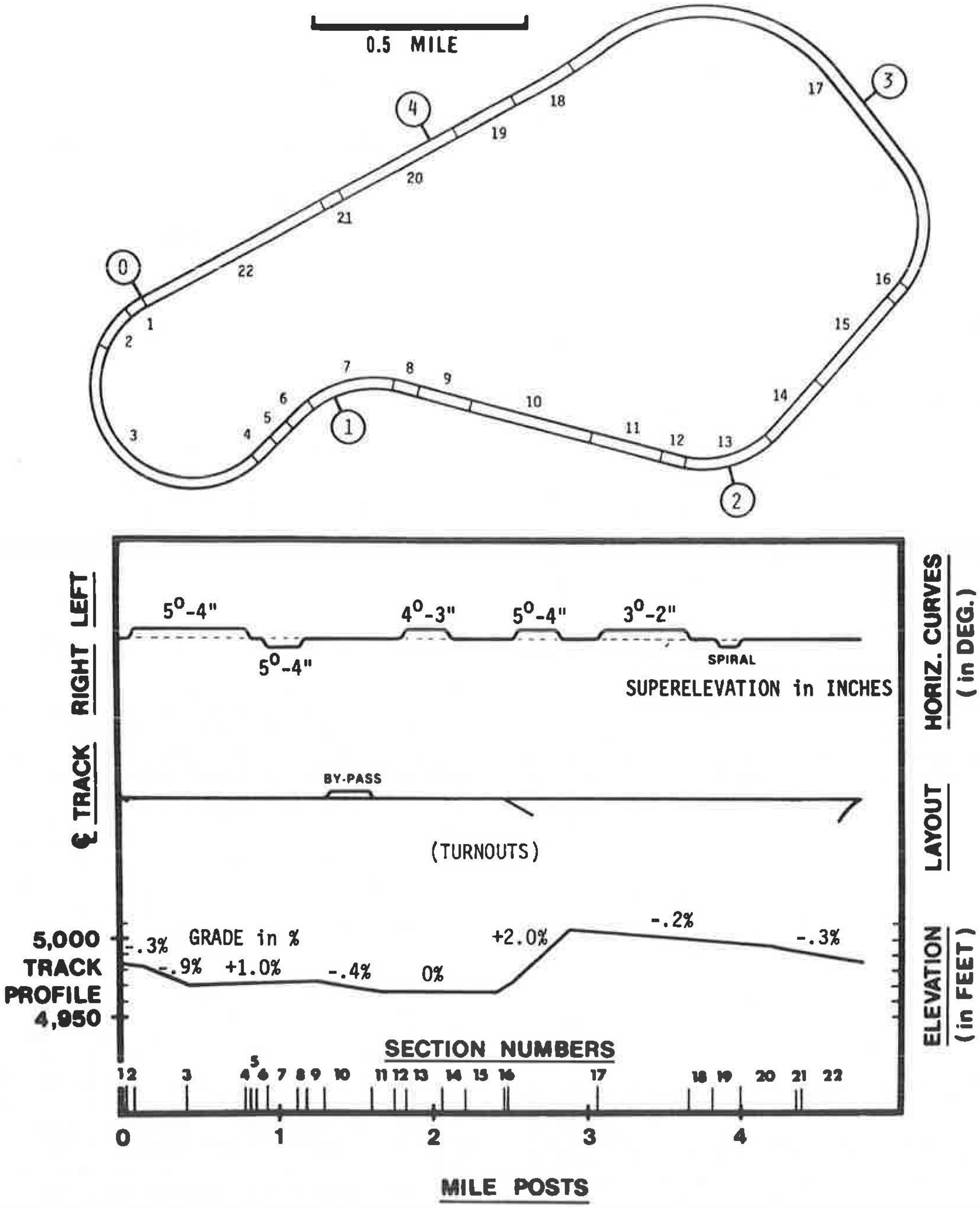

FIGURE 6 FAST track layout.

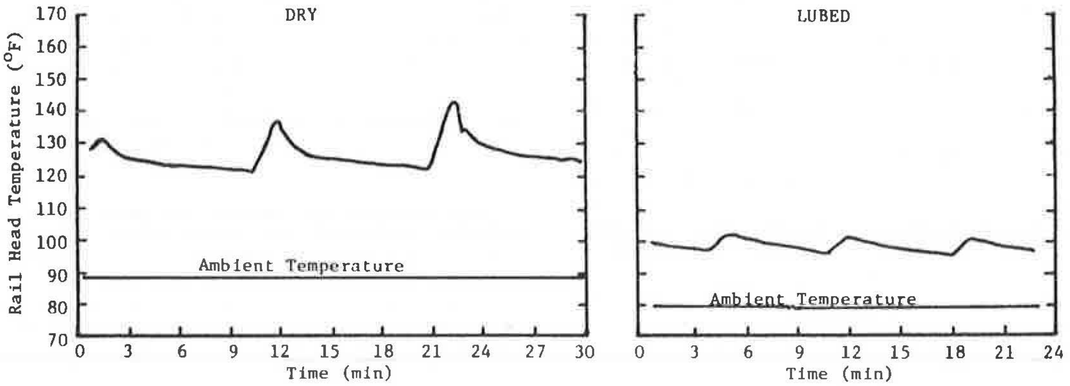

FIGURE 7 Lubrication effectiveness measurements.

TABLE 1 Rail Temperature and Wheel Force for Successive Laps After Grease Application (Lubricator-Car Test)

Lubrication Condition	Longitudinal Wheel Force (kips)	Rail-Head Temperature Rise[a] (°F)	Lubrication Adequate?
Bone dry (metal flakes); no lubrication	6.6	10-18	No
Fully lubricated during pass of lubricator car	1.0	2	Yes, too much
First train after lubricator car	1.1	2-3	Yes
Fifth train after lubricator car	1.7	6-8	Low
Tenth train after lubricator car	3.2	8-10	Marginal
Twentieth train after lubricator car	3.8	10-12	No

Note: Wheel force measured midtrain, rail-head temperature on high rail of 5-degree curve.

[a] Train with 80 cars.

FIGURE 8 Lubricator car in FAST consist.

FIGURE 9 Lubricator system mounted in Hyrailer truckbed.

maintain adequate lubrication between widely separated curves.

The on-board locomotive lubricator system followed the Hyrailer test. This system was supplied by the Bijur Lubricating Company and consists of a lubricant reservoir and spray system mounted in the locomotives (Figure 12). Oil (nongraphite lubricant) is periodically sprayed onto both wheels of the lead locomotive axle. The system operates whenever the locomotive is moving, applying a small amount of lubricant every 200 to 300 ft regardless of curve or tangent. The FAST train was tested by simulating two and three locomotives equipped with this system.

After the system output was adjusted to increase the level above that set at its European origin, sufficient lubrication was obtained to adequately lubricate all trains. It is important to note that the FAST simulation represented a railroad operation where each train was equipped with at least two locomotives (on a 75-car train) carrying such a system. Figure 13 represents typical wheel-force and rail-temperature measurements during the Bijur test. The on-board system differs from the other systems used at FAST in that no instant effectiveness was observed. Between 10 and 15 train passes with operating lubricators were required before system efficiency was obtained. Each train supplies a small amount of fresh lubricant to the rail, building on the layer already in place. The lubricant layer, once applied, lasts for quite some time, requiring at least 10 to 15 train passes to lose its effectiveness with the system turned off. Over 100 train passes were required after completion of this phase of the lubrication study to obtain a dry track free of all traces of this grease for the next series of tests.

Table 2 indicates the relative fuel efficiency of the systems tested to date. It is important to be aware of test conditions for the systems. For example, the Hyrailer system fuel efficiency was based on one pass of the vehicle every 30 to 35 trains and conventional track grease was used. Alternative operational modes, such as applying lubricant every 20 trains or using a different lubricant, could significantly improve fuel efficiency results.

A word of caution must be interjected when the wayside lubricator fuel efficiency figures are used. The lubrication under this operation was based on the use of backup lubricators located at each of the two sites. After every 10 laps of train operation, all curves were inspected with goop gauges and each lubricator was adjusted as required. The rail was in a highly lubricated condition almost all the time. It is not expected that railroads could economically maintain this level of lubrication at all locations by using trackside lubricators.

Other series of tests for the lubrication study assessed how rapidly different track greases spread around a curve and how they stand up to hot wheels from braking and are affected by locomotive sanding. Subsequent test series also investigated the effects of trackside lubricator location (tangent, point of spiral curve, etc.) and blade configuration (small individual blades, two moderate-length blades, and one long blade).

An additional test involved five different, conventional trackside lubricators in constant operation at FAST. These lubricators are installed in a normal manner, with the exception that lubricant is not applied to the track but is pumped into barrels. The amount of grease pumped from each lubricator is monitored daily, as are lubricator repair and adjustment activities.

An important note in all of the tests at FAST is that they were designed to simulate an entire territory equipped with the system being examined. Because the FAST track has but one train making multiple passes, each train is then subjected to the same conditions. Results of FAST testing, most notably those of fuel consumption, may not be directly

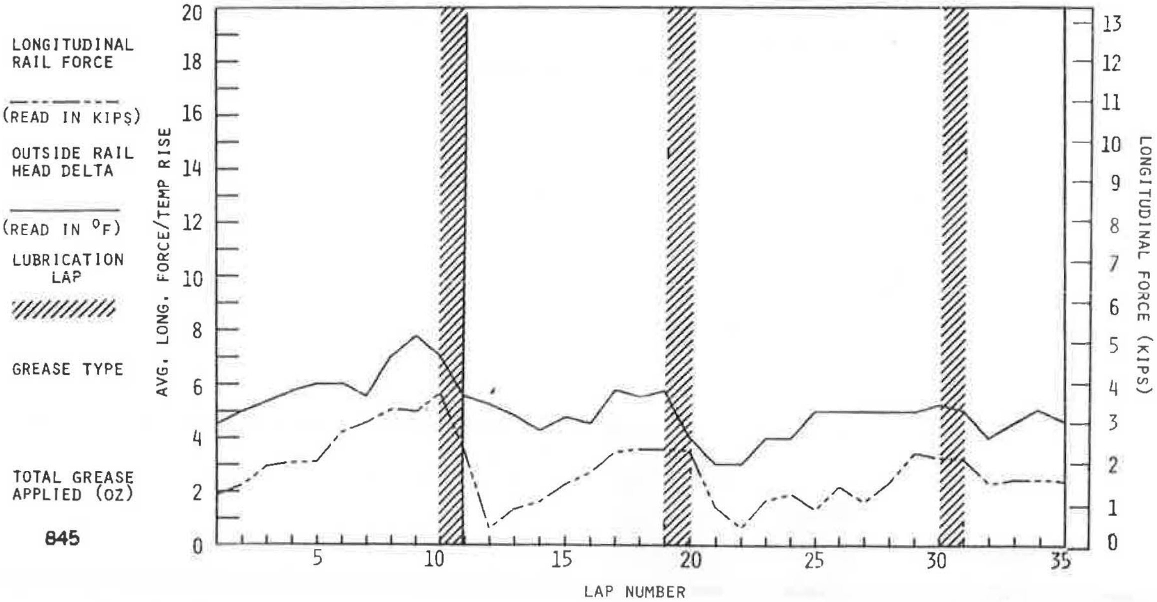

FIGURE 10 Wheel force and temperature rise with lubrication every 10 trains (Run 1216).

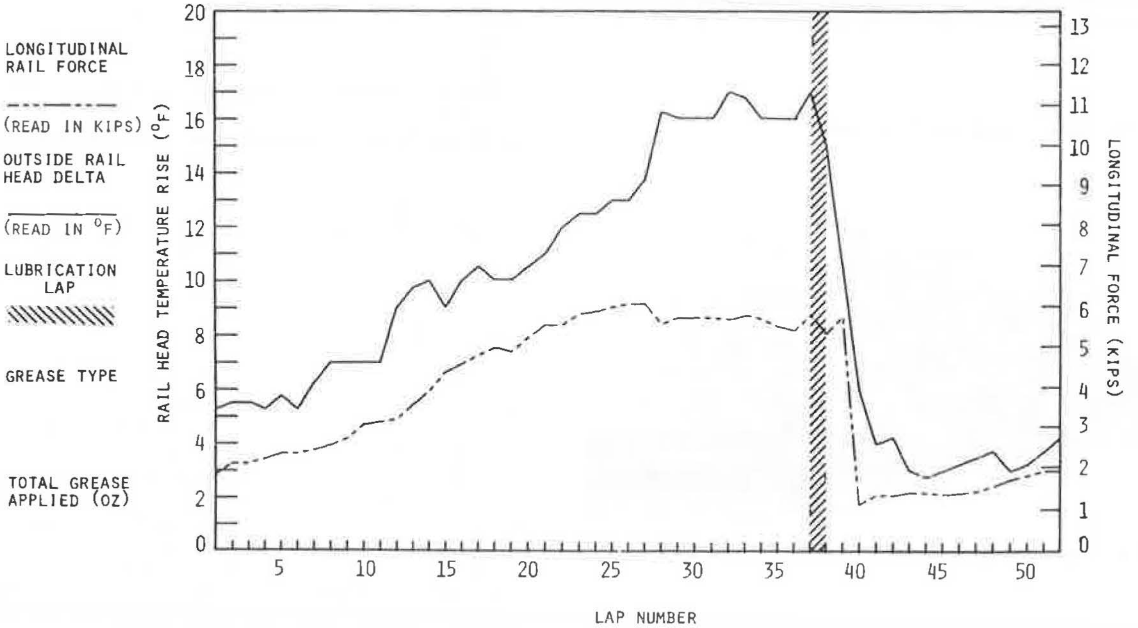

FIGURE 11 Wheel force and temperature rise: lubrication condition after 40 trains (Run 1220).

translatable to the field unless an entire territory is uniformly lubricated. In most revenue service environments, this is difficult to obtain, because long tangents may be interrupted by a series of curves to be followed by long tangents. Because of the variety of conditions seen in the field, no one lubrication application system tested to date has indicated that it can provide a uniform level of lubricant at all locations.

A combination of a mobile system suited to an operating property's environment with trackside lubricators at selected locations may provide the most appropriate means of applying a proper amount of lubrication yet controlling the tendency to overlubricate.

CONCLUSIONS

It is quite apparent that effective wheel-rail lubrication has considerable potential for fuel savings in North America. This is particularly true in curved territory, and although more testing is required, indications are that operations on tangent track will also benefit. Proper lubrication will also provide noticeable increases in wheel and rail wear life as well as improved resistance of rail degradation to welded joint batter and corrugation.

Work has also begun to ascertain an optimum lubrication level to obtain the best combination of a number of factors. Nearly infinite rail wear life is not feasible because of rail fatigue along with the possible safety problems in train handling should too much lubrication be applied. A lubrication policy that allows moderate rail wear may provide the best compromise of wear and fatigue life and still permit significant energy savings. FAST experiments have indicated a large variation in resultant lubrication effectiveness by using different lubricants in a given application system.

FUTURE RESEARCH

There are still a number of potentially detrimental aspects of lubrication that remain to be investigated, including locomotive adhesion and train braking problems as well as rail fatigue failures. The AAR will conduct adhesion and braking tests with member railroads in 1986 and a FAST experiment on defect occurrence and growth will investigate the rail fatigue problem.

In addition, the AAR is investigating lubricants and application systems to determine desirable levels of lubrication. Results of these studies will be made available to the industry in order to aid in determining a given operating railroad's optimum lubrication policy.

FIGURE 12 Spray nozzle, bracket, and grease spray pattern.

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Most of the research described in this paper has been carried out under the auspices of two research programs, the AAR Energy Research Program and the FAST Program. The majority of the funding for the latter is supplied by the Federal Railroad Administration. In addition, a number of railroads have made significant contributions to the research findings through donations of materials and manpower, through participating in joint tests with the AAR, or through carrying out their own testing. The authors are most appreciative of the efforts, guidance, and assistance of all those who have contributed to the research described in this paper.

TABLE 2 Relative Fuel Efficiency of Lubrication Systems Tested at FAST to Date

System	Fuel Efficiency (gal/MGT[a])	Savings over Dry (%)
Dry track	6,000	–
Lubricated by wayside lubricator	4,100	32
Lubricator car (simulated for one train in four equipped); graphite grease	4,800	20
Hyrailer System (operated once every 30 to 35 trains)	5,500	8
On-board locomotive system (two locomotives equipped, modified for American use)	5,140	14

Note: Data for 80-car train, 45 mph, four locomotives on 4.8-mi loop, 56 percent curved track of 5, 4, and 3-degree curves. Baseline data: overlubricated by wayside systems; one trackside lubricator every 2.5 mi.

[a] Million gross tons.

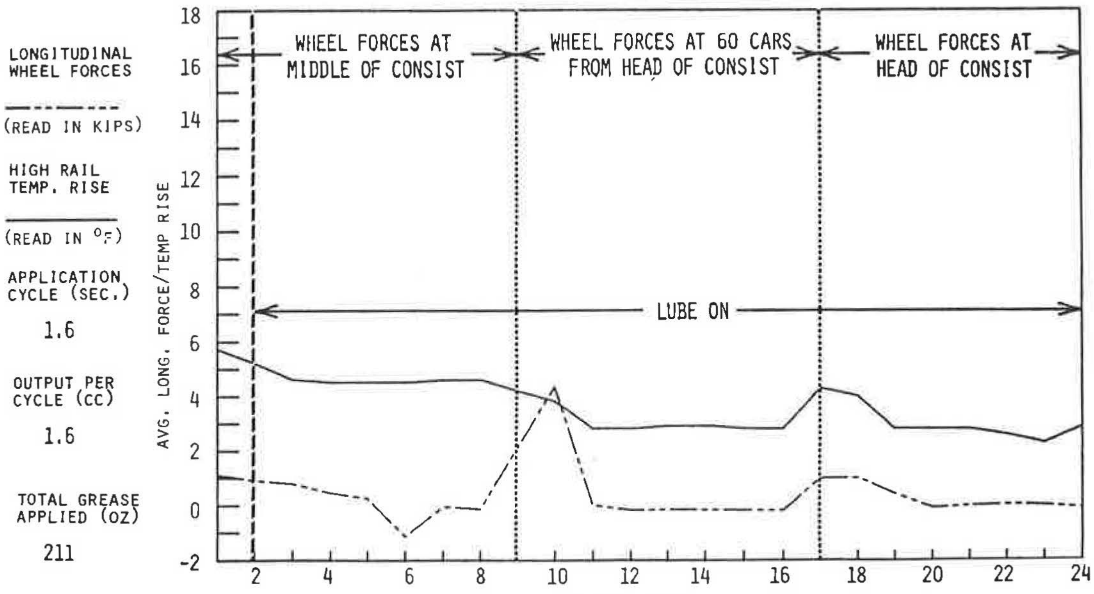

FIGURE 13 Example of wheel force and rail temperature data for Bijur Lubrication system test (Run 1253).

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Research and Development and Productivity: High-Productivity Integral Trains

SCOTT B. HARVEY

ABSTRACT

Some preliminary conclusions concerning the rate of technological change and railroad productivity are drawn based on the railroad industry's High Productivity Integral Train project. First, the economic targets established for integral trains appear to be reasonable in light of already available alternatives to conventional technology and opportunities for further improvement resulting from the design of noninterchange equipment and the exploration of possible improvements in truck and brake systems. If the targets are realized, integral-train technology should affect at a minimum 20 percent of railroad business and enable the industry to meet competitive challenges in the foreseeable future. Second, integral trains are not new conceptually or radically different in engineering. What is new is the economic and institutional environment. Mergers, deregulation, changing transportation markets, and truck competition have all improved the potential for integral-train technology and for other innovations that promise productivity improvement. Third, innovation in railroad equipment must overcome the adverse impacts of slow output growth, current excess capacity, long asset life, and the financial condition of the railroad supply industry. Therefore, the railroad industry may well need to explore new approaches to R&D and equipment purchasing policies if the rate of innovation is to be increased.

For the economy as a whole, technological change--advances in knowledge that are incorporated into new or improved plant and equipment--has accounted for over one-half of measured productivity growth since World War II (1). Certainly, railroad productivity has been enhanced by technological changes--dieselization and subsequent improvements in power and efficiency, increased freight car capacity, lighter car designs, computerization, communications systems--a long list could be developed. Yet most examinations of the rate of innovation and technological change in the railroad industry have found it to be uneven, relatively slow, and hampered by institutional and economic barriers such as slow output growth, long-lived assets, regulation, labor agreements, and balkanized industry structure (2).

Any examination of railroad productivity needs to address the question of technological change and the rate at which new and improved technology is introduced and spread through the industry. In this paper an attempt is made to discuss the general subject of technological change in the railroad industry from an economic perspective, using a specific technological possibility, integral trains, as a case study. Integral trains and a railroad industry effort to stimulate their development--the High Productivity Integral Train project--are discussed first. Then trends in some of the economic variables that influence the rate at which new technology, such as integral trains, is developed and introduced are covered. Last some general conclusions are drawn based on integral-train experience concerning policies and programs the industry might consider to increase technological change and productivity growth.

The general conclusions reached are, first, that integral trains are a source of significant potential productivity improvement; second, that the economic and institutional environment now favors their introduction; and, third, that changes in railroad policies toward development and purchasing may be required if integral trains are to reach their full potential.

INTEGRAL TRAINS

High-Productivity Integral Train (HPIT) Project

In April 1984 the railroad industry announced at a public meeting a project to facilitate and promote the development of integral trains. Integral trains are trains designed and built to operate as a functional unit as differentiated from unit trains, which are composed of conventional locomotives and freight cars that happen to be employed as a unit. The study is known as the High Productivity Integral Train (HPIT) project.

The HPIT project seeks the development of integral trains under guidelines purposely written to maximize the chances for innovative designs and stressing the need to develop trains that would significantly reduce operating costs. The targets suggested are a 50 percent reduction in road-haul intermodal costs and a 35 percent reduction in bulk unit-train costs when compared with conventional railroad equipment.

Twelve companies or groups of companies in the railroad supply industry responded to the project by beginning the process of developing integral-train concepts and designs. The industry and the Association of American Railroads (AAR) are assisting these companies by reviewing various concepts in terms of their technological, operating, and economic feasibility and have offered to test trains or components or both. Developers are in various stages of the conceptual and design process, and some are beginning to market their concept. It is possible that integral-train components will be ready for testing in 1985.

The concept of integral trains has been known for years, and proponents have advocated integral trains as a means of improving productivity. During the 1960s, the Santa Fe developed a "coaxial train" concept that was characterized by a continuous center sill running the length of the train and all powered wheels. The Railway Systems and Management Association (RSMA) held a conference on integral trains in 1963 (3) and Kneiling wrote a book on the subject in 1969 (4). It was acknowledged even in the 1960s that integral trains are based on logical extensions of engineering principles long known and understood in the industry.

During the 1970s, when the railroad industry's problems were the subject of considerable public debate, integral trains were often mentioned as a promising innovation. In 1973 a special Task Force on Railroad Productivity formed by the Council of Economic Advisors and the National Commission on Productivity devoted a chapter of its report to railroad technology and innovation and found the integral train particularly promising (2,p.288):

> Unit trains of specialized design will probably become more common. Unit trains of container flatcars or . . . bulk commodity cars need not be disassembled and switched with anything approaching the frequency of freight cars in conventional train operations. This may suggest some redesign of freight cars and train systems.
>
> Specifically, the suspension, coupling and braking systems of present-day freight cars are designed to accommodate the need to detach and switch cars frequently. These systems have deficiencies that might be overcome in cars that would remain permanently or semi-permanently attached and would not have to be interchangeable with all the other cars in the fleet.

A report by the National Research Council in 1979 on possibilities for future freight systems reached a similar conclusion (5,p.104).

Integral Trains and Productivity

From the perspective of railroad productivity, the key aspect of integral trains is the possibility of dramatically reducing train operating costs in comparison with conventional unit-train technology. The possibilities for cost reduction arise from two opportunities that integral trains offer designers. The first is to design a train system rather than motive power and load-carrying units individually. The second is to design trains that do not necessarily meet AAR-established interchange requirements. Because integral trains will not be subject to shocks and forces associated with classification and yard operations, there are possibilities for weight reduction that are not present on cars designed for full interchange. Drawbars and coupler systems, as well as other aspects of car design, can be designed to accommodate only the longitudinal forces anticipated in the service for which the train is designed.

The first point to make concerning potential cost reductions is that there are several existing technologies that can be employed toward the achievement of integral-train targets. In Table 1 the magnitude of the impact of these technologies in intermodal service is suggested. The road-haul costs included

TABLE 1 Costs per Cubic Foot-Mile for Intermodal Service

Technical Configuration	Dollars per 10,000 ft^3-mi		
	Road	Terminal	Total
TTX flat–two 45-ft trailers	0.74	1.26	2.00
Articulated car			
45-ft trailer	0.70	1.26	1.96
45-ft container	0.63	1.26	1.89
Trailer without flatcar	0.48	1.32	1.80
Articulated car–two 45-ft containers	0.43	1.27	1.70

Source: AAR Research and Test Department.

in Table 1 were developed by using AAR cost models (6).

Table 1 demonstrates the impact of introducing improvements to the base technology of two 45-ft trailers on a conventional TTX flatcar. Articulated cars reduce the weight per platform and make possible improved aerodynamics. Containers further reduce aerodynamic drag. Trailer-without-flatcar designs like the Road Railer further reduce weight and have superior aerodynamics. Double stacking containers permits further improvements primarily because of the doubling of capacity per platform. Double stack containers, as indicated in Table 1, reduce road costs per cubic foot-mile by 41 percent. In sum, currently available technology significantly reduces cost per cubic foot-mile from conventional technology and goes a long way toward meeting the targets established for HPIT.

In the bulk area, available technology is compared with conventional 263,000-lb gross vehicle weight (GVW) steel car unit trains in Table 2. Aluminum cars restricted to the common 263,000-lb GVW limit used on most roads permit replacing tare weight with lading, which reduces costs on a net ton-mile basis. A 50 percent reduction in tare weight (some current cars offered on the market come close to that target) plus an increase in GVW to 286,000 lb (the limit on one major railroad) reduces road-haul costs per net ton-mile by 23 percent. Replacing tare weight with lading, and the resulting decrease in the number of trains required to move a given volume of traffic, more than offset the increased track maintenance costs because of increased weight. As in the intermodal case, it is possible to significantly reduce costs by using currently available options.

Integral trains have the potential for still further reductions in unit-train costs. Research and development (R&D) efforts might address a number of areas, including the following:

- Changes in truck design to improve performance and reduce weight with resulting reductions in accident, fuel, and equipment and track maintenance costs. Freight car trucks represent 28 percent of conventional unit train weight (7).
- The use of live loads to develop tractive effort, eliminating the need to ballast motive power units (although marked improvements in adhesion in new locomotive designs may make this option unattractive).
- Improved braking systems. Studies have shown that one-half of the cost of freight car running repairs result directly from the braking systems (8). Improved brake response time, uniformity, and load-compensating brake systems could be a source of significant savings.
- Slack reduction through the use of, for instance, slackless drawbars, to reduce shocks; lading damage; draft system, suspension, and running gear wear; and car fatigue.
- Reduced design loads (and hence weight requirements) as a result of the ability to design noninterchange equipment.

TABLE 2 Costs per 1,000 Net Ton-Miles for Coal Unit Trains

Technology	Dollars per 1,000 Net Ton-Miles		
	Road	Terminal	Total
Steel cars, 263,000-lb GVW	9.45	1.23	10.68
Aluminum cars, 263,000-lb GVW	8.99	1.31	10.29
Tare reduction of 50 percent, 286,000-lb GVW	7.21	0.89	8.10

Although the emphasis has been placed on road cost reduction in most integral-train analyses, terminal costs and costs incurred by shippers are also important. Terminal costs are particularly important in intermodal service. According to the AAR Estimate from Rail Energy Cost Analysis Program (RECAP), over a 1,000-mi route with conventional intermodal equipment, terminal costs are over 60 percent of total operating costs. Therefore an increase in terminal costs resulting from integral-train designs must act as an offset to road cost reduction. Costs to the shipper are also important, especially in bulk service. Don Ruegg, Senior Vice President of the Santa Fe, noted at a recent meeting of the AAR Mechanical Division (June 29, 1984) that

> if we come up with (integral train) designs that would require, for example, a grain elevator operator to redesign his loading facility or one that would require a coal mine to acquire new dumpers then we are in big trouble. We have to remember our customers all have tough problems and accommodating us (should not be) one of them.

The productivity implications of integral-train designs can be summarized by looking at how costs are generated in the railroad industry--or in productivity terms how output generates input requirements. The two important factors are service units (train miles, train hours, switching hours, etc.) and costs per service unit (such as labor costs or fuel costs per train mile). Integral trains affect both the service units required and the costs per service unit. The most important impacts are as follows:

- Reductions in train miles and train hours necessary to move a given volume of freight as a result of substituting lading for tare in bulk designs and increasing load per unit length of train in intermodal design and
- Reductions in the cost per train mile due to improved fuel efficiency, reliability, and maintenance cost performance.

These productivity impacts are in addition to the economies that unit-train operation itself provides.

Potential Market for Integral Trains

Integral trains that meet the economic targets established in HPIT could have a significant impact on overall railroad productivity. A rough estimate is that at least 20 percent of current railroad traffic could move in integral trains. An examination of carload waybill statistics shows that about 50 percent of coal traffic moves in point-to-point volumes of 5,000 carloads or more annually (which would generate a train of 100 cars weekly) and that 50 percent of intermodal traffic originates at points generating 8,000 or more containers or trailers annually (9). These large traffic flows would be the initial market of integral trains, and because coal and intermodal traffic account for 40 percent of total rail car loadings, an estimate that 20 percent of current rail traffic could move by integral trains is not unreasonable. This assumes, however, static market conditions despite the dramatic savings that integral trains promise. These savings may well change railroad and shipper traffic patterns and extend integral-train service into other bulk commodity markets, where the potential applications of integral-train technology could be increased.

ECONOMICS OF TECHNOLOGICAL CHANGE

A first question to ask concerning integral trains is why there is now a major effort to develop a concept that has been known and espoused for decades. The answer is of more than academic or historical interest because the rate at which new technology is introduced into the industry--the rate, that is, with which R&D translates concepts into usable innovations--will be a major determinant of future productivity growth.

Does current interest in integral trains reflect changing conditions that are relevant only to integral trains or are there basic changes applicable to interest in railroad technology and innovation in general?

To suggest an answer to this question, the variables that influence the rate of technological change in an industry are discussed in the railroad context. Economists generally agree that the rate of technological change in an industry depends on the resources devoted to improving technology and that the resources devoted to that end are determined by the anticipated profitability of the investment (10). Investment in new technology is of two types: R&D to develop the technology and capital investment in new plant and equipment that embodies the technology. Like any economic concept, the anticipated profitability of investing in new technology is influenced by demand and supply variables. On the demand side, the most important variables include

- The rate of growth in output--industries that are growing have the opportunity to employ new technologies as capital investment requirements increase in response to demand;
- Asset life--the shorter the life of capital assets, the greater the opportunity to replace existing capital with capital that employs new technology;
- Financial health--the ability to invest in capital and in R&D;
- Competition--the pressures placed on a firm or industry to develop or use new technology to maintain or increase market share and profitability; and
- Appropriability--the ability to capture the benefits of new technology; appropriability refers to the extent to which a company investing in technology can sell or employ the technology in actual operation and reap the benefits.

On the supply side, the major variables include

- The quantity of resources devoted by other industries (in this case, railroad suppliers) to the improvement of capital goods;
- Cost, influenced by the amount of R&D required and the probability that R&D will be successful; and
- Experience, the amount of effort the industry has employed in the past to make improvements and conduct R&D based on practical experience.

Each of these variables is now examined within the railroad context.

Demand for Improved Railroad Technology

Railroad output growth has been flat over the last 10 years in ton-miles and declined in terms of car loadings and tons originated. The primary growth market has been intermodal transportation. Intermodal growth has prompted new investment and led to a number of new and innovative car designs, but overall growth in demand has not been a stimulus to new technology. Most forecasts are for continuing slow growth in output--except in intermodal transportation and perhaps in coal.

The service life of railroad assets is quite long, about 30 years for most freight car types and 15 to 20 years for road power. In addition, peak years for new car deliveries were relatively recent--1979 and 1980. In such circumstances, the pace of technological change is slowed considerably from the rate that could be achieved in trucking, for instance, where tractors and trailers have service lives of about 4 and 7 years, respectively.

Railroad profitability has improved. Return on net investment was under 2 percent for most of the 1970s but has improved dramatically in the 1980s, despite the recession, reaching 4.1 percent in 1980 and 3.6 percent in 1983. Final 1984 figures will show improvement. Nevertheless, railroad return on investment is low in comparison with that for other industries and with the cost of capital. Improvements in earnings should signal growth in capital investment and in R&D expenditures. Indeed the industry's expenditures for research through the AAR have increased sharply in recent years--from less than $8 million in 1980 to over $17 million planned for 1985.

The market for freight transportation has become increasingly competitive. Deregulation and the growth of nonunion trucking significantly lowered costs for rail-competitive truckers. Recent increases in truck size and weight limits and the use of double bottoms enabled trucks to realize major productivity improvements. In the future, truck competition could become even more severe because it is estimated by the AAR that long (48-ft) double bottoms would, if generally permitted on the highways, lead to a 40 percent drop in trucking costs and a $1.8 billion loss in rail revenues. In coal markets, slurry pipeline competition, though successfully combatted economically and legislatively to date, is a constant possibility, and competition for coal markets from other energy sources, and from other countries in export markets, is constant and real. Competition should, and has, acted to spur railroad interest in ways to improve productivity, including technological change.

Finally, there is the variable of appropriability, or the amount of benefit an investor in new technology can expect to achieve. Here two factors act to significantly improve the prospects for technological change. One is railroad mergers.

In 1970 there were 71 Class I line-haul railroads in the United States, and over one-half of railroad traffic was interlined. This balkanization of the industry inhibited railroad innovation particularly in interchange equipment because if the full benefits of any innovation were to be realized, all or a large part of the industry would have to adopt the innovation. There are now 28 Class I railroads and the 7 largest railroad systems account for over 84 percent of the industry's operating revenues. Now only slightly over one-third of rail traffic is interlined and individual railroad systems have the ability to fully control operations for a number of high-volume traffic corridors. Technological change can therefore be introduced by an individual road and that road can reap a larger portion of the reward.

Another factor increasing a railroad's ability to realize the benefits of innovation has been deregulation. Regulation made it difficult, if not impossible, to engage in innovative marketing and pricing strategies to take advantage of new technologies and in general acted to enforce the status quo. The freedoms provided by the Staggers Rail Act of 1980, particularly those relating to contract rates, considerably enhance the prospects for integral trains and other technological improvements and the ability of railroads to design innovative price and service packages using such trains to retain business in the face of competition and to enter new markets.

In recent years, then, the potential for new technology has been significantly improved by mergers and deregulation and improving rail profitability, and the need for such technology has been heightened by the increasing importance of coal and intermodal traffic and their susceptibility to competition. These factors should act to increase railroad receptivity to all innovations that promise to increase productivity, but mergers and competition are particularly relevant to integral trains.

Supply of New Technology

A major determinant of an industry's rate of technological change is the resources devoted to innovation by its suppliers. Here a major problem area is the financial health of the railroad supply industry. In 1979, spurred by traffic growth and incentive per diem, new car deliveries reached over 93,000 (11). Since then, general economic conditions and improved utilization have dropped new car deliveries constantly and drastically to under 6,000 in 1983. Although new car deliveries will rebound in the next few years, they will be unlikely to exceed a level about one-half of that achieved in 1979.

The decline in new car deliveries has taken its toll. The number of car builders has dropped from 20 to 12 and the ability of the supply industry to undertake major R&D efforts has been reduced (12). The railroad industry has relied on the supply industry for the development of technological innovations and is continuing to rely on them in the HPIT project and other research efforts, but the ability of the supply industry to invest in railroad innovation has to be a major concern.

On the other hand, there have been changes in the industry that ought to significantly reduce the cost of developing new technology.

R&D efforts by suppliers and the railroad industry have improved the ability to analyze important technical dynamic interactions between vehicles and track and to better understand and determine the economic implications of alternative designs and the interactions between those designs. The ability to successfully design new equipment has been dramatically improved by the development of mathematical modeling techniques dealing with wheel and rail wear, vehicle and train dynamic behavior, finite-element analysis techniques, and many others. These techniques, and economic models that permit the translation of technological changes into cost elements, enable designers to evaluate concepts before actually building hardware. There are several examples of the use of such techniques in design efforts, including the design of advanced covered hoppers under the sponsorship of the railroad-government-supplier Track Train Dynamics program (13).

Finally, there is the factor of experience. An industry's ability to develop and utilize improved technology depends in part on its experience--the base of knowledge that can be used as a springboard for further applications. An example is provided by the industry's energy research program conducted through the AAR. Prompted by the energy shocks of 1973 and 1977, the industry and government began in 1978 a small program to analyze possibilities for alternative fuels. The AAR's portion of that program was relatively modest. But success in defining lower-cost fuel alternatives established credibility for the program and demonstrated potential economies. Since then, the energy research program has broadened to include train resistance, locomotive component efficiency, and other areas, and has grown from $250,000 to over $4 million annually. The results of other research efforts--such as the recognition of the potential for track lubrication to save fuel, which was a byproduct of accelerated service testing at the Transportation Test Center--have greatly improved the potential for new technology development. The same is true with improvements being made by suppliers and railroads in intermodal equipment design, which expand the base of knowledge and experience and make further improvements more likely.

Summary

The preceding analysis of demand and supply variables influencing the rate of technological change in the railroad industry reveals some positive and negative factors. On the positive side, rail profitability, though still inadequate, is improving; competition is accelerating the search for productivity improvement; and deregulation and mergers make it more possible for railroads to gain the benefit of new technology. At the same time, past R&D expenditures by railroads and suppliers offer the opportunity to reduce the costs of R&D by permitting mathematical analyses and simulations before actual detailed design and prototype construction and have significantly improved the base on which new technology can build.

On the other hand, the rate of growth in rail output is slow and projected to continue to be so. The life of railroad assets is long and the supply industry, the primary source of innovations in rolling stock, is experiencing considerable financial difficulty and a consequent reduced ability to invest in R&D.

Railroad interest in integral trains has been accelerated by competition, deregulation, and mergers in recent years. To translate that interest into actual integral trains in operation, R&D investments must be made for concept development, detailed design work, and prototype construction and testing. And the investment must be made despite continued slow growth in railroad output, existing excess capacity for many car types (and the long life of rail assets), and the financial pressures facing the railroad supply industry.

STRATEGIES FOR INCREASING TECHNOLOGICAL CHANGE

Although there are positive factors influencing the prospects for technological change in railroading, there are some negative factors to overcome. The primary concern is the volume of resources devoted to R&D by railroads and suppliers alike. Innovation strategy ought to address this issue. In particular, it is important that railroads and their suppliers be in agreement concerning priorities. In HPIT the railroad industry told suppliers that it was seeking new technology to reduce the costs of two particular types of rail movement--unit-train service for coal and intermodal traffic. The same approach was used in the Advanced Train Control project.

Although this procedure serves to focus R&D efforts, participants need to consider other issues. Implicitly or explicitly, potential investors in R&D will try to estimate the time stream of costs and benefits that would result from undertaking R&D and the ratio of benefits to costs. Anything that will increase the prospective benefit/cost ratio of R&D projects will therefore increase investment and speed the process of innovation. The elements of benefit/cost analysis of R&D projects include

- Research and development costs,
- Anticipated benefits net of implementation costs (that is, for a railroad benefits less capital or operating costs or both and for a supplier gross revenue less costs of production),
- Probability that research can produce the desired innovation, and
- Probability that the innovation will be successfully marketed.

The HPIT project is designed to reduce R&D costs incurred by developers and to increase the probability that R&D efforts will be successful technically and in the marketplace. In particular,

- The project was announced as an industry effort to encourage R&D addressed to performance rather than design specifications. This approach emphasizes to suppliers the performance criteria that the industry judges most important and maximizes the chance for creative response. Although the approach is not unique (it has been used for the development of high-performance covered hoppers, for instance), it is not generally employed in equipment purchasing and research policies.
- The project attempts to reduce the R&D costs that integral-train developers would incur by offering technical assistance from railroad experts and the AAR. Committees have been organized to serve as a forum through which developers can discuss ideas. In theory this procedure offers developers a means of avoiding unnecessary expenditures and concentrating efforts on areas that industry experts feel to be of the greatest importance. The procedure should not only reduce R&D costs but also increase the probability of R&D success.
- The project makes available to integral-train designers economic and technical models developed by the AAR that can be used to examine the feasibility and impact of various design options.
- The project provides a vehicle through which the testing costs to developers can be reduced. If developers are willing to make results of tests generally known, the industry will absorb the testing costs incurred.
- The project attempts to increase the probability that successful innovations will be marketed by offering developers an evaluation of the technical and economic feasibility of the project that the developer can use, at his option, in marketing efforts.
- Benefits realized by suppliers will depend on their ability to maintain proprietary rights. HPIT is designed to protect these proprietary rights by maintaining confidentiality and by making it clear that concept reviews and evaluations are the sole property of the company developing the concept.
- Finally, the project recognizes that the major costs of integral-train development will be incurred in detailed design work and in prototype construction. The timetable for the project suggests that developers engage in marketing efforts to ensure that the market for the concept is sufficient to warrant the additional development costs.

It is this final point that will be the key to integral-train development. A number of possible arrangements between railroads and suppliers could be developed through individual railroad-supplier negotiation before detailed design and prototype construction. These arrangements could range from direct railroad participation in R&D costs to agreements similar to those reached in the airline industry, which would involve railroad commitment to purchase integral trains if certain design objectives are successfully met.

In sum, HPIT is as much an experiment in the process of innovation as it is a technical research effort, and the eventual utilization of integral trains will depend as much on institutional and financial arrangements as on technical accomplishment. In particular, the resources devoted to R&D by railroads and suppliers are in short supply. Therefore, for maximum impact on innovation, they must be used as productively as possible. The procedure developed for HPIT involves cooperation between suppliers and the industry to ensure that research efforts are channeled in the right direction, in an attempt to avoid misallocation of time and effort and to maximize the chances for successful research and marketing. It may be, however, that efforts such as HPIT will require further changes in industry purchasing policy if they are to lead to successful innovation.

SUMMARY

Some preliminary conclusions concerning the rate of technological change and railroad productivity have been drawn. The conclusions are based on the railroad industry's HPIT project. Although the project is ongoing, some points can be made that relate to railroad R&D, innovation, and productivity.

First, the economic targets established for integral trains appear to be reasonable in light of already available alternatives to conventional technology and opportunities for further improvement resulting from the design of noninterchange equipment and the exploration of possible improvements in truck and brake systems. If the targets are realized, integral-train technology should affect at a minimum 20 percent of railroad business and enable the industry to meet competitive challenges in the foreseeable future.

Second, integral trains are not new conceptually or radically different in engineering. They have been advocated for some time. What is new is the economic and institutional environment. Mergers, deregulation, changing transportation markets, and truck competition have all improved the potential for integral-train technology and for other innovations that promise productivity improvement.

Third, innovation in railroad equipment must overcome the adverse impacts of slow output growth, current excess capacity, long asset life, and the financial condition of the railroad supply industry. Therefore, the railroad industry may well need to explore new approaches to R&D and equipment purchasing policies if the rate of innovation is to be increased.

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Track Maintenance Cost Analysis: An Engineering Economics Approach

MICHAEL B. HARGROVE

ABSTRACT

A methodology that allows the determination of the track maintenance costs incurred because of a specific rail service is the topic of this paper. The recommended methodology is a life-cycle costing approach based on engineering economics that allows not only the costing of a specific service over a specific existing route but also the evaluation of alternatives in the equipment, the operating plan, or the track structure and maintenance standards. This methodology can provide the type of track maintenance cost inputs required either by planners who are considering alternative strategies for providing service or by cost analysts who are providing input to the marketing functions. The recommended methodology has been incorporated into a computer program, TMCOST, which allows estimates to be made without undue user effort.

A methodology that allows the determination of the track maintenance costs incurred because of a specific rail service is the topic of this paper. The recommended methodology is a life-cycle costing approach based on engineering economics that allows not only the costing of a specific service over a specific existing route but also the evaluation of alternatives in the equipment, the operating plan, or the track structure and maintenance standards. This methodology can provide the type of track maintenance cost inputs required either by planners who are considering alternative strategies for providing service or by cost analysts who are providing input to the marketing functions. The recommended methodology has been incorporated into a computer program, TMCOST, which allows estimates to be made without undue user effort.

INTRODUCTION

The traditional methodology for estimating track maintenance costs incurred by providing rail transportation is an accounting-based statistical procedure using aggregated data covering the entire range of traffic on the railroad. Aggregate measures of service activities (gross ton-miles of traffic for track) are statistically related to aggregate expenditures for various categories of resources (materials, including rail, ties, and ballast, and the labor, equipment, and supplies used to install them in track) across a number of railroads using data from several years to smooth out the effects of the timing of track maintenance projects. This methodology, which is used both by the old Interstate Commerce Commission (ICC) Rail Form A procedure and the recently approved Uniform Railroad Costing System (URCS), results in an estimate of track maintenance costs per gross ton-mile that are constant for all services over all routes on a railroad.

This type of track maintenance cost estimation may have been adequate for regulatory purposes when railroads offered a wide variety of individual low-volume services in relatively homogeneous equipment moving in mixed-consist, general service trains. It is not adequate for the purpose of costing high-volume services over specific routes using specific equipment, as required to analyze the costs of unit coal trains, dedicated intermodal trains, and other bulk services including grain, ores, and fertilizers. The importance of accurate track maintenance cost estimation is increased by current marketing trends toward the coverage of much of this traffic by long-term contracts that do not allow the recovery of high track maintenance costs that unexpectedly exceed inflation through later rate increases.

In addition, the track maintenance costs estimated by traditional accounting-based methods do not provide the transportation and engineering planners with inputs concerning the track maintenance cost implications of various alternatives in equipment, operating plans, and track that may be used in providing the service. For example, opportunities to use profitably lightweight aluminum cars or cars equipped with steering trucks may be overlooked if the track maintenance costs do not reflect the impacts of the curvature and gradient of the route and the axle loads and dynamic characteristics of the alternative equipment. In many cases where the shipper or a third party may be supplying the equipment, it is necessary that the cost implications be communicated effectively to the marketing personnel so they can develop a contract that encourages provision of the optimum equipment at a net benefit to both the railroad and the shipper.

The shortcomings of Rail Form A and URCS for the purposes of costing unit-train moves have been recognized, and many cost studies conducted both for managerial and regulatory purposes have utilized Form A adjustments that have ratioed the standard track maintenance costs upward to compensate for the increased track maintenance costs expected under the heavy axle loads of bulk commodity unit trains. Although better than using unadjusted accounting-based costs for the purpose of setting rates that will allow cost recovery, these adjusted costs are not sufficiently sensitive to the wide range of route- and service-specific factors that must be recognized to plan optimum services and infrastructures to meet the demands of individual markets. What is needed is an approach to track maintenance costing that estimates the relationship between the provision of service and the incurrence of various track maintenance expenditures based on accurate estimates of the causal factors as determined from engineering studies.

An engineering economic methodology for estimation of the relationship between rail traffic over a route and the incurrence of track maintenance costs is described. The best existing models available to estimate the track component life cycles required to utilize this methodology and a computer program, TMCOST, that ties these models together and quickly performs the required computations are also described. An approach is demonstrated that provides on an incremental basis the track maintenance cost information required by economic theory to plan and market specific high-volume rail services. Because the causal relationships within the models are correct from an engineering perspective, alternative approaches can be evaluated on a prospective basis and lower cost alternatives found. Although the inputs required are greater than those required by the accounting-based approach, the level of effort is not excessive where unit-train contracts are concerned, given the magnitude of the costs and revenues involved.

ENGINEERING ECONOMIC METHODOLOGY

The methodology proposed for estimation of track maintenance costs is a component life-cycle approach. The basic logic flow of this process is shown in Figure 1. For each major component of the track system, a model of the deterioration of the component in response to traffic and environmental stresses is required. These deterioration models are developed from engineering relationships between the incremental unit of traffic and the forces exerted on the components of the track structure that result in their degradation. The unit of traffic utilized is the individual wheel loading exerted on track by each passing axle on the locomotives, cars, and other equipment used to provide service. From these models the state of any component after a given flow of traffic can be estimated.

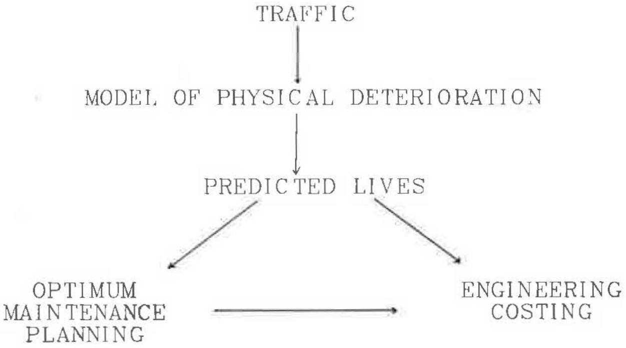

FIGURE 1 Engineering economic analysis.

The second step is to compare the estimated rate of deterioration of the components against the required performance standards for those components to determine the accumulated traffic of a given composition required to deteriorate these components to their condemning limits. Given the traffic densities and the aggregate traffic required to deteriorate to the condemning limit, the life cycle of the major track components can be estimated. The determination of the condemning limits is outside the modeling effort. They may be determined from the track standards of the railroad, from the limits established by the Federal Railroad Administration (FRA) track standards, or from models such as the Rail Performance Model (1) that estimate the economically optimal performance standards for track components.

The third step in the costing methodology is to estimate the unit costs of the required maintenance activities. This requires an industrial engineering study of the resources employed and consumed in the maintenance procedures and the productivity achieved. This is a difficult task, but a set of computerized spreadsheets has been developed to ease the computational tasks. The most difficult dimension to specify accurately is the productivity actually achieved in the field.

Finally, given the life cycles of the components in the track and the costs associated with their renewal, the costs per unit of traffic and costs per year can be estimated. The costs can be estimated on a year-by-year basis for maintenance budgeting purposes and on an equivalent annual basis for financial planning and analysis purposes. In addition to the costs estimated on a life-cycle basis, some relatively minor costs that result from causes for which no suitable deterioration model exists must be estimated by examining maintenance records to establish typical annual expenditures for these routine noncyclic maintenance activities. The total costs, both cyclic (programmed) and noncyclic (routine), are estimated for the specific traffic over each segment of the route, and these segment-by-segment costs are totaled for the route costs.

The costs required for managerial and marketing purposes are the incremental costs associated with a specific traffic segment. Unlike the accounting-based procedures, which estimate the percentage of cost that is variable with traffic over a wide range of traffic volume and apply that average percent variability to the total maintenance costs to estimate the cost variable with traffic, the engineering economic methodology estimates the incremental cost of a component of the total traffic over the route by estimating the track maintenance costs twice. First, track maintenance costs are estimated for the total traffic over the route. Then a second set of track maintenance costs is computed with the particular traffic component to be costed removed. The estimated incremental cost of the specific traffic component over the specific route is the difference between the two.

DETERIORATION MODELS

The deterioration models for the track components are the heart of the engineering approach to track maintenance modeling. These models must not only accurately estimate the deterioration rates of components when exposed to typical traffic mixtures but must also accurately reflect the deterioration rates that will be experienced under new traffic components not currently experienced if the methodology is to be useful in a planning and prospective costing environment. This requires models that are based on accurate engineering representations of the forces exerted on the track components by the wheel loads of different traffic components and accurate representations of the deterioration of the components in response to these forces. The ability of the track components to resist the forces exerted by the traffic depends on environmental factors to some extent. For example, the deflection of the track under load is related to its stiffness or modulus, which is determined in part by the moisture in the subgrade. The deterioration of many components is a result of an interaction of traffic and environmental stress.

All the deterioration models used in the current version of the computer program TMCOST are fully documented in other publications. A complete description of these models and their calibration and validation process is beyond the scope of this paper; however, a brief description of the models along with a discussion of the important traffic parameters that affect their predictions of component lives are presented. As is true of all fields of scientific inquiry, all the specific techniques used in the current version of TMCOST are subject to review and improvement. The existing models have proved to be adequate for the tasks currently required, but as new knowledge of the fundamental deterioration processes is developed, new models capable of accurately modeling an even wider range of situations can be anticipated. The critical element is the engineering-based methodology, not the specific models used to implement the methodology.

Rail Deterioration Models

Rail deteriorates in two modes. First, it wears where it comes into contact with the wheels of passing traffic, and second, it fatigues and breaks because of the initiation and propagation of subsurface cracks in response to repeated loading-cycle input by the passing axle loads of the rail traffic. These two mechanisms are competing failure modes. In curves of 2 degrees of curvature and greater, the forces between the flange of the wheel and the gauge face of the outer rail cause wear on the gauge face of the rail sufficient to reach a wear-condemning limit before fatigue progresses to a sufficient degree to warrant the removal of the rail. In other environments, rail defects due to fatigue occur at an accelerating rate and reach unacceptable levels before reaching wear limits. Separate models are used to predict wear and fatigue of the rail, and the mode of deterioration that first reaches its condemning limit determines the estimated life cycle of the rail.

Rail Wear Model

The rail wear model used in the current version of TMCOST is one developed by Michael Roney at the Canadian Institute for Guided Ground Transport (CIGGT) (2). This model estimates the creep forces between the wheel and rail at the flange and rim of the outside wheel and the rim of the inner wheel during curving. Tribology relationships between creep forces and wear are used to estimate the wear associated with each wheel passage and are totaled for all the wheels in the traffic flow to estimate the wear rate. Because the force calculations are based on the dynamic characteristics of each equipment type, the effects of innovative equipment such as radial trucks, lightweight cars, or improved suspension systems can be evaluated. The effects on rail wear of such varied pieces of equipment as six-axle locomotives or empty freight cars in environments varying from level tangents to sharp curves on steep grades can be determined.

The model translates the traffic as specified by the equipment, the operating plan, and the gradient and curvature of the track into a spectrum of creep forces at the wheel-rail interfaces. Basic tribology relationships developed through laboratory studies are used to translate these forces to relative wear estimates. To calibrate the relative predictions of the model to the actual rail wear rates observed in rail operations, a number of field wear studies both in Canada and the United States have been conducted. In addition, results of rail wear studies at the Facility for Accelerated Service Testing (FAST) have been incorporated into the calibration activities (3). This extensive calibration activity has produced a model that can predict rail wear with sufficient accuracy to support planning and costing activities.

Rail Fatigue Model

Rail fatigue is produced from the cyclic loading of the rail by the wheels of passing traffic. The steel in the head of the rail is subjected to stress from a number of sources, including the contact stress in the wheel: rail contact zone, thermal stress, and vertical and lateral bending stresses from the axle loadings of the traffic. Under modern rail traffic the resulting stresses exceed the yield strength of the steel, and after sufficient loading cycles, the regions of maximum stress in the rail head will develop cracks that will propagate to critical size. The resulting transverse defects and other forms of broken rail must be detected and the rail replaced, either through magnetic and ultrasonic inspection of the rail head or after in-service failures, which may result in derailments. The Rail Performance Model, developed by the Track Maintenance Planning Committee of the AAR, is designed to determine the rate of defect formation at which it is economically efficient to lay new rail to replace the existing rail.

The expected defect rate after a given flow of traffic is predicted in the current version of TMCOST by the Rail Fatigue Life Analysis Program (RFLAP) developed by Alan Zarembski (4). This model calculates from a given traffic axle load spectrum the cumulative fatigue damage done to the rail steel at the point of maximum stress, typically 1/4 in. below the surface at the gauge corner of the rail. When the cumulative damage reaches the fatigue limit as specified by Miner's rule, crack initiation is predicted, and the rate of critical fatigue defects predicted from an empirically developed Weibold distribution. The predicted fatigue defect rate is compared with the condemning rate established from the Rail Performance Model or the maintenance standards of the railroad to determine the fatigue life of the rail, both in terms of millions of gross tons (MGT) of traffic and years.

The RFLAP model has been extensively calibrated to North American rail experience and gives predictions of sufficient accuracy to support costing and planning studies. A new fatigue life program (Phoenix) is currently under development to better model the rail head stresses, especially the stresses resulting from the lateral forces during curving, thus producing better predictions of shelling and other fatigue defects occurring in curves. When Phoenix is fully developed and calibrated, the new fatigue model will replace RFLAP in the TMCOST program. The methodology and the computer program to execute the methodology allow the development and incorporation of new, improved deterioration models without modification of the basic approach.

Tie and Ballast Deterioration Models

The deterioration of both ties and ballast is currently modeled as being proportionate to the deflection of the track under load. The formula for the deflection of a beam on elastic supports developed originally by Talbot is used to predict the relative response of the track to various axle loadings and the relative deterioration of the ties and the ballast. Field studies of available data on tie replacement rates and surfacing cycles for various traffic volumes and axle load spectrums have been used to calibrate the tie-life and ballast-surfacing models. The models are documented in the CIGGT report on their Roadway Maintenance Cost Model (RMCM) (5).

The current tie and ballast models are limited in that they only model the observed responses of railroad management to the deterioration of the alignment and strength of the track under traffic, rather than model the actual performance deterioration and then compare that deterioration with a specified condemning limit. Work is currently under way to model the actual deterioration of track support and geometry in response to normalized loadings due to traffic. This will eventually lead to the ability to model actual maintenance requirements, independent of the maintenance standards of the railroad, and to study the cost implications of alternative standards for tie replacements and surfacing cycles. The new work in the area of ties will also incorporate the interaction between biological and physical forces in deteriorating ties.

Areas Not Modeled

The current version of TMCOST does not contain deterioration models for all mechanisms of track component deterioration. Cost estimates for the maintenance activities that these various deterioration mechanisms require must be developed outside the structure of the TMCOST program. These noncyclic maintenance costs can then be input to TMCOST and added to the cyclic costs estimated by the models to arrive at the total maintenance cost estimates.

Many of these maintenance activities, including the routine inspection and adjustment activities, probably cannot be modeled in any meaningful way and should continue to be estimated by examining the records of local maintenance forces. There are, however, some areas not currently modeled that should be modeled in the future. These include corrugation of the low rail in curves, the deterioration of switches and other special trackwork in main-line track, and the need for heavy ballast work such as undercutting. The maintenance requirements for these components are clearly related to the nature of the traffic and the route; thus, the costing of incremental traffic would be improved if these maintenance activities were systematically related to the flow of traffic.

Determination of Unit Costs

Given the deterioration rates and condemning limits, the tonnage and time lives of the components are easy to calculate. The unit costs of the required maintenance activities divided by the lives gives a cost per ton or per year for each individual track segment. The individual cost per track segment then can be aggregated to produce route costs. The incremental cost of a given traffic component can be determined by the difference between two estimates, one with and the other without the traffic component. From the incremental cost and incremental ton-miles of traffic, the route-specific, service-specific track maintenance cost per ton-mile is computed directly. However, before any of this can be done, the difficult task of determining the appropriate unit costs for track maintenance activities must be accomplished.

The unit costs required include the total costs of providing the maintenance activity, including the materials, the manpower, the tools and maintenance machines, the fuel and repairs for the maintenance machines, and the support services, including housing, food, and transportation. All activities associated with the maintenance, including setup, cleanup, and nonproductive time caused by the passage of traffic or other causes, must be included. These costs are best determined by industrial engineering techniques outside TMCOST. The AAR has participated with several member roads in developing unit costs for important maintenance activities such as rail relays, tie replacements, and surfacing.

To improve the productivity in developing these unit costs a series of computer-based computational aids has been developed, including both spreadsheet formats and special programs. These tools provide both a conceptual framework and computational assistance to the required industrial engineering studies. The level of detail required to develop accurate unit costs requires the development and input of a substantial amount of data to the programs; thus, the effort required is substantial even with the assistance of these computer tools.

A secondary benefit of the development of the unit cost inputs to TMCOST by the use of these computer programs is the ability to quickly conduct cost sensitivity studies for a number of alternative maintenance gang structures. These studies may produce sufficient insight into the complex maintenance process to allow the improvement of maintenance productivity and the reduction of maintenance unit costs. The total track maintenance cost implications of any changes in maintenance unit costs can be developed by running TMCOST with the new and old unit cost inputs.

OVERVIEW OF TMCOST

The basic component life-cycle methodology is far more important than the particular set of computerized models developed to implement the methodology; however, a brief overview of the current TMCOST program is useful to better understand the methodology. Figure 2 shows the TMCOST flowchart. Comprehensive route, track, and traffic files are input to a preprocessor subprogram, GENER, which generates input files to the component deterioration models, RMCM, RFLAP, TIE, and SURF for rail wear, rail fatigue, ties, and surfacing, respectively. One important function performed by GENER is to determine which of the potentially thousands of individual track segments are exposed to the same traffic and have the same gradient, curvature, and track structural components, and thus would be predicted to have the same life. GENER produces only one set of inputs to the deterioration models for each unique set of life-determining inputs in the route, track, and traffic files. This allows the deterioration models, which are rather complex and computationally slow, to be run only once to estimate the life, and the life is applied to each segment of the route for which it is appropriate during the costing and output phase based on a code assigned by GENER. This reduces the computer costs typically by a factor of 5.

The deterioration models, which have been described previously, are run separately and the resulting estimated deterioration rates and unit costs are fed to a costing program, COST, which determines the component lives based on the input maintenance standards and determines cost per year and MGT. Detailed reports on component lives and maintenance costs for rail, tie, and surfacing including both cyclic and routine maintenance activities are printed along with a summary report on costs.

TMCOST is a set of program modules integrated into a system to execute the methodology. This architecture allows the substitution of new modules for old with a minimum of reprogramming.

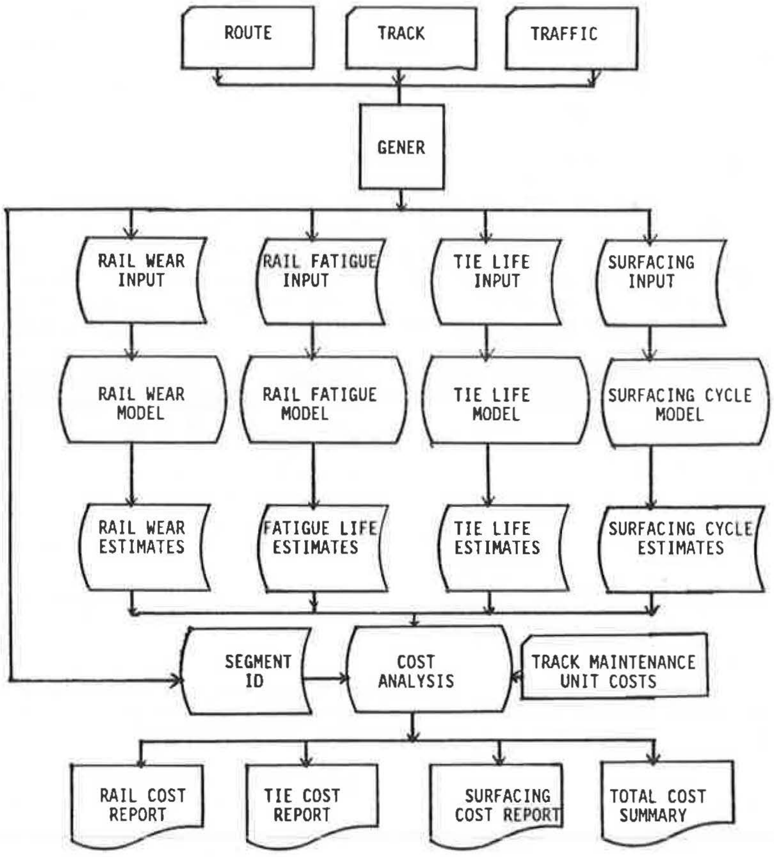

FIGURE 2 TMCOST flowchart.

EXAMPLES OF TMCOST RESULTS

Although the methodology is of greater importance in the long term than the costs estimated for specific services by using the current version of the model, two sets of results are presented to illustrate typical results obtained through the use of TMCOST. In Figure 3 the relationship between axle loading and costs per gross ton-mile are graphed for two track curvatures, tangent track and a 5-degree curve. The costs are certainly shown to be sensitive to both factors, but the greater increase due to curvature than axle load in the range relevant to modern rail equipment indicates the critical importance of route characteristics in determining track costs.

The importance of density is shown in Figure 4. The extremely high costs at low density levels reflect the significant component of track maintenance, which is related to environmental impacts and the need for maintaining a minimum level of inspections and noncyclical maintenance activities even in low-density territory. The costs per year are not high, but the costs per ton are very high because there is little traffic over which to spread the costs. The increasing costs per ton at the higher levels of density reflect the decreasing productivity of the maintenance activities, which result in increasing unit costs of rail, ties, ballast, and surfacing. This effect is the result of decreasing track maintenance "windows" or periods of track occupancy by maintenance gangs in areas of great train density. The exact position of the curve is a function of the nature of the track infrastructure, the maintenance gang makeup, and the railroad's policy for dispatching trains during periods of track maintenance; however, the general tendency toward increasing economies of density in low-density territory and decreasing economies of density at higher density levels is common to all scenarios.

SUMMARY

An engineering-based life-cycle costing methodology that can be applied to determine the route- and service-specific track maintenance costs associated with

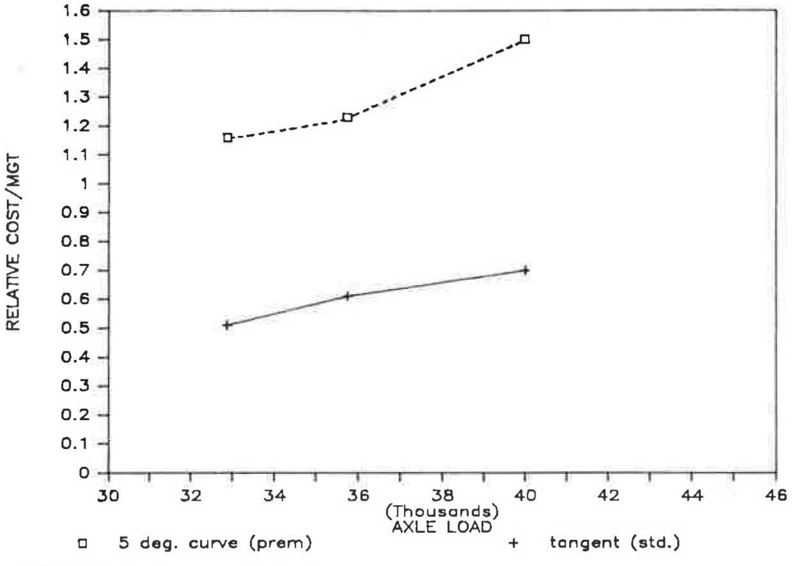

FIGURE 3 Cost versus axle load.

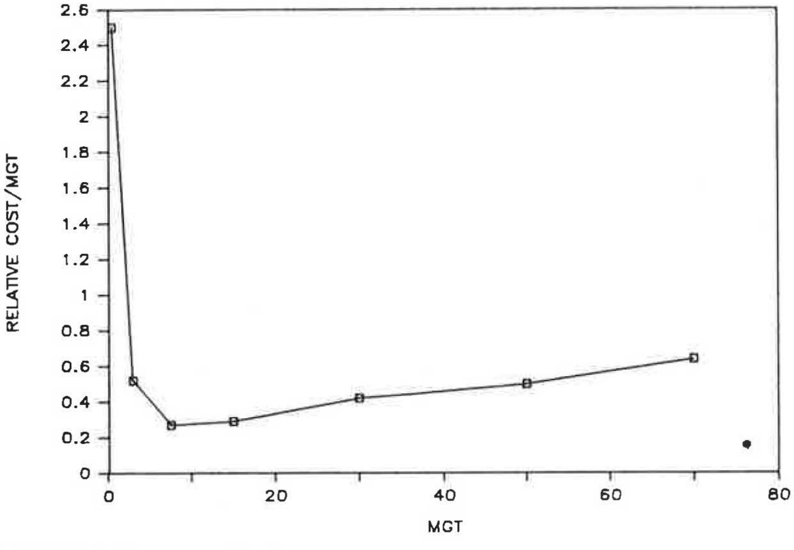

FIGURE 4 Cost versus density.

specific rail services is described. This methodology allows the estimation of track maintenance costs to support engineering planning and equipment selection as well as marketing activities. This methodology can be implemented with the aid of a computer program, TMCOST, which allows the voluminous calculations to be performed without undue effort. The data requirements are significantly greater than those of the traditional accounting-based rail maintenance costing procedures, but the cost estimates are route- and service-specific rather than system averages.

The current deterioration models used in TMCOST are sufficiently accurate to support the planning and marketing functions. Work continues to develop even more accurate models for rail, tie, and ballast performance, especially in high-density territory. As the railroads develop more detailed computer data bases to support operations and maintenance, the ability to calibrate and utilize these models will increase. This methodology provides the basis for utilizing this additional information to produce more accurate cost information for managerial purposes.

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Track Maintenance Policy and Planning

H. G. WEBB

ABSTRACT

Track maintenance planning within the railroad industry is described. The efforts of the Association of American Railroads to develop maintenance planning models to assist in such planning are reviewed and the problems involved in railroad bridge maintenance and replacement are discussed.

In defining the maintenance policy of a railroad, all major railroads, as well as other private industry companies, have the policy to maintain their railroad and property to the standards necessary to move the traffic designated at a volume and speed necessary for their company to earn a reasonable profit. They must accomplish this goal within certain monetary constraints established by their management. The cost of maintaining the property and trackage is a big portion of the cost associated with the profit.

To accomplish the policy described, the maintenance manager must plan the expenditures involved with accomplishing the satisfactory maintenance of his trackage and property.

Planning, as defined by the dictionary, is a scheme for making, doing, or arranging something; project, schedule, etc. A railroad maintenance officer has defined maintenance management as the planning of all maintenance operations to economically maintain the facilities of the railroad at the most economical level possible to satisfactorily meet the needs demanded by management. To accomplish this level of planning, the manager must project maintenance needs far enough in advance to coordinate funding, personnel, equipment, materials, designs, and operations by using the most up-to-date predictive technology available.

Today's railway maintenance engineering can be divided into three operations:

1. Planning,
2. Execution of the plan, and
3. Maintenance of the completed plan.

Note that in every operation, the plan devised is the key to each of the other operations. There is no function in today's railroading that does not involve planning. It is in every function of every maintenance-of-way and engineering department operation from the lowest level of supervision to top management.

Although the tendency is to think of planning in terms of major renewal programs such as rail, ties, surfacing, and ballast, because of their major effect on costs, planning occurs at all levels of operation and supervision. Planning at all levels must continue to improve. The best-laid plans cannot be accomplished without the proper detailed planning right down to the last spike to be driven.

In terms of the major expense items in today's railroading, the following are considered major items because they account for approximately 30 percent of a railroad's capital and operating expenses:

1. Rail renewals,
2. Tie renewals,
3. Surfacing operations,
4. Ballast and subgrade maintenance, and
5. Bridge and building maintenance.

All of the foregoing maintenance functions can and must be planned. They must be planned to ensure

1. Expenditures to match the property's needs,
2. Current technology of materials so that there is efficient expenditure of funds,
3. Maximum safety of personnel and operations,
4. Maximum use of the minimum number of machines and personnel,
5. Service to all departments according to their needs by maintenance planning operations, and
6. Coordination of train operations to allow efficient operations.

All maintenance-of-way and engineering planning must be

1. Both short- and long-term;
2. Made by using the most current technology available;
3. Originated at the basic maintenance supervisional level;
4. Detailed in design, materials, and operations for field execution; and
5. Controlled by a centralized manager.

To accomplish the planning of these renewals and to be able to satisfy the economic requirements, certain basic history and engineering facts must be known. The following are considered necessary to efficiently and effectively plan today's maintenance:

1. A complete and properly designed data base of the property,
2. Acceptable safety and material life limits on the various portions of the property,
3. Inspection frequencies and methods as a source for planning, and
4. Computer systems to use the data base, limits, and inspections to predict planning needs.

I once heard an old timer say, "We have been railroading for 100 years and we still don't know how to do it." Well, I agree with him, although as an engineer, I would like to state that the environment has continually changed during that 100 years. In fact, the environment has changed at a rate that is difficult to stay ahead of. But those who are responsible for the maintenance of the railways must stay ahead. Railroad managers must continue to contribute to the effort in developing new materials, methods, theories, and maintenance approaches in order to stay ahead of the deterioration of their properties.

One critically important additive to all planning operations is supervision. A railroad, as in all engineering fields, must continue to develop quality supervisors. The tendency is to think that good, knowledgeable supervision just happens, that supervisors will naturally develop from normal operations. However, considerable effort and planning are involved in the continuing development of good engineering supervision, which is one of the most important items in a manager's ability to fulfill his company's policy of track maintenance.

DATA BASE

The computerization of a data base for all maintenance and engineering functions and operations of the property is and must be a necessity. Almost all railroads have engineering records, statistics, historic maintenance operations, and other records on paper. Although these were and are important for a permanent record, they are cumbersome to use in planning efficient maintenance operations. There tends to be too much opportunity for error and too much input tied to the old timers' knowledge of the facility and maintenance functions of the past.

The computerization of a railroad's records is an expensive undertaking. It takes computer hardware, many man-hours of accumulation and input, and constant updating to keep the records current.

The data base must be planned. This is a most important point that is often overlooked. In many cases, because the department developing the data base is not the department using it, it is inadequate as a usable information source. And because communications are not a strong point of railway departments, all data are not included for proper functioning of the operating of maintenance planning models. Of course, another reason for not developing an adequate data base is simply that the information is not available. Thus alternative methods must be developed such as using other railroad statistics or just choosing an estimated limit for the missing function or data.

What should be in a data base? Committee 32 of the American Railway Engineering Association (AREA) is working on recommendations for various data bases. The Track Maintenance Research Committee of the Association of American Railroads (AAR) has developed and is continuing to develop recommendations for data bases for planning maintenance operations for rail, ties, and ballast and subgrade. These are available to all as a basis for each railroad to begin its data base development.

Railway managers must make the commitment to develop a data base for their railway at whatever cost if they are going to efficiently plan their maintenance operations for the future.

Rail

Rail is the most expensive maintenance renewal operation, and it is one of the most important basic necessities in the operation of railroads. There is no more efficient manner of moving tonnage than the steel wheel on a steel rail. The planning of rail renewals becomes increasingly difficult as loads get heavier and are moved faster over varying conditions to match the speed of the competition. The replacement of rail must still be predicted in planning operations for efficiency and safety of operations within acceptable limits.

All maintenance officers realize at about what rate their rail deteriorates. They know the statistics of their rail such as age, metallurgy, tonnage, defect rates, and joint conditions. From these they develop a rail renewal plan. But is this plan the most economical for their railroad? Is it developed based on proper priority ranking of rail renewal projects? Is it developed with the needed skill of economical cascading of rail? Is the renewal of curves planned? I think not. A more organized, more technologically correct approach to rail renewal planning and cascading must be developed.

The AAR Track Maintenance Research Committee has a working group on rail planning that is developing just such a model, and it will be made available to all railroads in the near future. The committee consists of a mixture of research and technical personnel, railway-knowledgeable technical staff, consultants from several fields of specialty, and track maintenance operating officers. This committee is headed by Dave Staplelin, Planning Officer for the Seaboard Systems, who is a most capable engineer in rail technology, computerization, and planning. I am sure that there are some railroads developing their own planning models. Nevertheless, let me briefly describe what the committee has accomplished.

The working group has developed and published in the October 1984 AREA Bulletin an empirical rail wear model that has the ability to predict the life of tangent and curve rail. The model predicts this life in million gross tons (MGT). The model requires the input by the railroad of the following information:

1. Allowable cross-sectional area loss of rail head on tangents and curves,
2. Annual traffic density,
3. Degree of curvature,
4. Grade, and
5. Static wheel loads (in kips).

A model such as this, with some adjustments in its input variables to make it meet a railroad's particular conditions, could be used to develop a rail renewal long-range planning forecast. Short-range programs may be developed from revisions of the long-range ones by analysis of current rail defects, joint conditions, predicted traffic changes, and needs for cascading.

Thus any railway would have the ability to plan its rail renewals by using the most current technological means available. Of course, as the technology of improved metallurgy, lubrication, profile grinding, and so forth becomes more defined in terms of the effect on rail life, the model will be adjusted to take these material life changes into account.

The working group is developing a rail cascading model as well, thus making the model usable on secondary trackage and not just main-line renewals.

The economic justification of rail renewals is an approach that the committee has added to the normal rail renewal theories. The economist of the AAR, led by Mike Hargrove and Tom Gudiness, has given very valuable assistance in this endeavor. Many costs associated with rail left in the track beyond its economical life were considered, some of which are

1. Cost of changing a defective rail, including labor, materials, traffic delays, slow orders, and support equipment;
2. Cost of derailment liability;
3. Cost of additional surfacing;
4. Cost of tie life;
5. Cost of investment; and
6. Tax considerations.

Ties

Most railroads use field personnel to spot check or mark their railroad for tie renewals for the current or upcoming year's programs. Whether they use a system tie inspector or local supervision, they still must rely on each individual's ability to predict the life of the tie and estimate when it should be removed.

Thus there is no efficient or economical means of predicting or planning tie renewals. Field inspection is the only method known to be effective and is used by most railroads. In tie-renewal planning, it is of short-range use only.

The only long-range planning method for tie renewals is to use past renewal history. With the ever-changing rail conditions--the increasing wheel loads and tonnage, the method and frequency of surfacing, the condition of drainage, and the changing climatic conditions over the 20- to 50-year life of the existing ties--the prediction of tie renewals using the history of past renewals is unreliable.

Some railroads have tie-renewal prediction models of one type or another. Some are effective and some are not. Some have models but just do not use them because the field maintenance officer does not believe in their ability to effectively predict renewals. None are really reliable because of the many variables affecting the life of a tie. Even the tie itself is not made of a very predictable material. Not only is it made of various types of wood, it is treated with varying amounts of chemicals and methods. It is even made in varying sizes and carries the wheel load on various sizes of tie plates.

Thus the art of predicting renewal of crossties is most difficult. Yet if the maintenance engineer is to properly plan his tie renewals, he must have a means to predict them.

The AAR Track Maintenance Research Committee has a working group on tie planning chaired by Mike Roney, Manager of Engineering Systems for Canadian Pacific Limited. The group consists of AAR technical staff, railway maintenance officers, technical researchers, and various consultants. They are developing a model that will be able to predict tie-renewal life in terms that can be used by the maintenance officer in his tie-renewal planning.

In their study of the life of a tie, the group has investigated the different conditions that can affect that life. Many conditions were considered and through many discussions they limited the number to be considered in the model because many conditions thought to affect tie life were not qualifiable or not important. The group narrowed these conditions affecting tie life to

1. Foundation and support,
2. Precipitation,
3. Temperature (growth of bacteria and freeze-thaw cycle),
4. Operating speeds,
5. Wheel load spectra,
6. Ballast materials, and
7. Alignment.

Although the group has not at this time developed a working model, one is rapidly forming. They have developed a statistical tie-life model, a variation of the Forrest product tie failure distribution curve. They are now field testing this model with various railroad renewal statistics and actual personal field observations.

The model functions on an IBM Personal Computer (PC). The spreadsheet-type program is used. Much of the model's algorithm is included in AAR Report

R-515, Tie Failure Rate Analysis and Prediction Techniques (1). Inputs to this model include the number of ties inserted by year and the expected life of each group. Each group is then tested on the modified Forrest product curve to determine the number of ties that have failed since the last tie renewal. Up to 19 sets of yearly renewal statistics can be included.

The failed-tie count is projected into the future years. The model assumes a tie renewal of all predicted failed ties. Because the model can be run year by year, a predicted tie-renewal count is available. The tie cluster model uses these counts to estimate, by years, the number of clusters and then yields a prediction for that year of tie-renewal planning. The model provides a good working framework for the group but considerable work must be done in verifying the inputs to make it a usable predictor of tie-planning renewal.

The group has also developed a tie sampling scheme that would aid a railroad in long-range planning without actually having to count 100 percent of the ties in a given segment. It is basically a statistically random sampling of 50 tie clusters, varying in numbers to the length of the renewal segment. Thus it is able to reasonably and accurately predict gross required renewals over a segment of track.

The group has also investigated such areas affecting tie life and renewal predictions as

1. Clustering effect on other maintenance costs such as surfacing cycles, tie renewals, rail life, slow orders, fuel costs, and others;
2. Cost of the failed tie;
3. Cause of tie failure from one railway to another;
4. Effects of mechanical wear, axle loading, and curvature; and
5. Effects of a good adjacent tie.

Ballast and Subgrade

The riding surface of the track is the end result of all wheel-supporting materials such as rail, ties, and ballast and subgrade. Although most effort in the past has been centered on rail and ties, both in research and development and renewal techniques, ballast and subgrade must be recognized for their importance. Not only will there not be an operable track surface without good ballast and subgrade support, considerable life in both rail and ties will be lost. Therefore the maintenance of the ballast and subgrade to provide a serviceable track surface at an economical cost must also be planned.

Track surfacing of the ballast is the current method of maintaining track surface. Surfacing of the track is a necessary maintenance function but at the same time it is detrimental to the ballast and ties because of the crushing action of the modern tamper. The necessity to buy and maintain a good quality ballast that is capable and free to drain is even more important than in the past. With ballast in better condition, surfacing cycles are reduced.

The subgrade is also a most important track support material. Most do not consider subgrade a maintenance planning item until surface trouble shows the need for some kind of action. Subgrade problems can be predicted, thus allowing a planned maintenance operation.

Some research has been done by a few railways and university researchers in ballast and subgrade maintenance in the fields of ballast gradation studies and variances causing problems in subgrade soil support condition, ballast type, and so forth. Drainage improvements and undercutting-cleaning or straight renewals are the only maintenance operations now used to correct ballast problems.

Subgrade research and investigations have been conducted in the past by soil testing through boring and excavation techniques with the only maintenance operation being cement grouting, lime stabilization, use of fabrics, and various other temporary repairs. Even these are only used as a trouble-spot operation and only after prolonged problems with the track surface.

Several railroads and universities as well as the AAR have conducted ballast and subgrade research tests in the United States. All vary in their approach. Once again, because a particular railway or geographical area experiences specific problems, the research tends to center on solving that problem. Therefore a solution is not reached that could be used for maintenance planning of ballast and subgrade on all railroads.

The AAR Track Maintenance Research Committee has a ballast and subgrade working group chaired by Bob Ahlf, Chief Operations Planning Officer of the Illinois Central Gulf Railroad. The working group is developing a maintenance planning model for ballast and subgrade maintenance. In their investigations to date they have been trying to understand how to predict the amount of differential settlement for a given segment of track and therefore the required ballast or subgrade maintenance for a given MGT of traffic. To do so, such contributing factors as ballast and subgrade conditions, climatic variances and extremes, varying loading patterns, and other conditions affecting the ballast and subgrade must be understood, defined, and quantified.

The working group is considering many research projects and is wrestling with many difficulties to master the problems. Some of these difficulties are as follows:

1. Variability: To intelligently design a predictable structure, one must know the average strength of its material. Most track operated over today was placed before soil mechanics became the science that it is today. Ballast, although measurable in gradation, strength, and ability to resist climatic conditions, is almost unpredictable, because few railroads use a homogeneous type of ballast throughout their trackage. Each railroad has changed types, gradation, and cleaning policies in its ballast history, and few records are kept of those changes.
2. Accessibility: Because the ballast below the tie and the subgrade are hidden from view, the nature of their problems is not easily assessed. Testing and prediction of corrective actions are doubly difficult. In fact, it is often difficult to distinguish between a subgrade and a ballast failure solely by observation.
3. Ballast performance: When ballast fails to perform adequately, the ballast specification is often blamed. The real problem may be that the ballast has simply worn out and should be cleaned or, if necessary, replaced like a tie or a rail. However, predicting this maintenance operation or replacement is very subjective. One means could be to determine the time or amount of traffic tonnage at which the ballast must be cleaned or replaced. This can or could be tied to other maintenance functions such as tie renewals.
4. Ballast-subgrade interaction: When ballast and subgrade are finally defined and quantifiable in terms predictable enough to use in a maintenance planning model, the interaction between the two support materials must be defined. This interaction must be understood to the extent that its effect on

the ability of both materials to perform as predicted is also definable.

5. Ballast and subgrade monitoring and testing; Many means of monitoring and testing these materials are being investigated, such as

   a. Gradation,
   b. Sampling and identification of the subgrade soils,
   c. Absorption values,
   d. Effectiveness of tamping,
   e. Soil expansion,
   f. Track quality, and
   g. Subgrade moisture.

It is apparent that the working group has many irons in the fire. An excellent group has been assembled composed of AAR research personnel, university professors and their research staff, soils and ballast research specialists, railroad technical officers, and operating management.

It is expected that this group will develop a ballast and subgrade maintenance planning model that will be able to predict maintenance needs. These predictions will be for both short- and long-term needs and priorities. The model will operate with inputs from the geometry car data, ballast and subgrade random testing, historic data of maintenance cycles, and the ballast and subgrade data base. Ballast and subgrade maintenance planning can be predicted and managed much the same as that for rail and ties.

BRIDGES

Bridges involve another maintenance facility that is extremely important to the operation of railroad traffic but that falls into the category "out of sight, out of mind." The maintenance of bridges and structures is apparently not planned beyond a year or two ahead.

The reason for this short-range planning is that the maintenance or replacement programs are based on field inspection only. Most of these inspections are made annually. At the time of the inspection the subjective opinion of the inspector determines what maintenance is to be accomplished and when it is necessary to do that maintenance. The inspector has little assistance other than his visual observation and personal experience with the structure to use in making his decisions.

Long-range maintenance programs can and are developed to satisfy upper management's demands for such a prediction but are based purely on the age of the structures. This prediction, geared to the desire for a stable maintenance force and equipment inventory, is the controlling factor in these long-range programs. Because many railroads were constructed in segments with time frames of 10 or so years, the predicted renewals tend to come in large quantities. Thus many leveling-out processes to delay renewals have been developed in recent years. But the actual planning of the renewals still comes from the field inspection.

There are several problems in the long-range planning of bridge and structure maintenance or renewal. Some of them are

1. An unknown history of loading cycles,
2. The difficulty in prediction of loss of section from corrosion or wear because of its lack of visibility,
3. The rather long life of a bridge or structure versus ties and so forth, and
4. The gross number of these structures to be renewed.

There are some advantages to bridge maintenance prediction over other track maintenance material. Some of them are as follows:

1. The materials have had a known strength and design specification for approximately 100 years,
2. Excellent historic inspection records are available,
3. Excellent maintenance records are available, and
4. The foundations of the bridge structures involve few maintenance problems because excellent historic records are available, problems are easily definable, and the foundations have probably been repaired.

Canadian National and Burlington Northern have made some efforts toward bridge repair and replacement predictions. It appears that some problems exist with predicting the loss of section of the steel structures.

Because most timber fails from decay rather than crushing, most railroads have begun installing concrete or steel piling with concrete stringers and caps. This will help in the prediction of the individual unit's life because concrete is a much more predictable material than wood. The originally designed concrete now has had to be revised to prestressed concrete members to resist the moisture penetration found in standard concrete members.

One of the other problems with bridge renewal prediction is the fact that gross tonnage on the bridge has little to do with bridge deterioration. Decay, climatic conditions, quality and deteriorating rates of materials, and the structural design are the contributing factors for most renewals.

Thus little long-range planning is done with the confidence that it will be accomplished. Although a considerable portion of the maintenance dollar is spent on these structures, problems must be found before repair can be planned. It would appear that a better, more sophisticated means should be developed to assist the maintenance engineer in predicting his bridge and structure maintenance and renewals.

SUMMARY

There has been a start in track maintenance planning within the industry. Through the AAR's efforts to support a unified effort among the many technical and practical experts to develop maintenance planning models, considerable progress has been made.

Although there are still many maintenance officers of railroads who do not believe that they need such a tool, they soon become believers once they see what such a predicting model can do for them. There is still a lot of work to do before the models are usable. The working groups need the cooperation of all railroads in technical personnel, information on maintenance operations on their properties, and support through the AAR. All will be recipients of the end product: a tool to assist all railroad managers in predicting their track maintenance needs in both short- and long-range planning using their own wear and specification limits, known track conditions, and tonnage-wheel loadings--a universal model that can be tailored to match each railroad's specific needs.

REFERENCE

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