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Research and Development and Productivity: High-Productivity Integral Trains

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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.

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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