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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 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.

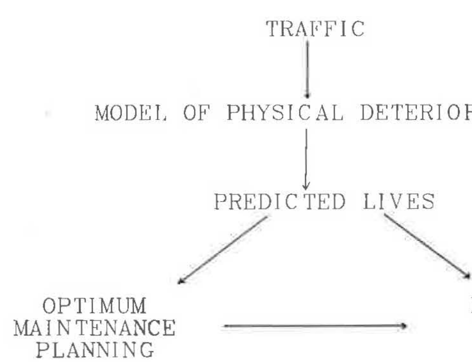

FIGURE 1 Engineering economic analysis.

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.

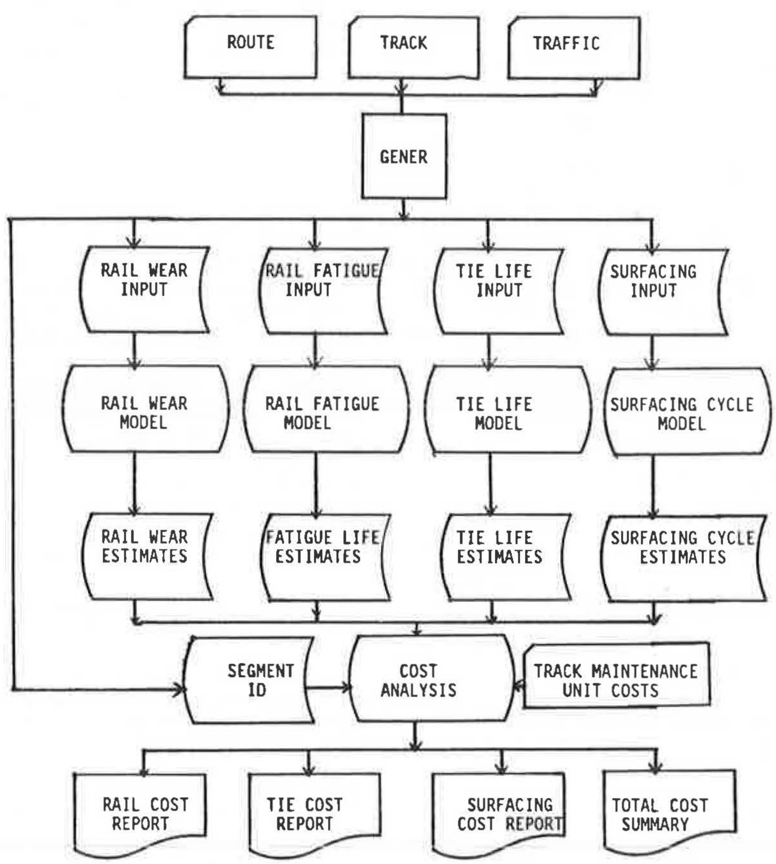

FIGURE 2 TMCOST flowchart.

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

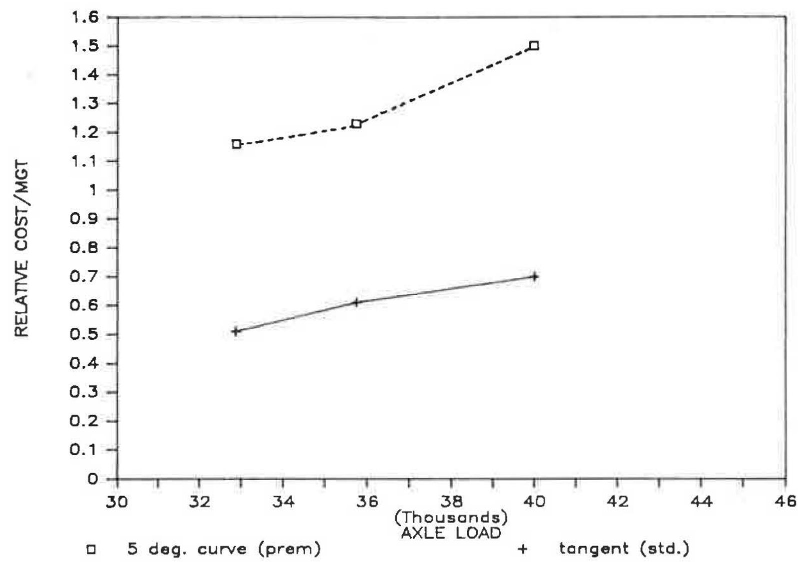

FIGURE 3 Cost versus axle load.

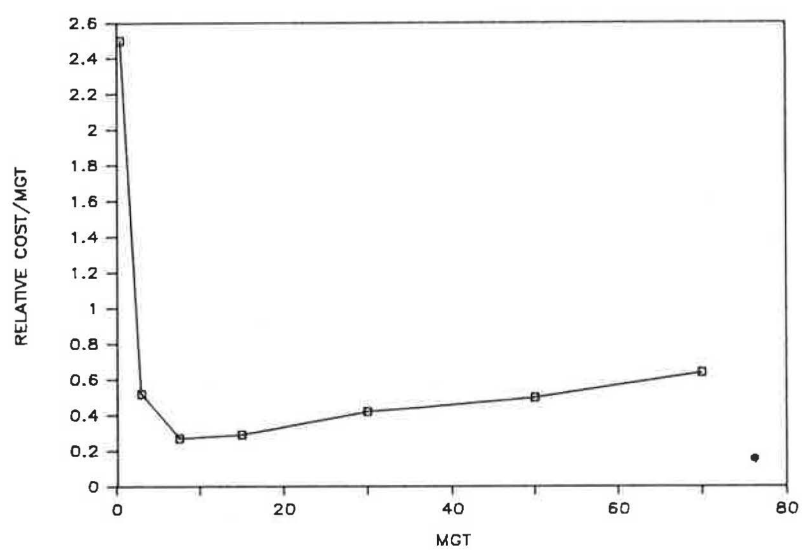

FIGURE 4 Cost versus density.

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