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# PROCEDURES FOR ANALYZING THE ECONOMIC COSTS OF RAILROAD ROADWAY FOR PRICING PURPOSES

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FINAL REPORT

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16. Abstract

It is only through determination and analysis of service-specific economic costs that accurate assessments of the profitability of railroad services can be obtained and the industry's scarce resources properly allocated. The primary objectives of this study are to develop procedures for determining the roadway (fixed plant) costs associated with specific railroad services (routes, equipment, service levels) for use in the pricing of such services, and to demonstrate how these procedures can be implemented as an element of a railroad costing system.

The costing procedures developed depart substantially from averaging techniques based on historical roadway expense data as currently used by most railroads. Determination and allocation of a major portion of roadway variable costs, i.e. those associated with the renewal of the track structure, is accomplished by applying predictive life cycle relationships to the specific track/traffic conditions under consideration. These predictive relationships are derived from existing track research data combined with the experience of track maintenance forces on the Southern Pacific. Methods are developed to systematically obtain and analyze relevant track/traffic data for use with the costing procedures.

Resulting costs demonstrate the variant nature of roadway economic costs and point up the potential pitfalls in the continued use of system average costs for pricing purposes.

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APPENDICES

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# I. INTRODUCTION

## Railroad Industry Costs and Profits

Although railroad operations began in the United States well over 100 years ago, there has never been a more critical need for the railroad industry to develop refined costing techniques than at present. The current inadequate profitability of the industry can in no small measure be traced to its inability to develop accurate costs for the multitude of rail services offered; costs which lead to soundly based rates sufficient to generate adequate earnings, insuring availability of the capital needed by the industry for improvement of fixed plant and acquisition of equipment.

## Federal Railroad Administration Cost Research

The Federal Railroad Administration (FRA) of the United States Department of Transportation has initiated a cost research program to foster the development of improved procedures and techniques for analyzing the various categories of railroad costs. This specific research project, designed to develop methods and procedures for analyzing the economic costs of railroad roadway for pricing purposes, represents a major initial element of the FRA cost research program.

## Importance of Railroad Roadway Cost Analysis

Expenditure requirements for providing, maintaining, and operating the nation's railroad roadway are massive. In 1974, roadway maintenance and depreciation expenses alone amounted to nearly $2.5 billion, or 18% of Class I railroad total operating expenses.

It is doubtful, however, that anyone familiar with current conditions in the industry would disagree that, as an industry, railroads are depleting their fixed plant resources by deferring roadway maintenance and renewal in an effort to reduce operating expenses. Reports filed by Class I railroads as required under Ex Parte No. 305, Nationwide Increase of Ten Percent in Freight Rates and Charges, 1974 indicated that as of June 30, 1974 these railroads had accumulated nearly $2.6 billion in deferred roadway maintenance and nearly $2.2 billion in delayed roadway capital improvements.[1] A separate study conducted for the Federal Railroad Administration estimated that deferred maintenance of track, signals, and structures for 25 selected Class I railroads was nearly $5.3 billion (1974 dollars).[2] Yet many railroads are

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[1] Interstate Commerce Commission Release No. 201-74, October 22,1974.

[2] Maintenance of Way Study, T. K. Dyer & Associates, Lexington, Massachusetts, 1975.

continuing to attempt to improve their competitive position by increasing productivity through the use of heavier, longer, faster trains, and heavier loaded cars.

Today, as never before, the financial condition of the industry, coupled with the increased demands being placed upon its fixed plant, have made imperative a more accurate determination of service-specific roadway costs. It is only through determination and analysis of these economic costs that accurate assessments of the profitability of railroad services can be obtained and the industry's scarce resources properly allocated.

## Nature of the Roadway Costing Problem

Refinements in roadway cost analysis procedures are difficult to achieve. Significant complexities continue to exist as deterrents to substantial improvement over current conventional approaches to the problem. These complexities include the presence of joint and common costs, the difficulty in distinguishing between "fixed" and "variable" costs, the absence of service-specific expense data, the effects of excess plant capacity, the wide variability of roadway costs with varying physical and traffic conditions, and the lack of substantive empirical research data describing the physical behavior of railroad track structure. These conditions, together with the present nature and extent of roadway expenditure deferrals constitute the environment attendant to the economic analysis of railroad roadway for pricing purposes. The development of roadway cost analysis procedures which effectively deal with this environment, together with the demonstration of how these procedures can be implemented as an element of a railroad costing system are the primary objectives of this study.

## II. SUMMARY

The approach to roadway cost analysis developed and utilized in this study has as its basis two fundamental precepts. These have been arrived at after thorough review of past and present roadway costing procedures and present-day conditions in the railroad industry:

- Meaningful economic cost analysis of the railroad roadway cannot have as its sole basis the examination of actual past expenditures. Considering roadway maintenance deferrals, together with the general lack of service-specific expense data, historical expenses are generally inadequate for purposes other than determining order-of-magnitude system or regional average roadway costs.

- Relevant economic costs of maintaining the roadway track structure - those costs which should be used in evaluating rail service profitability - must be ascertained by analyzing the specific roadway segments under consideration. This analysis, which must treat actual traffic and track conditions, must currently rely on a combination of engineering judgement and available empirical research data to develop predictions of the physical and economic behavior of the track structure under varying service conditions.

The research effort is directed at developing procedures for determining and allocating the maintenance, operating, and investment costs associated with the following specific roadway service environments:

- linehaul roadway
- yard roadway
- miscellaneous trackage
- service-specific facilities
- other (nonservice-specific) facilities and systems

The procedures developed herein depart substantially from averaging techniques based on historical roadway expense data currently used by most of the industry. Capability is demonstrated to predict the variable costs associated with specific types of traffic (tonnages, speeds, wheel loads, train service types) for specific operating territories, and to integrate the roadway costing process into a costing system for use by railroad management in the pricing of rail services.

The procedures for determining and allocating variable track structure costs draw heavily upon relevant available track research information and the experience of the engineering forces of the Southern Pacific Transportation Company. Production functions were developed for predicting the physical and economic behavior of track structure based on an analysis of track and traffic conditions across Southern Pacific's main line track network. Track structure type and condition, together with actual traffic conditions were inventoried and classified as to primary cost-causal characteristics.

Relationships were developed which facilitated the analysis of specific track/traffic environments. This inventory of track and traffic characteristics, together with the classification procedures demonstrated are proposed as the basis for the application of these procedures by other railroads. In addition, capability is developed for incorporating railroad-specific policies and engineering practices, together with perhaps substantially differing assumptions as to track structure behavior, into the proposed costing system.

A revised system of accounting for roadway expenditures is presented as a means for more refined and meaningful analysis of roadway expenses on an incurred basis where appropriate. This system is superimposed on the current Interstate Commerce Commission (ICC) Uniform System of Accounts for Maintenance of Way expenses to demonstrate the levels of refinement attainable and to facilitate comparison of the two systems.

Systems were developed to produce cost reports and tables useful for relating roadway costs to other train service operating costs for cost and profitability analyses. Recommendations are made for the integration of engineering, operating, and marketing considerations into the analysis of current or potential railroad service requirements. Considerable emphasis is placed on the need to develop and adapt new and better engineering data and analytical techniques as tools for the refinement of roadway service costing for pricing decisions.

Comparisons are made between resulting cost categories and cost levels using both standard (ICC) From A cost procedures and the techniques developed in this study. A general framework is discussed for the application of these or similar costing procedures to regulatory proceedings.

Finally, guidelines for the implementation of the proposed roadway costing procedures by other railroads are discussed, including potential benefits and problem areas.

## III. RAILROAD COSTS AND THE PRICING DECISION

From the standpoint of determining costs, the dominant characteristic of a railroad is its multiple product operation under varying service conditions. In providing 100-ton or heavier cars for bulk loading and meeting expedited schedules in extreme climatic or geographical environments, a railroad provides a different output service than when it handles standard carload freight in 50-foot boxcars on normal schedules in a more favorable operating environment.

Basic cost definitions and a treatment of relevant costs for pricing and other purposes are given below. These will aid in the discussion and justify the development of roadway costs discussed in later sections of this study.

COST DEFINITIONS:

| | |
|---|---|
| Short-run | - refers to a time period sufficiently short such that productive capacity is fixed. |
| Long-run | - refers to a time period sufficiently long to encompass any change in productive capacity. |
| Fixed costs | - are those costs which do not change in total with changes in the volume of output. |
| Variable costs | - are those costs which do change in total with changes in the volume of output. |
| Incremental cost | - is a measure of the addition to total cost that arises as a consequence of additional output. |
| Decremental (avoidable) cost | - is a measure of the reduction in total cost that arises as a consequence of reducing output. |
| Marginal cost | - is the cost of producing one additional unit of output or the cost that would be saved by producing one less unit. |
| Short-run variable cost | - is the change in the sum of the cost components resulting from the temporary change in the production of some finite unit of output. |
| Long-run variable cost | - is the change in all operating expenses (excluding non use-related depreciation), capital consumption, the cost of capital, taxes and rentals resulting from a sustained change in production of some finite unit of output. |
| Fully-distributed cost | - represents an allocation of total expenses to the various units of output. Included are variable costs plus an arbitrary distribution of the fixed costs. |

Common costs - occur when the same plant or equipment is used to produce two or more products.

Joint costs - are those costs incurred in the production of two or more products which result from a single, indivisible process.

Capacity costs - are those elements of fixed costs incurred for the purpose of providing a given amount of productive capacity.

Historical costs - refer to those costs incurred in the past, generally as recorded in the accounting records.

Future costs - are costs expected to be relevant at some time in the future.

Original cost - is the amount actually paid for installing the original plant and equipment, plus additions, when first devoted to public service.

Reproduction cost - is the cost of constructing the identical plant (in its depreciated condition), estimated at price levels currently prevailing.

Replacement cost - is the minimum cost necessary to create a modern plant capable of rendering equivalent service.

Opportunity cost - is the amount of money into which an asset could be converted in the market place.

Sunk costs - are those costs incurred in the past that have no bearing on future investment or other economic decisions.

Cost of capital - the minimum discount factor applied to prospective cashflows that will induce investors to provide capital in order to claim those flows.

Capital costs - are the before-tax earnings required over time to compensate and repay the suppliers of the capital used to acquire assets.

SOME DISTINCTIONS:

Long-Run Versus Short-Run Costs.

The relevant distinction between short-run and long-run costs refers not to a time period but rather to the relationships between the changes in cost structure and changes in productive capacity. Short-run relates output decisions within a fixed productive capacity to operating costs that vary with such decisions. Long-run applies to changes in operating costs and to investment decisions (broadly defined as "the acquisition of fixed factors of production") which give rise to costs that do not vary as the capacity thus created is more or less fully utilized.

Incremental Versus Decremental or Avoidable Costs.

Variable costs are not constant per unit of output but vary with the degree to which productive capacity is utilized. As a result, incremental costs and decremental (or avoidable) costs are seldom the same. This distinction can be illustrated by the following example:

Assume: 1. Operation of a single, 100-car train.
2. The maximum number of cars per train is 105.

If it is elected to reduce the size of the train by 10 cars, only a slight reduction in linehaul costs will be experienced. On the other hand, if we choose to haul an additional 10 cars, an additional train will be required at substantial increase in linehaul costs. Thus, in this case, the variable costs of the added increment (incremental costs) would be substantially greater than the variable costs (decremental or avoidable costs) of reducing traffic by the same amount.

Common Versus Joint Costs.

When the same plant and equipment are used to produce both service A and service B, and when producing A uses capacity that would otherwise be used to produce B, the production costs are referred to as common instead of joint. Production of these services may be variably proportioned at the discretion of management, with the result that, in principle at least, it is possible to identify the incremental costs attributable to each. A familiar railroad example is the use of track for both freight and passenger service.

Joint costs, however, occur when the decision to produce service A necessarily results in the provision of the capacity to provide service B. This means that owing to conditions outside the control of management, it is impossible to increase or decrease the amount of capacity available for sale in one market without changing in the same proportion (and in the same direction) the facilities available for serving another market. It must be emphasized that fixity of the proportions in which capacity is actually used is not the significant test. Looking at the cost of production alone, there is no objective way of attributing casual responsibility for either service A or B. The principal example of joint costs in rail transportation is the return movement of linehaul equipment.

COSTS APPROPRIATE FOR PRICING DECISIONS:

Pricing of rail services is obviously one of the most important decisions (perhaps the most important decision) facing railroad management. It is an activity for which there are few absolute guidelines. It is generally accepted that minimum prices (rates) should never be set below "variable cost," and that maximum rates will either be determined by competitive forces or by regulation. It is not the purpose here to explore all the considerations in rail service pricing beyond these "basics," but to describe in general the nature of costs appropriate for evaluating the profitability of rail services i.e., costs for use as "tools" for pricing decisions. Economics dictates that four general principles apply:

First, it is generally the determination of marginal cost with which railroad cost analysis is concerned for pricing purposes. Most railroad costing activity relates to the determination of cost associated with the additional carload or train load of traffic.

Secondly, the essential criterion as to what belongs in marginal cost and what does not, and which marginal costs should be reflected in price, is causal responsibility. All purchasers of railroad services must bear at least the additional costs imposed on the carrier by the provision of that additional service (output).

Thirdly, in the general environment surrounding the provision of railroad service, it is the long-run variable cost (as previously defined) which constitutes the appropriate measure of "marginal" cost. The choice of marginal cost is inextricably linked to the duration of the anticipated change in output. In the usual circumstance, questions as to the length of time the traffic will be carried, the length of time that specific rates will be in effect, and the nature of potential or eventual service alterations resulting from the distribution of the additional output over particular time periods ("peaking" problems), are seldom answered adequately. Hence, in the absence of substantive information to the contrary, the time perspective for railroad cost analysis should reflect an assumed sustained change in the production of output service. This does not rule out either the existence of true short-run (temporary) output changes nor the applicability of short-run variable costs in those instances where sufficient knowledge exists to allow the carrier to benefit from such a (temporary) pricing practice.

Fourth, it should be emphasized that any additional costs associated with the provision of additional output, costs for which production (service) is causally responsible, regardless of when such costs are actually felt or give rise to additional cash outlays, should appropriately be considered the marginal cost of that service. This is required since they constitute, in effect, a sacrifice of future value or a future realization of higher costs causally attributable to the present service.

It is obvious that this aspect of the service/cost relationship bears heavily on the proper determination and allocation of railroad roadway costs for pricing purposes.

# IV. RAILROAD ROADWAY

## General

The railroad roadway as considered under this project includes the railroad right-of-way, roadbed, track, structures, and all attendant systems, facilities, and equipment. Analysis of roadway costs for pricing purposes is based upon the separation, to the extent possible, of the roadway into functional components, hereafter termed "service functions." These are listed and described briefly below.

### Linehaul Service

Linehaul service is treated as that "service" (trackage, structures, systems and facilities) from the last switch in a yard where trains originate to the initial switch in a yard where trains terminate. Thus, yard tracks are not ordinarily thought of as being part of the linehaul service and have different maintenance requirements. Branch line tracks between any originating/terminating node would also be considered linehaul service as would mainline tracks through yards. This, of course, does not exclude the possibility of service to intermediate tracks. Passing tracks and crossovers are also considered to be "linehaul" trackage.

### Yard Service

Yard service includes all roadway "service" (trackage, structures, systems and facilities) provided for assembling a train prior to initiating the linehaul, for disassembling the train and for preparing cars for delivery to industry.

### Miscellaneous Trackage

This roadway service function includes industry drill and spur tracks, team tracks, other support trackage such as repair tracks and way switching tracks and sidings other than CTC passing sidings.

### Service-Specific Facilities

These are facilities devoted to a specific type of rail service and would include wharves, major intermodal (TOFC/COFC) facilities, auto-rack loading facilities, grain elevators, coal dumpers, passenger stations, etc.

### Nonservice-Specific Facilities and Systems

This service function includes roadway facilities and systems not related to specific types of rail service or to other specific service functions and whose variable costs must typically be apportioned among other service functions. Such roadway elements as communication systems, office buildings, shops, etc., are included with this service function.

It will be seen that distinctions between these service functions are sometimes difficult to maintain and that arbitrary cost allocations must occasionally be made. It is believed, however, that treatment of roadway "service" costs on this basis will provide for determination, analysis, and allocation of roadway costs most nearly descriptive of the different types of service rendered by railroad roadway.

The service functions described above constitute what is usually referred to as the railroad "fixed plant" or "permanent way." In actuality, the railroad roadway is anything but "fixed" or "permanent." It is, rather, a complex, dynamic, guidance and support system for the nation's rail freight and passenger traffic. As such it is subjected to an extremely wide range of natural and traffic-imposed forces and exhibits physical and economic behavior equally as variant. Rail, for example, may last 20-30 years or more in straight and level track under light or moderate tonnage density and wheel loading conditions, or, the same rail may require replacement in as little as 18 months in track with sharp curves, steep grades, subjected to heavy annual tonnage and heavy wheel loads. In spite of this wide range of physical and resultant economic behavior observed for railroad roadway under varying service conditions, there is less known, in terms of relevant empirical research, regarding such behavior of the railroad roadway than is known about the "fixed plant" of almost any other transport mode.

At a time when greater demands are being placed upon the roadway to render improved "service" in the form of supporting longer, heavier, and faster trains and higher unit loadings, sufficient funds for the necessary maintenance and improvement of the roadway to meet such operating requirements are frequently not available. At no other time has there been a greater need for the coordination of roadway maintenance and improvement programs with railroad operations planning to insure the optimum allocation of available funds. Doing so will require far more extensive research into the dynamic nature of railroad roadway under varying service conditions as well as continued technological and work methods improvement.

## Significant Factors Affecting the Physical and Economic Behavior of the Roadway

This research has developed a list of factors or conditions which, acting separately or in combination, are felt to significantly influence the physical and resulting economic behavior of railroad roadway. Costing methodology developed under this project seeks to isolate the presence and impact of these factors and conditions in order to develop true economic costs for pricing purposes. The factors of managerial policy and budgetary constraints which weigh so heavily upon observed roadway maintenance expenses are discussed in Section VII.

Track-related Factors

- rail weight
- type of rail (welded or jointed)
- rail metallurgy
- condition of rail laid (new or secondhand)
- type of tie (material)
- tie treatment
- condition of tie installed (new or secondhand)
- tie spacing
- type of ballast
- depth of ballast
- condition of ballast
- subgrade stability
- curvature
- gradient
- climatic/atmospheric environment
  - precipitation (rainfall and snowfall)
  - temperature range
  - corrosive conditions
  - flooding conditions
  - icing/frost heaving conditions
- operating environment
  - areal nature (urban, suburban or rural)
  - vegetation

Traffic-related Factors

- tonnage density (annual and cumulative)
- maximum and minimum train speed
- traffic wheel loading characteristics
- traffic service type (unit train, intercity passenger, conventional mixed freight, commuter passenger)
- train movement frequency and schedules
- equipment characteristics (car length, center of gravity, type of truck, suspension system, etc.)

While these factors do not represent the total "universe" of conditions affecting roadway behavior and economic cost, and do not act with the same influence upon any given service function or specific track segment or facility within a particular service function, they do describe the significant cost-causal factors for the purpose of roadway cost analysis.

Roadway Track Structure

Track maintenance and renewal costs typically constitute 40-50 percent of the reported industry total expenditures for "Maintenance of Way and Structures." It is therefore these track-related costs which must receive primary attention within the scope of overall roadway cost analysis.

As stated previously, the railroad roadway, and particularly the track structure, is neither a simple nor a static system. It is only through a basic understanding of the variables acting upon such a system (indeed of their interaction) that the engineer and/or cost analyst can begin to associate primary work activities and their related labor, material, and other costs with specific conditions pertaining to any given segment of the roadway system under analysis. The following sections describe the basic elements of the track structure and will serve as the qualitative foundation for the development of procedures for analyzing track-related costs.

Rail

Rail is the prime element in the track structure. Rails serve the dual purpose of providing direct support to wheel loads and of guiding the wheels (or wheel flanges) in the appropriate path. Rails are composed of steel that includes small amounts of carbon, manganese, sulphur, silicon, and phosphorus and for special applications, other elements. Rails are designated by weight per yard - 90-lb., 100-lb., 115-lb., 132-lb., etc.- and by sections, which indicates the designing agency - RE for AREA design, PS for Pennsylvania Railroad Standard design, RA for American Railway Association (now AAR) design,CF&I for CF&I Steel Corporation design, etc.

Stiffness, the resistance to deflection under load, is an important characteristic of rails. The more deflection of the track, the greater the differential movement of its components and the rate of wear. Rail stiffness varies as the square of the weight but also as the cube of the height. Hence a high, girder-like rail is stiffer than a low squat rail for the same weight per yard.

Factors Affecting Rail Life. The frequency of rail replacement has a significant effect on rail costs. Therefore the matter of rail life and the factors that determine it must be of significance in establishing cost of rail maintenance.

a. Abrasive Wear. Abrasive wear is an obvious rail life factor. It is usually expressed as a function of millions of gross tons of traffic carried, although corrosion may accelerate wear beyond that of traffic alone. Abrasive wear occurs more rapidly per million gross tons with very low annual tonnages than with high annual tonnages because of minute films of rust that develop between the polishing action of infrequent wheel movements and also because of the lesser degree of cold rolling that occurs. Although varying with rail section, an average vertical wear of 3/16 in. is sometimes taken as limiting the useful life of rail in main line track. Wear for different annual tonnages has been set forth in a plot of values by Committee 4 (Rail) of the American Railway Engineering Association (AREA).[1] It should be noted that rail may be removed from track for reasons other than abrasive wear of the rail head.

Rail wears more rapidly on curves than on tangent and is almost directly proportional to the degree of curvature for the middle range of usual curvatures, i.e., between $3^{o}$ and $8^{o}$. Below $3^{o}$ curve wear is only somewhat more rapid than tangent wear; above $8^{o}$ the rate tends to level off. Curve wear involves side wear as well as vertical wear. The combination can have an adverse effect on the total bending strength of the rail. Studies on the life of continuous welded rail (CWR) at the University of Illinois have recognized this fact by evaluating rail life in terms of total loss of head area.[2] Rail is not normally worn to the limit imposed by bending stress. Before that point is reached, the wheel flanges strike the upper edges of the joint bars. Although the bar may then wear along with the rail, good practice warrants removal of the rail at that stage. Where CWR is laid without joints, the amount of permissable vertical wear may be significantly greater. Condemning criteria used in the University of Illinois study for CWR were as follows:

| | Bending Stress Criteria | | Joint Bar Clearance* | |
|---|---|---|---|---|
| Rail Weight | Vertical Wear | Equivalent Area of Wear | Vertical Wear | Equivalent Area of Wear |
| 115 lb. RE | 5/16" | 0.68 $in.^2$ | 1/4" | 0.543 $in.^2$ |
| 132 lb. RE | 3/4" | 0.93 $in.^2$ | 11/32" | 0.804 $in.^2$ |

The University of Illinois studies produced a formula for abrasive wear of the form:

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* Wheel-flange clearance with joint bar taken as 1/32".

1. Annual Proceedings of the AREA, Vol. 60, 1959, p. 971, Report of Assignment 9, Rail Committee 4, Recent Developments Affecting Rail Sections.

2. First Progress Report: Evaluation of Rail Sections, Civil Engineering Studies, Transportation Series No. 9, by Hay, Butler, Martin, Franke, et al, June 1970; also Second Progress Report, May 1973.

$$W = A\,(1 + KD) \times HMGT$$

Where
- $W$ = rail wear in square inches
- $A$ = wear on tangent track in square incles
- $D$ = degree of curve
- $HMGT$ = 100 million gross tons of traffic
- $k$ = wear factor varying with the degree of curve

The report sets forth tables of wear factors for 115 lb. and 132 lb. rail as developed for the conditions of the sponsoring railroad, the Burlington Northern.

A different form of rail life formula has been developed by the AAR and AREA and reported in the AREA Proceedings.[3] The form is:

$$T = K \times W \times D^{0.565}$$

Where
- $T$ = total life in millions of gross tons
- $W$ = weight of rail in pounds per yard
- $D$ = traffic density in millions of gross tons per year
- $K$ = a "standard of maintenance" factor that can also be used to reflect different rail metallurgies, jointed or CWR, or other conditions. It can also be manipulated to reflect the amount of curvature and the effects thereof.

In modifying K for curvature in a particular territory, the equivalent miles of track for each degree of curve can be computed and the value of K adjusted accordingly. The effects of rail end batter and rail failures are included in this empirical equation.

b. Rail End Batter. Rail is often removed from track, not because of abrasive wear, but because of rail-end batter. Differential movement occurs between adjoining rail ends as a wheel leaves one rail and moves onto the next. The amount of rail end movement is a function of tie conditions and ballast support under the tie; also of joint-bar fit and wear on the joint bar bearing surfaces and corresponding surfaces of the rail. The receiving end of the rail receives a heavy impact from the wheel (and the rail being left receives a lesser blow). The effect is to batter down the ends of the rails and, in extreme cases, this leads to lateral lipping and spatulating. A result is rough riding and impact for rolling stock with accentuated rock and roll effects and potential for derailment. Batter of 3/16 inch or more is considered undesirable and requires a repair effort. The more the traffic and the heavier the wheel loads the greater the impact and the more rapidly the battered conditions develop. It is probable, however, that the greatest impact occurs at slow speeds when the wheel has time to fall completely into the depression already created at the rail end.

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3. Annual Proceedings of the AREA, Vol. 58, 1957, Committee 16, Assignment 7, Rail Life, p. 360.

A lesser secondary area of batter occurs a few inches beyond the principal area.

Rail end batter can be reduced by heat treating rail ends (the first four to eight inches). This may be done at the mill as part of the manufacturing process, or it can be performed in the field using portable rail end-hardening equipment. Fully heat treated rail does not require any special work on the rail ends as they already possess the desired hardness.

When the condemning limit of 3/16 inch of batter has been reached, the rail ends can be rehabilitated by gas torch or electric welding (preferably the latter). The built-up ends are then ground to a smooth contour.

Coincident to building up rail ends by welding, it is usually desirable to change joint bars. Reformed bars (or oversize bars) are often used as replacements for the worn bars to assure a snug fit.

Rail removed from main track and marked for relay in secondary tracks is usually first sent to a cropping plant where, six to eighteen inches are cropped from each end to remove the battered portions. The amount of rail cut from each end depends upon the degree of fillet wear and extent of batter. For bolted track, new bolt holes must be drilled.

c. Rail Defects and Failures. Rail is subject to a variety of defects and failures that contribute to shortened economic service life.

1. Some potential defects arise at the mill in the rolling process. As molten steel is poured into the ingot molds, impurities such as slag particles float to the top. After stripping, the ingot cools from the outside in. Shrinkage cracks may form in the top of the ingot. A portion of the ingot is always sheared off and scrapped. This removes any impurities, bubbles, cracks or inclusions that might exist in the upper portion of the ingot. Such impurities or cracks could become the source of transverse defects, pipes, or vertical split heads. Rails rolled from the top part of ingots are designated as "A" rails (from the "A" position in the ingot.) They are usually identified by being painted yellow on the ends. Most railroads refrain from laying "A" rail on, or in approach to such locations as high bridges, tunnels, or high embankments because of the possibility that inherent weaknesses within the rail might cause it to fail.

   Rails containing transverse defects, i.e., transverse fissures or detail fractures, present a problem to the maintenance organization. Such defects, propagate within the rail invisible to ordinary inspection. Rail failure can occur suddenly, and without warning. (Fortunately, however, modern rail detection equipment can identify transverse defects before they become dangerously large.) Detail fractures result from several causes; hot torn steel (rails rolled at too high a temperature), blow holes, slag, high impacts, etc. Inclusions act as stress risers and as a nucleus or point of initial separation which, under the stress of heavy and/or repeated wheel loads, causes the metal to separate in a series of growth rings outward from the nucleus. If not detected and removed, rail fracture will eventually occur.

Transverse fissures are the most serious types of transverse defects. They are caused by entrapped pockets of hydrogen gas, the result of too rapid cooling of heavy rails. The transverse fissure has been virtually eliminated by processes of controlled cooling and vacuum degassing, but a large quantity of non-controlled rail still remains in track, especially in branch lines.

Vertical split heads and piped rails are vertical separations of metal in the head or web. They represent the presence of seams, inclusions and/or inadequate molecular homogeneity of the metal.

Horizontal split heads and head and web separations are defects in the horizontal plane. They are caused by seams or laminations due to segregations or inclusions or overstressing of the rail by heavy wheel loads. A rash of head and web separations at one time did lead to revised rail sections with 115# RE and etc. etc.

One other defect, corrugated rail, <u>may</u> arise from mill practice. "Chatter" in the rolls when those become worn may permit minute ridges to form on the rail surface. Some railroads operate a grinding train over new rail to remove any ridges before they enlarge into objectionable depressions, some with crests of a fraction of an inch, 8 or 10 inches apart. Some corrugations may arise from roll "chatter", but there are undoubtedly other causes of corrugations as well.

2. Certain types of defects and failures are associated with the concentration of stresses immediately beneath the point of contact between wheel and rail. These include head checks, spalls, flaking, shells, and, perhaps, certain types of corrugations.

   (a) Head checks appear as minute cracks on the gauge corner resembling a fish scale in appearance with the "pointed" end in the direction of prevailing traffic. Head checks usually wear away as tonnage accumulates but may presage spalling and/or a detail fracture.

   (b) Spalling is the breaking out from the gauge corner of rather large particles or chunks of metal. Spalling may arise from too brittle a metal, especially with alloy steels, or it may be an advanced stage of head checking. Spalling weakens the cross section of the rail and its resistance to bending stresses. Transverse defects may also begin with a spall.

(c) Flaking is the breaking out of small particles of metal about the size of finger nail from the rail's running surface. Excessive flaking makes a rail look "scabby" but, of itself, is not serious. Flaking may, however, lead to shelling and does, perhaps, represent shelling that has occurred close to the rail surface.

(d) Shells are formed on the gauge corner as a separation or crack appearing 3/8 to 5/8 in. below the gauge corner. The crack is usually accompanied by a flow of metal (plastic deformation) that may in turn become the source of the shell. Studies at the University of Illinois indicate, however, that the crack probably is initiated inside the rail head.[4] The flowed portion, losing wheel contact, turns black. Shells may start from inclusions, blow holes, hot torn steel, etc., but a majority are of undetermined origin. Studies have indicated that a concentration of residual stresses at the gauge corner will cause shelling, and other studies have indicated lateral and longitudinal forces to be of sufficient magnitude to cause residual accumulations. The interacting relationship of shelling to track geometry, to curvature, and to the degree of uniformity in train consists represent areas that warrant further investigation. Regardless of initiating cause, it is generally accepted that heavy wheel loads and concentrated tonnage cause shells to grow.

Shells as such are not particularly serious, although a broken out shell reduces the effective cross section and bending strength of a rail. Shells do, however, pose a very serious problem in that the shell crack may turn downward, creating a transverse defect and rail failure.

Opinion differs as to what should be done with shelly rails. Some railroads remove the rails as soon as the shell is discovered. Others impose slow orders. A large number simply "watch" the rail until the shells become excessively large, or other flaws develop. In any event, shelling may limit the life of continuous welded rail.

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4. AREA Proceedings, Vol. 49, 1948, Sixth Progress Report on Shelly Rails, pp. 437-446.

3. Corrugated rail, as earlier noted, consists of a series of ridges and low spots across the rail head, spaced from 1/4 to 1 inch apart, but more often the length measures 8 to 10 inches, crest to crest. Again, the cause is obscure. Two likely causes in today's track structure are (1) rate of rail vibration and (2) a combination of rotative and lateral slip. Corrugations on the high rail are often accompanied by correlative corrugations, finning, mashing, and head flow on the low rail. Corrugations, if unhindered, will grow deeper and lead to head crushing. A practical solution is grinding the rail by special grinding equipment before the corrugations grow too deep and too long.

d. Use of Rail. The way rail is used has a marked effect on its service life and cost. It is the general practice on American railroads to use rail of 132, 136, or 140 lbs. per yard where annual gross tonnage exceeds 20,000,000 tons. The 115 and 119 lb. rail is in frequent use for annual tonnages of 5 to 20 million gross tons. Lower tonnages with normal or light wheel loadings can be handled on 90 and 100 lb. rail, but the trend is toward heavier sections. Branch lines may contain rail from 60 to 132 lbs. + in varying amounts, the quantity of the heavier rail sections depending upon how much of it is available from main track rail relays. There is a point at which a heavier rail (costing more per foot of length) is economically preferable to a lighter rail with attendant higher maintenance costs. That point is a function of rail weight, mill price, annual gross tonnage, and length and amount of curvature and gradient.[5]

Rail replacement practices also affect costs. Provided that rail is available, a railroad with considerable secondary and branch line mileage can practice so-called cascade replacement. Selected jointed rail removed from main line track is sorted, cropped and welded into long strings and relaid in main lines. Other mileage of the same rail may be relaid in secondary and branch lines releasing rail of the same section which in turn is laid in less important branch lines and yard tracks. Usually rail is removed from main line before its physical life has been used up. This makes rail available for branch line relay. Whether or not rail is removed too soon or too late has a marked effect on rail and track maintenance costs. A railroad without secondary tracks and yards cannot derive full use of all rail released through relay programs. In view of the high cost of rail, every practical means must be employed to maximize the life of rail in its present location. When cost of maintenance

5. Second Progress Report: Evaluation of Rail Sections, by Hay, Schuch, Franke, Mikkelsen, Civil Engineering Studies, Transportation Series No. 9, University of Illinois at Urbana, May 1970.

becomes prohibitive, rail should be replaced.

Additional life can be obtained from rail on curves by transposing the high rail to the low side, and vice versa. Occasionally, rail from the low side goes to lesser tracks; new rail is laid on the high side and the high rail is set down. The extent to which rails of special metallurgies--heat treated, high silicon content (hi-si), flame hardened, etc.--are used will also affect life and costs.

Wheel loads affect rail wear and life. For loads less than 26,000 lbs. the shearing stresses are within allowable limits, and rail will withstand an indefinitely large number of load repetitions. For wheel loads over 26,000 lbs. the rail is likely to deteriorate at a rapid rate through rail-end batter, corrugations, shelling, abrasion, and similar contact stress effects.

Rail is subject to a variety of maintenance procedures that involve cost in their performance and even more cost in damage to the rail when not performed.

Care for rail must begin when it is laid--or even before. Track should be re-tied, ballasted, and placed in good line and surface in preparation to receive the new rail. Soon after relay it is desirable to give the rail a running or smoothing surface and to realign it. Old joint locations must be tightened even though new locations and earlier surfacing have occurred. Failure to accomplish these activities will lead to bent rail which will never hold proper line and surface. An especially bad situation obtains when rail is laid in late fall or winter and not surfaced until spring. Bent rail can also arise from poorly maintained surface, especially when heavy wheel loads are prevalent, from soft subgrade support and from unbalanced steam locomotives (their effects may still persist in old rail currently in track).

With jointed rail, plastic flow in the surface metal usually occurs at the rail ends sufficient to bear against the adjoining rail, especially in summer when the rail has expanded. The flowed metal may then break off into the parent metal forming a chipped rail end. To retard such rail-end chipping, rail ends are slotted transversely by a thin grinding wheel to provide room for the flowed metal. Slotting must be performed as needed, usually several times during the rail life.

Rail end welding or rebuilding has already been discussed in connection with rail-end batter. It is an operation that may occur at least once during the life of plain rail, sometimes more often. Driver burns that leave deep irregular grooves and burned metal in the rail surface can also be repaired by welding and grinding, if promptly and properly performed.

The use of the grinding train to remove corrugations and lips or lateral flow has been mentioned. This operation is performed every three to five years by some roads, and might be considered more often by roads with heavy tonnages and high wheel loads.

Joint maintenance has been briefly mentioned. Bolts should be tightened initially to 20,000 to 30,000 lbs. of tension to overcome roughness in the fishing area and to provide a proper fit. Three months later bolts should be retightened with 15,000 to 20,000 lbs. of tension per bolt after the mill scale has been worn away and the joints "seated". In some cases bolts require frequent tightening, at least once a year, to maintain a minimum tension of 10,000 lbs. per bolt, because of bearing surface wear and elongation in the bolt material. Eventually, worn bars must be replaced by oversize or reformed bars as noted earlier.

Defective rails must be changed out as soon as practical after defect is detected even though this policy might cause some inconvenience to maintenance forces. A broken rail must be removed immediately on an emergency basis. Known minor and small scope defects such as shells, vertical split heads, and horizontal fissures are sometimes kept in track until an opportune time in order to gather a working force or work train and change several at a time, with train speeds being appropriately reduced as dictated by the nature of defect.

A major maintenance cost of rail is renewal and relay.* Costs involve distributing rail and fastenings at the relay site, taking out the old rail, adzing new bearing surfaces for the tie plates on the ties, setting in and bolting, gauging, and spiking the new rail, picking up the old rail and fastenings for transport to the reclamation plant, applying track circuit bonding, and surfacing and lining. At the reclamation plant the old rail is inspected, sorted, and some is scrapped. The remainder is cropped to remove end-battered portions and, for jointed track, new bolt holes are drilled. It is then ready for relay in secondary tracks. Rail relay is a heavily mechanized operation.

One final cost item needs identification--rail inspection and testing. This may range from a cursory glance as the trackmen ride to work on a motor car, to regular patrols daily or semi-weekly, etc. on foot or on motor cars, to the elaborate checking of interior rail conditions by rail detector cars. The number of inspection trips by detector cars varies from twice a year to once every two,

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* Relay of rail may involve both investment and operating money, depending upon accounting practice. Under betterment accounting the increased weight of the rail, together with the additional rail anchors applied in case of CWR, itself is the only portion capitalized, while the rest of the rail is expensed.

three, or five years, depending on age and type of rail, train speed and tonnage, incidence of rail failures, and, most recently, requirements of the Federal Railroad Administration. Some railroads have their own detector cars and keep them in continuous operation. Others utilize the services of a contractor on a combined per-day and per-mile basis.

Continuous Welded Rail. Most of the foregoing applies as well to rail formed by welding standard 39-foot rails in long strings, usually 1440 feet in length. These rails, in turn, may be field welded into strings of indefinite length(up to 36 miles or more), limited only by the intervention of turnouts and insulated joints. CWR eliminates most rail joints, said to account for 50 percent ± of track maintenance. Without joints, rail life is extended: A smoother ride results with less wear and tear on equipment and track.

Welding is performed by one of three processes. The oldest (originally used in welding street car rails), thermit welding requires only a small quantity of portable equipment, and finds its only use today in making field welds. Oxy-acetylene butt welding, usually performed at a central welding plant, employs a battery of gas torch tips to heat the rail ends to a welding temperature while gripper pads bring the rail ends together with an upsetting pressure. Surplus metal must then be ground off. Electric flash butt welding, the most frequently used method today, depends upon the short-circuiting of electric current, introduced through gripper pads, to heat and fuse the rail ends.

There are relatively few joints in CWR. The life of CWR is little affected by rail end batter at the occasional joints. Batter can be countered by rail end welding or building up, grinding, or by rail end cropping in track. As noted earlier, shelling (and perhaps the incidence of corrugations) will limit CWR life. Otherwise, a long life based on abrasive wear can be anticipated.

In addition to failure from defects inherent in jointed rail, CWR may experience weld failures. These are due to improper practices at the welding plant: current fluctuations, mill scale not being removed, slippage of gripper pads, particularly at the moment of impact, improper weld grinding, etc. Cold weather uncovers many weaknesses through pull-aparts as the long rails contract.

The solution to the problem of thermal stresses causing expansion and contraction is simply one of restraining finite forces that can vary from 100,000 to 250,000 lbs. ±. Rail anchors, applied with a friction grip to the rail base, bear against the ties which are anchored in the ballast. AREA recommendations call for every tie throughout the first six 39-foot rail lengths at each end of the long rail to be box anchored, i.e., with an anchor bearing against each side of the tie. In the body section of the rail, every other tie (on some railroads every third tie) is box anchored.

Special techniques are required in laying CWR. It must be loaded at the welding plant, transported to the relay site, and unloaded onto the ground or onto tie plates. Rail is laid, ideally, at an average or equilibrium temperature within the anticipated range of temperatures. Because this is seldom practicable to do, an equalized state can be achieved by artifically elongating or contracting the rail by heating or cooling it until the rail attains the desired length before the rail anchors are applied.

Rail wears more rapidly on curves. There are different practices involving the use of CWR on curves. Most railroads lay CWR through curves of 3° or less. Above 3° some roads still lay around the curves and then later cut out and replace the worn section as needed. Others use CWR on curves and locate joints at each end of the curve for ease in replacement. It is the practice on several roads to lay 78 foot length rails on curves over 6°, thereby eliminating half the joints.

To insure a stabilized track condition that is indispensable to prevent lateral and vertical buckling (sun kinks), a full ballast section is required. This includes filling the cribs between ties to the top of ties and providing a ballast shoulder of 6 to 12 inches beyond the ends of ties. Quantitative data is lacking on exactly how much restraint various types of ballasts and ballast section configurations provide.

When performing any work on CWR, great care must be taken to avoid disturbing the track when the rail is in compression, i.e., wanting to expand. If too much ballast or too many ties are removed or loosened while renewing ties or surfacing,sun kinks will occur. Desirably, all out-of-face work should be scheduled at, or below, the temperature at which rail was laid or adjusted to. Normally no more than half a rail length should be "skeletonized" at a time. Under extreme conditions, the track should not be disturbed at all. When sun kinks do occur, it may be necessary to cut out a portion of the rail to relieve the rail stresses. In the case of pull-aparts, rail can be expanded by heating and joint bars applied, or, again, filler rails may be used.

Cost Factors. In summary, rail costs are noted as arising from:

a. Out-of-face renewals: a function of rail life based on rail section, train tonnages and speed, standard of track maintenance, incidence of grades and curvature, condition of subgrade, etc.

b. Routine maintenance: spot renewals of broken or defective rails, rail end welding, rail grinding, rail end slotting, properly supporting rail ends to prevent bending rails or causing batter, and maintaining adequate gauge, line and surface.

c. Rail joint maintenance: all of the above plus tamping joint ties, renewing joint bars, tightening bolts, replacing broken bolts, renewing insulated joints and/or insulation.

d. Rail inspection and detector car operation: to search out defective rails and remove those that constitute a safety hazard to operation.

## TIES

Ties perform three primary functions:

a. Hold the rails to proper gauge.

b. Bear and distribute wheel loads with diminished unit pressure to the ballast in which they are imbedded.

c. Provide anchorage (in the ballast) for the track, i.e., to prevent lateral, longitudinal, and vertical movement of the rail by restraining rail stresses. Rail has a tendency to elongate and contract subject to the law of thermal coefficient of expansion and due to the wave action behavior of rail under each wheel load. Rail anchors prevent rail movement by transferring rail stress through the anchor to the tie and thence into the ballast between the ties. Thus, for the anchor to satisfactorily function, it must impinge snugly against the tie; the tie must be sound and the ballast must be capable of being consolidated into a homogeneous body strong enough to resist the movement of the tie.

Ties are conventionally made of wood and as such will receive most of the following comments, with some attention given to concrete ties. Rolled section steel ties have no place under present U.S. railroad practices.

Tie Life Factors. Those factors that affect tie life may be grouped into four categories: (a) natural causes, (b) tie size and treatment, (c) mechanical wear, and (d) traffic effects. As will be noted in the following paragraphs, these factors overlap and intermingle.

a. Natural or Inherent Factors. Tie wood specie and type is the first item considered here--whether a hardwood or softwood, whether heart wood or sap wood. Hardwoods such as white and red oaks and gum offer a longer life than softwoods--fir, pine, hemlock, etc.--and can withstand heavier loads as indicated by maximum allowable fiber stress of 1,000 to 1,200 psi in contrast to 900 psi or less for the softwoods. The condition of the tie after seasoning may also be considered a natural or inherent factor. The extent of splits and shakes that have developed is significant even when within the allowable limits of AREA and ASTM specifications. Tie end splitting tendencies can be lessened by applying anti-splitting devices such as S-irons or similar designs into the tie ends to hold the wood together. Bands may be placed around the ends of ties (a European practice), or the ends may be dowelled. Nevertheless, end splitting can occur and develop under traffic until, in extreme instances, the split extends to the tieplate-rail position, thereby lessening the effective spike holding capacity of the tie.

In track, ties are subject to insect attack and to rot and decay. Insect attack is not a serious problem in the United States, especially with treated ties. Decay and rot will occur at an early stage (3 to 10 years) with untreated ties, but can be forestalled for 20 to 30 or more years if given proper preservative treatment and if protected against the exposure of untreated fibers by mechanical wear and abuse. Wood fibers abrade and decay more readily if wet. Excess moisture (from dirty, poor-draining ballast, etc.) will hasten decay and rot. Dry rot may set in with certain types of woods, especially in slag ballast with a high sulphur content.

b. Tie Size and Treatment. The size of a tie--its thickness, width, and length--influence a tie's capacity to withstand traffic loads, loads from thermal stresses, and the effects of the elements and environment. Size may determine tie assignment. The AREA has established seven grades of ties, 0 through 6. Only grades 4 (7 in. x 8 in.) and 5 (7 in. x 9 in.) find use in main line tracks. Grade 3 (7 in. x 7 in.) ties are used in sidings and secondary main tracks (branch lines). Thus tie size and tie load are usually correlated (but not always). The standard tie length is currently 8 ft. 6 in. Some branch lines are laid with 8 ft. 0 in. ties. Ties 9 ft. 0 in. offer greater stability and resistance to lateral and longitudinal forces because of the greater weight and greater length in frictional contact with the ballast. This length has been recommended by the AREA for new construction and rehabilitation and is the current standard on a number of railroads.

Practically all ties except those for purely temporary construction and some industry tracks are given a chemical preservative treatment to retard decay and repel insect attack. An early treatment of limited effectiveness involved the use of zinc chloride. Modern treatment involves forcing a creosote oil, usually under pressure, into the wood cells from which moisture has been driven. Natural drying, usually for several months' duration, tends to cause tie ends to split. A vapor drying process introduces moisture-absorbing chemicals into a tie-filled cylinder. After the moisture has been removed, the creosote oil is forced into the outer cells of the tie under pressure. This process requires about 16 hours in contrast to 3 to 6 months for air seasoning. Vapor drying reduces tie-end splitting.

c. Mechanical Wear and Abuse. By far the factor with greatest impact on tie life is mechanical wear and abuse.

1. Tie splitting. This may be considered a type of mechanical action, especially when proper drying and use of anti-splitting devices are not employed.

2. Careless tamping. Blows from carelessly directed tamping tools, manual or mechanical, can knock off corners and edges of ties and increase splitting tendencies. The underlying material thus exposed offers easy entry for moisture and decay.

3. Outer fibers are damaged by contact with sharp, rough ballast particles. The edges are also worn away by the rocking motion imparted by the repetitive application of wheel loads and the wave action behavior of the track. Again, moisture can enter and accelerate decay.

4. The crushing effect of wheel loads will hasten early deterioration of tie wood if the tie is not properly protected by tie plates of adequate size. As recently as 20 years ago, studies made in connection with transverse fissure investigations indicated that one out of every 1,000 wheels delivered a load of over 40,000 lbs. to a tie. Wheel loads of modern equipment come close to 40,000 lbs. with static loads alone, to say nothing of impact effects. Hardwoods can stand crushing loads of 400 ± psi, softwoods 250 ± psi. To withstand a load of 40,000 lbs. concentrated on one tie (a not unusual occurrence), a tie plate should have an area of 100 sq. in. for hardwood ties, 160 sq. in. for softwoods. Seven-3/4 in. x 13 in. tie plates have an area of 100-3/4 sq.in.; 8 in. x 14 in. plates 112 sq. in. Many dynamic wheel loads today exceed 40,000 lbs., and many plates in track are less than 100 sq. in. Also many ties are softwood. Fortunately, not every tie has to bear 100 percent of the load (40 percent is an accepted estimate). With poorly maintained track (or with good track just before a surfacing cycle is ending) a tie might have to carry 2 to 3 times its share of the wheel load. Also, where some ties are ready for removal, a disporportionate share of the wheel load is placed on neighboring solid ties.

   Insufficient plate area coupled with crushing loads result in plate cutting of ties, i.e., the plate eats into the tie. Simultaneously, lateral loads force the plate outward on the tie, widening gauge and requiring track to be regauged. The plate has to be removed and a new, flat bearing surface adzed under the rail. Adzing removes a part of the tie and reduces tie life. However, the adzing operation usually assures a more even distribution of the loads to a group of ties, in which case tie life may well be increased.

5. Loose tie plates contribute to tie wear. Plate and tie should act as a unit with the rail free to bend downward or upward if need be. If the tie and plate rise with the rail, pumping ensues, which is bad for the tie and for line and surface. Any play between tie and plate, especially if moisture is present, will destroy the wood fibers more rapidly and hasten plate cutting and decay. Plate holding spikes or studs are sometimes used to secure the plate to the tie. The bearing area may be waterproofed by applying rubber or fiber pad between the plate and the tie.

6. Abuse. Any action that punctures the creosote treated tie fibers and allows moisture to enter the tie interior contributes to decay. Abuses that so destroy the fibers appear in many forms. Carelessness in handling or transporting tie to the place of use can break off corners and edges to expose unprotected interior fibers. The practice of tossing ties carelessly from a moving train can damage the tie and reduce its usefullness.

   Hitting a tie to straighten, align, or space it in track can destroy wood fibers, especially if a small-headed spiking maul is used.

   Frequent respiking of ties enlarges spike hole area and destroys the tie by "spike-killing." The area around the rail base becomes so full of holes that moisture easily penetrates the untreated interior, causing decay. Even the use of tie plugs is not sufficient to entirely prevent moisture penetration. As noted earlier, deterioration is accelerated if moisture is present in the plate-rail bearing area. Spike holes from which a spike is missing or in which a spike stands loose are ready sources of entry to the tie's interior by moisture.

   Excessive adzing sometimes occurs when correcting plate cutting. A smooth plate bearing surface is needed, and only the minimum depth of cut should be adzed to secure that bearing.

   Improper selection of ties for renewal can also shorten tie life. If a tie is removed too soon there is an obvious loss in economic service life. If a tie is left in track beyond the serviceable life it cannot adequately fulfill its function. Adjacent sound ties become overloaded, thereby shortening their service life. (Such track may become unsafe).

   The incidence of ties destroyed by fire has diminished since the demise of the steam locomotive. Nevertheless, ties do occasionally catch on fire from hot brake shoe slivers.

   Derailments can and do destroy several hundred ties at a time, depending on the severity and type of derailment.

d. Effects of Traffic. Some effects of traffic have already been considered. Wheel loads have an obvious and direct effect. They deliver crushing loads to the ties, which often are only partially compensated for by adequate size of tie plate. This leads to plate cutting, gauge widening, and the need to further weaken the tie material through adzing, regauging, and respiking. Lateral forces from traffic also tend to widen gauge and cause plate cutting. Traffic volume will determine how rapidly deterioration from these causes will progress (other conditions being equal). Modern rolling stock with long truck centers and high centers of gravity tend to rock and roll and derail with consequent tie damage. The braking action of long trains sets up lateral pressures that widen the gauge; so also do locomotives and cars with three-axle trucks. As noted earlier, axle loads and wheels approaching and leaving a tie cause a slight rocking motion that abrades away the bottom edges of ties, rounding them and facilitating the entrance of water.

Concrete Ties. Concrete ties have been installed in sparing numbers and hence are a somewhat unknown quantity in the United States. The period and extent of main track use is limited, and even the AREA-AAR specifications are of recent development and labeled "tentative". Economic analyses for concrete ties have been based on a life of 50 years. Theoretically, it probably should be much more. In practice, many concrete ties have been removed after only 2 to 5 years of service account failure due to one cause or another.

The ties designed and manufactured in the United States are in general terms a pre-stressed concrete beam. Problems with such ties include poor initial concrete, concrete deterioration, hair line expansion crack, and breakage and pull-out of hold down devices. These are problems for which solutions will unquestionably appear eventually.

An initial spacing of 30 in. center to center (to warrant economic parity with wood ties) is currently proving less than satisfactory, and closer spacings are likely to be required, thereby increasing the basic number of concrete ties required and raising costs. The heavy weight of concrete ties (from 30 to 100 percent greater than equivalent dimensioned wood ties) means more labor and/or machine costs for installation and maintenance.

Sources of Tie Costs. The principal cost associated with ties is that of tie replacement. Under I.C.C. accounting rules this is treated as an operating expense rather than as a capital replacement. The rate of renewal reflects all of the foregoing factors and conditions. Small additional costs arise from the use of tie plugs to fill old spike holes, tie adzing (by hand or machine), and the painting with creosote oil of newly adzed surfaces.

Because there is more load concentration on rail ends, more movement, displacement, and tamping of ties at the joints, joint ties wear out more rapidly. The lateral thrust on curves probably causes curve ties to wear out more rapidly but at a presently indeterminate rate. It is a known fact that more frequent spiking of ties on curves--due to rail transposing and sooner rail replacement--shortens tie life to about one-half that for tangent ties.

If ties are not properly maintained, they can contribute markedly to maintenance costs of the entire track structure. Ties that give inadequate support will hasten degradation of line, surface, and gauge. When the area under the tie plate is decayed, spikes no longer hold. Tie plates slip out of place. Wide gauge occurs. Joint ties that give poor support will cause an excessively rapid accumulation of rail-end batter. Elsewhere, a tie that gives poor support, whether because of splitting, decay, or inadequate tamping, compels adjacent ties to bear more than their share of the wheel loads, thereby hastening their rate of wear. All of these conditions, carried to extremes, can lead to derailments.

SUBGRADE AND BALLAST

Subgrade. A subgrade serves to bear and distribute with diminished unit pressure the load imposed by traffic through the track and ballast. It facilitates drainage and forms a smooth platform on which the track structure can be laid. A subgrade is the foundation on which the track structure rests and thereby performs as vital and necessary a function as does the foundation for a bridge or skyscraper. It most often appears as an extended mound of earth in the shape of a truncated prism, but it may also be in the form of a cut through higher ground--the cutaway portion also being truncated-prism in shape. On narrow side hill cuts the cutaway portion may be triangular in shape. (Some sections, particularly on the side of hills, may be combinations of cut and fill.) Regardless, the subgrade must be so constructed that it will support the imposed loads without deformation. It must have a high degree of permanence, i.e., stability.

The soil materials used in construction (or in soil replacement as a maintenance procedure) must have high shear strength and (if a fine-grained soil) cohesion. Moisture must be excluded, either by use of a highly permeable granular material or by compacting the soil particles so tightly that there are no voids between particles into which water can enter. Tight compaction also promotes stability, cohesion, and shear strength of the ballast particles. Good drainage is a prime essential. Almost any soil will provide a stable subgrade if it can be made dry and kept dry. This is seldom easy to achieve.

Most track in the United States is already constructed and in operation. Due to the pioneering nature of early construction and lack of adequate knowledge, machines, explosives, and money, much of the trackage was built without benefit of present day good practices. (Also, the loads imposed during early construction did not require as strong a subgrade, being much lighter than those experienced today.) Soils were used as they came to hand, without benefit of compaction, admixtures, or moisture control. Consequently, some of the track built in the early days still contains a variety of soft spots, sinks, unstable fills, unstable cut slopes, fouled ballast, pumping joints, and long stretches of weak subgrade that require excessive maintenance and/or the expense of one or more of a variety of stabilizing procedures. A brief statement regarding major types of instability, corrective action, and associated cost factors follows:

a. Unfavorable Soils in Subgrade. A subgrade generally composed of unfavorable soils will be a continuing source of trouble. The fine-grained soils--silts and clays--are the most troublesome. Sands and gravels--the coarse, granular soils--usually make a stable subgrade. Most soils are mixtures, not purely one kind or the other.

1. Unfavorable soils would include:

- Swelling soils such as montmorillonitic clays, false shales, and compressible silts. These soils expand when wet (from rains, snow melt, underground seepage, capillary rise), thereby disturbing the track surface and alignment.

- Varved clays are usually found in old lake beds. The soils have been laid in alternate layers of very fine and relatively coarse clay particles. They have a high moisture content and are subject to sliding and failure of fill or side slopes, and to frost heaving.

- Swamp muck or muskeg soils have a high organic content. They are subject to uneven settlement and swell; also to frost heaving.

- Sensitive clays and silts. Water has no shearing strength. Soils with a very high water content may liquify under shock or impact. They create hazardous conditions when used in a railroad subgrade or as a subsoil.

2. Corrective Action. Two courses of action are open--to live with the situation or to bring about corrective action.

- Continual excess maintenance may be necessary in the form of labor to restore line and surface and to clean ballast more frequently. Component parts--rails, ties, and fastenings--will have to be renewed more frequently.

- Slow orders may be necessary to protect trains moving over sub-standard track.

- Injection of cement grout or lime as a stabilizing agent and/or performance of other stabilizing procedures, such as installing subdrains, sand-filled spud or blast holes, pile or pole driving, etc.

- Excavation and replacement of unstable subgrade materials with stable (select) materials.

- Line relocation to more stable soils.

3. Cost Factors.

   - Costs associated with any of the foregoing corrective or "live with" actions.

   - Shortened life for ties, rails and fastenings, with more frequent replacement.

   - Possible loss of revenue traffic due to longer running times (decreased schedule performance), plus the incremental operating costs associated with longer running time.

   - Excess wear and tear on locomotives and cars.

b. Weak Subsoils. Any of the soils enumerated in Section I. serving as a bottom layer in a subgrade or more generally as a subsoil in natural ground (as when a fill is built across an old lake bed or swamp muck) may be too weak to support the fill and the trains moving over it. There can be a gradual settling of the fill, requiring that more fill and/or ballast material be placed to maintain the grade, as the weak soil is squeezed out at the toe of the fill. Settlement will continue until sufficient soil has been squeezed out at the toe to form a balancing counterweight. Fill failure can occur suddenly depending upon the nature of disturbing stimuli.

1. Corrective Action.

   - Live with the condition by applying additional fill and ballast materials as needed to maintain grade, resurfacing the track, and applying slow orders for the worst conditions.

   - Add a corrective counterweight of soil at the toe of the fill.

   - Perform any or all of the stabilizing procedures for generally unstable soils.

2. Cost Factors.

   - The same costs as are incurred by generally unfavorable soils.

   - Cost of placing the corrective soil counterweight before failure has occurred.

c. Unstable Cut and Fill Slopes. Fill and cut slopes are subject to a continuing process of wear and erosion. The extent of such erosion varies with soil types, extent of natural ground cover (grasses, shrubs, vines, etc.) or artificial cover (rip rap, cinder or asphaltic blankets, etc.), and with the incidence of rainfall or winds. Also, burrowing animals such as gophers may have a direct and substantial effect on fill stability. Water can enter their burrows and lubricate the supporting material to the point of failure. Slopes may also suffer from causes as outlined above when untable materials are overloaded. Even stiff clays can cause difficulties. During dry periods cracks will form, often of considerable depth. A later wet period fills the cracks with water, thereby saturating and weakening the adjacent soil creating a potential for a slide. If the cut slope is of rock, frost action can loosen portions of the face to cause slides. Slides may also arise when sloping bedding planes undercut, or when a smooth bedding surface or clay seam forms a slick sliding plane.

1. Corrective Action.

   - Removal of load materials from the top of slide area.
   - Scaling loose rocks in the spring.
   - Drainage; often extensive subdrainage is required. Installing perforated pipes, or hydraugering.
   - Slope flattening. Retaining toe walls and earth counter weights.

2. Cost Factors.

   - Watchmen or patrolmen labor, usually computed at overtime rates.
   - Scaling rock faces, in the spring or summer.
   - Slide fences--construction and maintenance.
   - Removal of slide material and repairing any track damaged by slide.
   - Excavation of overburden materials.
   - Construction and maintenance of drainage facilities.
   - Restricted speed of trains and attandent effects upon schedules and traffic.
   - Slope flattening and/or cut widening.

d. <u>Ballast Pockets.</u> Where fine grained soils (clay or silty soils) are in contact with the ballast, the moisture content (augmented by rain runoff, snow melt, underground seepage, or capillary rise) is brought to the soil surface by the pumping action of the passing wheel loads. The soil face in contact with the ballast becomes softened and may turn into a paste or slurry-like consistency. Traffic loads force ballast into the subgrade material, and the action is then repeated at a slightly lower level. More ballast must be added to replace that which is pressed into the subgrade. Eventually, pockets of ballast are formed and water is entrapped therein by the surrounding impermeable clay materials. Depths of 3 to 6 ft. are common, but depths of 10, 20, and even 50 ft. are on record.

1. Corrective Action.

   - Sub-surface/soil surveys to determine soil type, sources of moisture, and extent of the problem.

   - Sub-drain installation to drain the water pockets and to intercept underground seepage that contributes to the excess moisture.

   - Application of stabilizing procedure, such as cement grout or lime injection, sand-filled spud or blast holes, pile or pole drivings, etc.

   - Excavation of unstable materials and backfill with select materials (track must be temporarily put out of service).

2. Cost Factors.

   - Excess maintenance--labor to restore line and surface where the pockets cause settlement; labor and materials to replace track components subjected to accelerated wear.

   - Effect on traffic by slow orders protecting the pocket areas.

   - Effects associated with frost action where freezing temperatures exist.

   - Cost of the stabilizing process adopted.

   - Costs associated with derailment caused by fill failure, when such occurs.

e. <u>Water Pockets.</u> These are soft spots in the subgrade other than ballast pockets that may also become water-filled. They are caused by any one of the following, or a combination thereof:

- Inadequate compaction.

- Inclusion of frozen lumps (of clay) during subgrade construction (again leading to inadequate compaction).

- Decay of stumps, logs, timbers, or old frame trestles that have been filled in.

- Arching of soil against rocks, stumps, old trestle timbers, etc., forming an inadequately compacted soft spot or cavity.

1. Effects. Repetitive action of wheel loadings may cause pockets to increase in size. Effects similar to those of ballast pockets may ensue, including failure due to collapse of a portion of the fill.

2. Corrective Action. Same as for ballast pockets.

3. Cost Factors. Same as for ballast pockets.

e. Frost Heaving. During cold weather, excess moisture, dirty ballast, and unstable subgrade materials can add to the cost of winter and spring maintenance, either singly or in combination. Moisture from whatever source, but especially by capillary action, will freeze in the top of subgrade areas and in areas of dirty, moist ballast. Ice lenses form which swell and distort track line and surface. Ice lenses normally build from the bottom upward. Distortions are corrected by shimming the rails on the ties, i.e., by inserting wooden plates of varying thicknesses between the tie plate and the tie to achieve approximately correct cross level and profile. This is a time-consuming and costly operation. If the distortions are extensive or relatively large, slow orders may be imposed. The worst condition is that of alternate periods of freezing and thawing, which may require several adjustments of the shims. Shims have to be removed and the track resurfaced as the frost leaves the ground in the spring. In certain extreme cases it has been necessary to dig out the frozen ballast and replace and resurface with clean, dry ballast during the winter season.

1. Corrective Action.

    - Subgrade stabilization as previously outlined; a summer operation.

    - Shimming track during the winter; possible slow orders placed over the shimmed track.

    - Excavation and replacement of frozen ballast materials with clean, dry ballast.

2. Cost Factors.

    - Material and labor to apply and remove shims.

    - Effect on train movements due to slow orders.

    - Derailments, if such occur.

- Labor and materials for any summertime stabilization work performed.

- Costs of extraordinary winter correction.

Ballast. Railroad ballast to be of good quality is a sound, hard, clean, heavy, sharpfaced material capable of being compacted into a homogeneous pervious mass. It is usually composed of crushed rock or crushed gravel. Placed on top of the subgrade, and surrounding the faces of ties to a level even with the top of ties in the ballast section, ballast holds the ties securely in place and provides a resilient cushion for the track structure, distributing the wheel loads uniformly over the roadbed. Forces transmitted downward by the wheel loads are concentrated with maximum intensity directly below the ties (or similar support), i.e., within the top 2 feet (±) below the bottom of the ties. For this reason the most select materials available for ballast are chosen. Ballast is, in fact, the best portion of the foundation, an extension of the subgrade. This becomes literally true in those instances, when the subgrade and ballast section are composed of the same material, i.e., cinders or pit run gravel. Actually these latter materials are not considered first quality main line ballast and are usually employed only on less important tracks.

a. Ballast Functions. The purposes of a ballast section are as follows:

1. To provide a firm bearing for the ties and distribute with diminished unit pressure the wheel loads uniformly to the subgrade beneath.

2. To provide proper drainage to the track structure.

3. To anchor the track and provide vertical, longitudinal, and lateral stability.

4. Retard vegetal growth.

5. Facilitate track work during periods of rainy weather.

The third function is especially important in providing restraint to the stresses present in continuous welded rail.

A ballast shoulder at the end of the tie, plus the friction between tie and ballast throughout the tie length, restrain the track from laterial movement. More data is needed on the amount of restrainst so provided. Restraint is also provided against thermal expansion and contraction of CWR, and is especially helpful in preventing sun kinks (both lateral and vertical) in CWR. Rail anchors grip the base of rail and bear against the ties. Ties are then re-

restrained from movement by the ballast. A restraining force of 800 to 1,000 lbs (per rail) per tie has been generally assumed. These limits may double when the ballast is frozen. Again, more definitive data on the amount of restraint is needed.

Desirable ballast characteristics include stability, drainability, hardness, toughness, durability, sterility, workability, availability, low price, and minimum overall economic cost. Availability and low price are usually the governing factors. Overall economic cost is difficult to evaluate and is too often ignored.

Ballast should have sufficient depth to distribute ties loads to within the bearing capacity of the subgrade soil. The latter may vary from 10 to 20 psi for weak soils to 50 to 60 psi for strong soils. If a weak subgrade soil is overstressed, some form of failure can ensue. If there is inadequate subgrade strength, a greater depth of ballast beneath the tie is necessary to absorb the load. A strong subgrade soil, well compacted and stable, can do with a lesser depth of ballast.

If subsidence is to occur, it should occur uniformly. A uniform transmission of pressure from the lower face of the tie to the subgrade is highly desirable. Experiments and theory indicate a depth of ballast equal to the center-to-center spacing of the crossties to be approximately the depth at which uniform distribution occurs. The subgrade should be strong enough, or the ballast deep enough, to sustain stresses at this depth plus a reasonable factor of safety. This distance need not be entirely taken with high grade material. Lower grades, such as gravel, sand, or cinders, may be used as a sub-ballast. Dr. A. N. Talbot and his Committee on Stresses in Track developed in 1920 an equation based on laboratory test data for the pressure intensity beneath the center line of a tie. It has the form:

$$P_c = \frac{16.8\ Pa}{h^{1.25}}$$

where $P_c$ is the pressure at a depth h inches, in psi, and $P_a$ is the average contact pressure of the tie on the ballast in psi.

b. Conditions for Stability. For a clean stable ballast material, stability arises from the degree of compaction given and from the characteristics of the material composing the ballast. The shearing strength of ballast as measured by the angle of internal friction is a direct indication of a material's stability, i.e., its resistance to deformation and its permanence. Internal friction and shearing strength are probably greatest for materials having a high Particle Index, particles with rough surface texture, irregular shape, and sharp edges. Such particles interlock tightly with adequate compaction (either pure vibration, pressure and concussion, or a combination) and give a high degree of permanency to the surface and line of the track. This is in contrast to smooth flat or rounded particles (like marbles) which have a low P.I. and shearing strength--washed gravels for example.

Grain size does not have the importance sometimes attributed to it. The P.I. properties are more significant. Weight and inertia of large particles may contribute some stability through shear weight, but it is more important that the material be well graded, that is, have a wide distribution of particle sizes so there are enough fine particles to "bed" the larger particles.

c. Effect of Wheel Loads. The reaction of ballast to repetitive loading directly influences track stability and life of line and surface. Well-tamped ballast has received maximum compaction under the rail, outside to the ends of ties, and for about 18 in. inside the rail. The middle third of the tie is not tamped, only filled in with loose ballast. As the wheels pass over the track, the ties, ballast, and subgrade compress slightly giving a track deflection of 0.10 to 0.40 in. (±). The greater the deflection the more movement and abrasion takes place among the ballast particles, the ties, and rail and fastenings.

Each passage of a set of wheels exerts a repetitive loading on the ballast and causes the tie to flex slightly, concave downward. Under elastic deformation, the track and ballast first compress and then rebound as the wheel moves on. When the process continues, however, plastic deformation sets in. The ballast immediately beneath the rail becomes slightly but permanently compressed. There may be an eventual loss of contact between the ballast and bottom of the tie. The tie must bend slightly to make contact and has a deflection that now becomes concave upward. There is a tendency for gauge widening. The process continues until the point of contact of tie with the ballast has shifted from under the rails toward the center of the tie which becomes balanced on a "wedge" of ballast. The track tends to rock. Such track is described as being "center bound". In extreme conditions the tie may break in the middle, although a surfacing operation should be performed long before this occurs.

Additionally, if there is no ballast shoulder or only a partial shoulder beyond the end of the tie, ballast may "unravel" from the tie end. Such a condition offers greatly reduced restraint to lateral movement. CWR track should have a shoulder of 6 to 12 in. beyond the ends of the ties at the base of the tie and within an inch (±), minimum, of the top of the tie.

d. Effects of Excess Moisture. Any material has been said to make a stable subgrade if it can be made dry and kept dry. Sometimes this is a very large order indeed. If fine-grained subgrade materials directly beneath the ballast are weak or become weakened by the presence of excess moisture, the pumping action of repetitively applied wheel loads will turn the soil materials into a soft plastic or slurry-like substance. The ballast particles are forced into the soft material by the wheel loads. There is a loss of surface (and line), ballast has to be added to replace that material forced into the subgrade, and local spotting, surfacing, or smoothing operations performed. The process continues repetitively. The ballast pocket being formed may fill with water, and may even fail, unless some form of sub-drainage is provided and stabilization is performed. Contact between the ballast and fine-grained subgrade soils may be prevented by inserting a filter blanket (a type of sub-ballast) between the two that will prevent fine particles and moisture from infiltrating upward into the ballast material.

Clean ballast does not stay clean. Abrasion alone creates a fine, powdery dust that, when wet, will clog the interstices of the ballast, destroying its drainage capabilities, providing a soil for growth of vegetation, and forming pockets in which moisture can accumulate, later to turn into ice lenses and create frost heaved track in some colder climes. Some ballasts abrade and weather (break through freezing and thawing cycles) more readily that others; hence a further need for care in the selection of ballast materials.

Ballast becomes fouled from other sources as well. Sand and dust are air-borne from nearby plowed fields. Leakage and dust from cars laden with coal, ore, agregates, or grain fall from passing trains. Fine-grained soils may ooze upward from weak subsoils. Excessive sanding from locomotives is probably the greatest source of fouling of ballast, particularly on mountain grades. These conditions are most severe when the accumulation of dirt permits moisture accumulation from rainfall, snowmelt, subsurface flow and seepage, and capillary rise from a too-high water table. Fouled wet ballast will contribute to ballast pocket formation earlier discussed, to the cementing action of abrasive dust from soft limestone ballast, frost heaving from expanding ice lenses, and general deterioration of ties and, eventually, of rails and fastenings.

Fouled ballast must be: (1) cleaned periodically with expensive ballast-cleaning equipment; (2) plowed from under the track, cleaned, and replaced; (3) plowed from under the track and replaced with new ballast; or (4) the track raised on new ballast and the old ballast retained as a sub-ballast. Other operations include disking to lay open the ballast shoulders at tie ends to permit escape of entrapped moisture and to dry out the ballast material. These are all obvious cost items.

When dirty ballast, low joints, and center binding combine with excess moisture, a condition known as pumping track or pumping joints is created. Under repetitive wheel load deflections, the dirty wet material is churned and splattered up and out at the ends of ties. Any adjacent clean ballast is fouled, tie fibers deteriorate more rapidly, and rail end batter is accelerated. There is always early loss of line and surface. Wet, dirty ballast is a major contributor to loss of track geometry--line, surface or cross-level, and superelevation. These must be periodically restored through spotting, smoothing, surfacing and reballasting operations. The frequency with which these operations take place for a given traffic loading is a function of subgrade support and type of ballast. Spotting operations may be required almost on a daily basis, smoothing operations at 2- to 3-year intervals, surfacing at 3- to 5-year cycles, and reballasting on an 8- to 10-year cycle. (It is understood that these are approximations.)

e. <u>Cost Factors</u>. To summarize, cost factors for ballast involve:

1. Cost of ballast materials--new and renewal purchase.

2. Ballast cleaning.

3. Roadbed stabilization.

4. Frost-heaved track, effects of slow orders, shimming, and later removal of shims and restoration of track surface and line.

5. Spotting, smoothing, surfacing, and reballasting programs.

6. Labor and machine costs incidental to the foregoing.

7. Foreshortened life of ties, rails, and fastenings.

OTHER TRACK MATERIAL

Other track material, usually referred to as OTM, enters into the cost of constructing and maintaining railroad track. There are two primary OTM categories: (1) track fastenings, including joint bars, bolts, spikes, tieplugs, tie plates, rail anchors, and miscellaneous small items, and (2) turnouts and crossings. The importance of these in construction and maintenance costs should not be underestimated.

Track Fastenings. The principal items in this group have been discussed in conjunction with rail and ties. A resume of each item will help to underscore the significance that such fastenings play in the fixed plant.

a. Joint Bars. A rail joint assembly has the function of providing continuity to a line of 39-foot rails and assuring a proper matching of the gauge corners and the running surfaces. The assembly should provide the same bending moment resistance as the rail itself. Theoretically, each bar bears half the load, but, because of eccentric loading of the rail and track irregularities, each bar must be capable of sustaining at least 60 percent of the load.

Early bars were mere straps of iron bolted against the web of the rail and called "fishplates". Later designs provided vertical support between the underside of the rail head and the top of the rail base with the back or rail side curved to fit the fillet curves at the juncture of head and base with the web. With light weight rails, sufficient space was not available between head and web to give the bar adequate stiffness and section modulus. Greater stiffness was secured by adding a toe to the bar at approximately right angles to the upright portion; hence the term "angle bar". Larger rails permit higher and stiffer bars thereby allowing the toe portion to be eliminated from the design. Bars are now nearly symetrical.

Headfree bars (accepted by AREA) establish support by frictional contact in the head-web and web-base fillets only.

Bars may be either 4-hole or 6-hole, 24 or 36 inches in length, respectively. Both designs give adequate support, but tests have shown the 6-hole bars to have a longer service life.

Special bars are used to provide proper surface and gauge corner alignment to rails of different section, weight, and dimensions. These are called offset or compromise bars. They are usually cast metal or forged rather than being made from rolled sections.

Insulated joints are used to isolate track circuits electrically. Insulating fibers are inserted between the bar and the rail, and an insulating material end post is placed between rail ends. Bolts pass through insulating thimbles or washers. Modern designs of bars have the insulating compound attached or the bars themselves are made of insulating material. This can create a problem in that loss of insulating property means loss of the bar as well.

In service, joint bars become worn on top immediately under the rail ends, and to a lesser extent, in the center along the bottom edge. Also the ends of the bars wear due to differential movement between rail ends under passage of wheels. The inner contact surfaces also become worn.

Joint bars experience bolt hole cracks and failures. These are becoming prevalent today where heavy cars run over light rails and bars, especially on branch lines. Cast offset bars crack more frequently than standard section rolled bars due to the inherent weakness of the cast bars.

Rail joints are normally renewed along with the rail during a rail relay in main line, except, of course, when CWR is laid. Branch lines and secondary mains using second hand rail may be laid with the same bars as released from main track. More often, wear on bars and/or rail is sufficient to require new or oversized reformed bars. A part of rail relay cost is that of applying joint bars and painting the rail ends with a lubricating compound before the bars are installed.

Joint bar maintenance begins soon after installation. Bolts are tightened initially to tensions of 20,000 to 30,000 lbs. to insure snug fit. They must be retightened two to three months later to provide a proper "set" and take up slack as mill scale is worn off the rail. Bolts require periodic tightening to maintain a minimum of 10,000 lbs. of tension in each bolt. Bars should receive inspection as required to note and replace broken bars and bolts or to tighten loose bolts.

Some railroads follow the practice of packing the space between the bar and the rail web with a lubricating compound to prevent bars from becoming corroded onto the rail. Sawdust or rubber mixed with graphite is sometimes used. The desirability of such a practice is a subject of debate.

A few railroads lay rail with "frozen" joints, i.e., the rail ends are butted together (instead of leaving a small space for expansion) and the bars are not only bolted but are also glued in place with an epoxy. The objective is to make the joint into a single unit, eliminating movement and avoiding rail end batter. Continuous welded rail strings are sometimes thus joined in the field.

Cost items for joint bars include:

- Initial installation (material and labor)
- Bolt tightening
- Inspection
- Replacement of bolts and bars
- Reforming of secondhand bars

b. Tie Plates. Tie plates protect the tie from the mechanical cutting of wood fibers by longitudinal movements of the rail, and from the crushing of wood fibers by heavy wheel loads. Additionally, the frictional resistance offered by the double shoulders heavy duty plates helps restrain rail movement, especially that of CWR, from expansion and contraction. The upraised shoulder assist in maintaining track gauge. Special plates perform similar functions under frogs, guard rails, and crossings--, where slightly larger plates are the standard. Under switch points, plates serve an additional purpose of assisting the sliding action of the switch rail as the switch is thrown.

While the entire wheel load is not normally carried by one tie, the possibility of such concentration is sufficiently great that adhering to the foregoing requirements will exceed normal loadings only by an amount that represents a prudent factor of safety.

Modern heavy tie plates, varying somewhat with the weight of rail in use, are in the range of 7-3/4 x 12 in., 7-3/4 x 13 in., and 8 x 14 in. computing to areas of 93, 101, and 112 sq. in. respectively. A few roads with very heavy tonnage and wheel loads are using 18 in. plates on the high side of 6° curves and sharper. The longer plates provide not only improved load distribution but also greater frictional area to resist lateral thrust and the tendancy for rail to overturn. Branch lines laid with older and lighter rail have plates that are far too small for some of the loads currently encountered today e.g. 7 x 9 in. (63 sq. in.) and 6 x 8-1/2 in. (51 sq. in.).

When plates are too small, the crushing load exceeds the compressive strenth of the tie fiber and drives the plate into the tie, causing a plate-cut tie. Lateral forces tend to tilt the rail outward with an overturning moment that causes the field side of the plate to dig more deeply into the tie. Gauge widens. To correct this condition a new smooth bearing surface must be adzed. This requires removal of the plates, adzing the tie, swabbing the adzed area with a protective coating, and respiking the plates and rail to the proper gauge. These procedures can often occur as part of a rail relay job, but regauging and/or replating may have to be performed as a separate undertaking when the rail canting is excessive and/or gauge variations exceed allowable limits. Modern plates are customarily designed with an eccentric placement of the load, i.e., the field side of the plate is longer than the gauge side, the better to resist overturning moments and to prevent gauge widening.

In the American design of track fastening, the plate and tie function as a unit. The rail is free to deflect upward and lift off the plate without raising the tie. If the tieplate, rail, and tie are secured as a unit, there is a tendency for upward deflections in the rail (occurring ahead of and behind the wheel) to cause the tie to rise up with the rail. European track thus differs from the American practice. European wheel loads are generally not heavy enough to cause such upward bending in the rail, especially with heavy concrete ties which tend to hold the assembly in place.

In this country plates are held to the ties by two or more rail-holding spikes and under certain conditions, two or more plate-holding spikes, i.e., spikes that hold only the plate to the tie. Screw spikes or occasionally studs are screwed or driven into pre-bored holes to serve as hold-down devices. Plates are sometimes attached to the ties at the treating plant or material yard before being taken to the job stie. Composition or rubber pads placed between the tie, and the plate are employed at selected locations as cushioned membranes or sealants. On curves, where lateral forces are greatest additional spikes are added to hold the rail against overturning.

Modern heavy duty tie plates will last many years in track if property installed, but that life can be shortened by improper installation. Plates that are not square with the rail will wear rapidly and unevenly in the shoulders. A rail not properly seated on the bearing surface, i.e., the edge of base resting on the shoulder, can cause a broken plate or rail. Care must be exersized to insure proper installation.

Tie plate costs include initial purchase of material and labor to install, plate renewal, tie adzing, creosoting adzed surfaces, and regauging. Plates have a potential long life; rails are frequently relaid on old plates, especially on secondary lines and branches.

c. Spikes. United States and Canadian railroads secure rails and plates with the so-called cut spike (referred to as "dog spikes" by the British). These are heavy, square nails with a chisel point, and an offset head. The common cross-sections are 9/16 or 5/8 in. sq. Corresponding lengths are 5-1/2 and 6 in. The spikes are driven through holes in the tie plates to hold rail and plate in correct position. Spikes prevent lateral movement and overturning of rails.

Screw spikes, extensively used in Europe, find only minor use in the United States as plate-holding spikes. Blunt-ended screws are turned into the wood, giving good hold-down capability. However, the contact area between thread and wood can become worn to such an extent that spikes may lose much of their holding power.

A variety of spring clips that perform a hold-down and anchoring action (especially with concrete ties), and numerous patented devices are available as alternatives to the cut spike. Nevertheless, the cut spike continues to be standard for the U.S. railroads.

d. Tie Plugs. When spikes are withdrawn, the spike hole is filled with a wooden plug. The plug keeps out moisture and insures a firm fit for a spike driven at the same location. Tie plugs are usually made from cedar or other woods, either treated or untreated with creosote or pentachlorophenol, 4-1/2 to 5-1/2 in. in length and approximately 5/8 in. square.

e. Rail Anchors. Rail anchors are used to transfer longitudinal forces in the rail to the tie and thence to the ballast. The anchor is driven onto the base of the rail where it remains relatively fixed due to a strong friction spring-like grip. The anchor bears against the face of the tie and thereby prevents longitudinal movement of the rail.

Much discussion has arisen over the proper anchoring pattern, particularly for CWR. For jointed track the AREA recommends 10 anchors per 39-foot rail for double track, 16 anchors per rail for single track where the ties have to be boxed, with an anchor on each side of the tie. A sufficient number of anchors should be applied to restrain the rail from running as a result of rail expansion and train traffic.

With CWR, the first six rails at each end of a string are usually box-anchored. For the rest of the string, every other tie (or every third tie) is so restrained.

Rail anchors must fit snugly against the tie. Anchors may move away from the tie as the rail expands or contracts. Anchors that permanently lose contact with the ties should be removed and reapplied in desired position. Rail anchors have a long service life. If there is an insufficient number of anchors installed or they are placed ineffectively,anchor life may be very short. Gauge, line and surface will suffer. New rail on main track is almost always relaid with new anchors. Secondhand anchors can usually be reused on secondhand rail with full serviceability, otherwise it becomes necessary to use a flat metal shim to give the necessary gripping action.

Turnouts and Crossings.

a. Turnouts. Turnouts are installed to permit divergence from one track to another. A variety of turnout designs is known, but the standard used throughout the world is the split switch. Diversion of an engine or car is accomplished by bringing a switch rail, sheared so as to permit a knife edge point, to bear against a stock rail in the track from which the diversion is to be initiated. The wheel flange is thus diverted away from the stock rail onto the route established by the switch point.

A turnout assembly consists of:

- The switch--comprising switch points (or switch rails), switch rods, throw mechanism, heel blocks, gauge plate and switch plates, and braces.

- Closure rails between the switch and frog.

- Switch ties.

The switch establishes diversion. The frog permits wheel flanges to cross opposing rails. The guard rail aligns the wheels and trucks and draws them away from the frog point to reduce frog point wear and throat batter and to guide the wheels along the intended path. The switch ties are selected in lengths that will support all rails between switch points and the heel of the frog.

Turnouts are designated by the amount of diversion as denoted by the frog angle and the frog number. The frog angle, F, is the amount of angular diversion or divergence in degrees. The frog number is the ratio of length to spread. The length is the measured distance along the heel leg from the point where unit spread occurs (in inches, feet, etc.) to the theoretical point of the frog. Frogs and turnouts are thus designated by number, e.g. ranging from Nos. 5 and 6 for short turnouts in yard and industry tracks to Nos. 8, 9, and 10 for branch line and principal yard design, and Nos. 10, 11, 12, 15, 16, 18, and 20 for main line tracks. The frog number is related to the frog angle by the equation:

$$N = 1/2 \ \text{Cot}\ F/2$$

Where $N$ = the frog number

$F$ = the frog angle in degrees

Because a frog that tapers to the theoretical point with a knife-edge thickness would be quickly battered and broken, the point is usually blunted or rounded off where it is 1/2 in. wide. This established the "1/2 inch" or actual point of frog located Np/12 ft. from the theoretical point where N is the frog number and p is the actual point width in inches.

The switch point rail is straight until bowed outward by the lateral pressure of wheels making a turnout move. It makes an angle with the stock rail known as the switch angle, s. The switch angle is customarily taken as $F/4 \pm$ based on empirical experience. It may be taken as something less, however, to avoid having a great many different length of switch point rails. In common use (AREA recommendations) are 11-foot points for Nos. 5 and 6 frogs, 16-1/2-foot points for Nos. 7, 8, 9, and 10 frogs, 22-foot points for Nos. 11, 12, and 14 frogs, and 30-foot points for use with Nos. 16, 18, and 20 frogs.

Frogs are of several types and designs. The bolted rigid frog is made up of ordinary rail sections, often heat treated, cut and sheared to proper shape and bolted together. Solid cast manganese frogs are just that, cast in one piece with high manganese steel. They are not in general use because excessive wear or failure at any point may be cause for scrapping the entire frog. Rail-bound frogs have rail sections for wings and legs but have a hard manganese-metal insert. Spring frogs have a pivotal wing that rests normally against the point to provide solid support for the movement of traffic over the point. It can be pushed open against a spring by traffic taking a diverging route.

Another important design feature of turnouts is length of lead--the distance from the point of switch to the point of frog. Actual designs differ, but as a rule of thumb the lead can be taken as eight times the frog number. Thus the lead for a No. 9 frog would be 72 ft. The AREA design length is 72 ft. 3-1/2 in.

A series of turnouts in a ladder track are used to connect the ladder or access track to the body tracks in a yard. A pair of turnouts connecting parallel tracks form a crossover used to go from one track to the other, usually in main or running tracks.

Speed through turnouts is limited by the length of rigid wheelbase of the locomotive or car and by the degree of turnout curve. Turnout speeds are roughly twice the frog number. Thus a No. 10 turnout would have an allowable speed of 20 mph.

Turnouts are expensive to purchase, install, and maintain. Considerable skill and experience are needed to adjust the throw of a switch so that the point fits snugly against its companion stock rail. If the fit is too tight, the point can become bent. If the point stands open, there is a possibility of a flange picking the point and taking the wrong route and derailing. In main lines, point detectors may be used to place an opposing signal in the "stop" position (or limit clearing a signal in an interlocking) if the point stands open in excess of an established tolerance.

Stock rails, switch points, frog points, and throats of frogs are subject to flow or lipping, chipping, and batter. A lipped stock rail is hazardous. It can prevent a proper fit of the point and lead to a picked switch or at least to point damage. Hence, grinding is a frequent maintenance task, usually performed with a portable one-man power grinding wheel. It is considered good practice to renew points and stock rails together if either has any appreciable wear. Otherwise there is the possibility of wheels being guided to the wrong path because of difference in height of the two rails, or the new member's service life might be prematurely shortened due to incomplete mating of point with stock rail.

Battered frog points and throats can be rebuilt in track by welding and/or grinding. The preferred practice is to change out the frog and send it to a reclamation plant. Railbound frogs can be unbolted and a new manganese point inserted, but this, too, is desirably a shop job.

Care must be exercised in positioning the guard rail. One set too close (gaugewise to the frog point) will permit excessive point batter. One too far from the point may engage the wheel flange and cause excessive side wear to the guard rail and throat wear in the frog.

The entire assembly must be kept in good line and surface to maintain riding qualities , to prevent excessive wear, and to reduce the tendency of derailments. A good grade of well-tamped ballast affording excellent drainage is a prerequisite for low turnout maintenance. Poor support (inadequate ballast or compaction, low or battered joints, or weak ties) under the heel of the switch (the place where the switch point rail is pivoted) can permit the point to rise above the running surface and receive battering and chipping impacts from wheels. Even more serious is that a potential source of derailment is created.

The switch requires adjustment from time to time. Switch plates must be kept clean and lubricated to permit free movement of the points. Switch plates are also termed "riser plates" because they raise the point rails progressively higher to insure the wheels keeping to the intended path in passing over the stock rail. Surfacing a turnout is difficult because of the long ties, the stiffness and weight of the structure, and the complexity of the rail pattern involved. Turnouts have traditionally been hand-tamped or tamped with individual power tools. Ordinary power tampers cannot be used through turnouts, but special power tamping machines have been developed to do this work efficiently.

The repair of run-through switches, especially in yards, is a frequent and costly item. Bent switch points, broken throw mechanisms, and even derailments are common consequences of run-through switches.

Another costly maintenance item involving turnouts is snow and ice removal. Formation of ice, from whatever cause, can bind up a switch from functioning. In early days and on present-day branch lines, reliance had to be placed on manual labor using shovels and brooms to keep switches operable. Later, snow-melting pots came into use. These had to be prepared in the fall, set under the switch points, kept filled, and lighted as need be at the approach of a storm. Still later, gas and electric switch heaters have come into common use. They can be turned on manually by local track forces, or automatically by remote control. The exhausts from airplane-type jet engines--rail-mounted--are used to blow switches clear of snow. Weedburners have also been pressed into service. Permanent installations of infrared beams placed vertically above the switch have proved useful. Even with such improved methods of snow and ice removal, much manual labor is still employed. In all instances with snow melting devices, a significant problem is disposal of the melted snow in freezing conditions--a problem involving drainage.

Flangeways in highway crossings also present a problem from ice build-up. Snow impacted and frozen in the flangeways can derail a train or, more often, a snowplow.

b. Crossings. Crossings are combinations of frogs used to cross one track over another. If the crossing is at right angles, four 90° frog corners of identical design can be used. If the angle is less than 90°, two different pairs of corners are needed--two end frogs with acute angles, and two side frogs with obtuse angles. Two types of frogs increase installation and maintenance costs. As often as not, the frog corners are all different and involve expensive fabrication and installation. Frogs may be bolted rigid or designed with manganese inserts.

While turnouts can be assembled or renewed piecemeal in track under traffic, crossings are usually set in track preassembled using a crane to lift and place the assembly. Because of the heavy impacts received, it is very important that crossings have excellent drainage, are placed on a firm foundation, and anchored with high-grade ballast. Ties should be long enough to provide adequate support for all parts of the assembly.

When the angle for the corners is very flat, the gap between frog points becomes excessively long--long enough to let the wheel drop down causing excessive impact and batter. This situation can be relieved by use of movable point frogs that close the flangeway for a through movement, then open on one side and close on the other for a movement in a different direction. Movable points can be hand thrown or mechanically operated.

Where it is desired to go from one track onto the track being crossed, a slip switch (single- or double-slip for one or two directions of access) is installed. A slip switch is a turnout installed with a short lead within the crossing, using the crossing end frogs for that portion of the turnout. The term "puzzle switch" is indicative of the complexity and difficulty in installation, adjusting, and maintaining this part of the track structure. Slip switches are usually installed--already assembled--by use of cranes. As with crossings, a good, solid, well-drained foundation under a slip switch is of prime consideration.

## TRACK GEOMETRY

As stated previously, the so-called permanent way is, in reality, anything but permanent. Great effort and expense are required to keep the track in a safe and usable condition. Lack of permanency stems from two sources: (1) wear and deterioration to the point of requiring replacement of the physical elements - ballast, ties, rails, OTM, and (2) disturbance of the normal geometrical relationship between those elements, i.e., loss of alignment, gauge, cross level or surface, superelevation and profile.

Significance. Loss of track geometry is of serious consequence. Primarily, it relates to the riding qualities and safety of the track. Rough track causes passenger discomfort, accelerates motive power and rolling stock deterioration through shock and impact, results in reduction of train speeds and increased running time through the need to impose slow orders, and, finally, rough track can be a source of expensive derailments.

Additionally, poor track geometry accelerates wear of the physical elements in the track structure. Wear or uneven track support increases rail end batter and joint wear. It can also increase the rate of tie deterioration. Irregular alignment will cause excessive wear on individual rails, as can irregularities in superelevation. Low spots in the track surface accentuate rock and roll and lateral thrust. Improperly secured ties can lead to sun kinks, especially in continuous welded rail.

As stated elsewhere in this publication, any part of the track that becomes worn or out of adjustment, or that is poorly supported, contributes to the deterioration of all other elements in the structure. Irregularities are cumulative at an accelerating rate.

Closely associated with track geometry costs is the frequency of maintenance cycles. Proper maintenance cycles reflect the amount of traffic, weather conditions, and the availability of ample manpower and equipment. Major surfacing cycles must be based on economic factors reflecting all of the above elements and must be balanced with spotting operations. Under the same traffic conditions, ties renewed on the basis of a 25-year life can be expected to offer a firmer support for the track and longer life of established geometry than renewals based on a 30-year life. One might expect line and surface to be more uniform at any one time if surfacing is performed every four years rather than every six years. Track will ride more smoothly if a spotting gang is kept constantly at work than if local irregularities are permitted to remain and develop until time for the next surfacing cycle. All of this is merely to say it is easier to keep up than to catch up. Obtaining a balance between economy and acceptable track performance is a difficult task and one that lies at the heart of any cost study.

Sources of Track Element Deterioration. The rate of deterioration in track geometry is a function of many factors. Chief among these are traffic tonnages, wheel loads, speed, train density, and type and length of trains operated. Track irregularities contribute to rail-end batter and may be an initiating factor for shelly and corrugated rail, also for wear on individual rails in curves and even on tangents.

Tie conditions and soundness of tie support are factors. The type of ballast, the amount placed in cribs and shoulders, its state of cleanliness and freedom from moisture, are also of great importance. The stability of subgrade soils affect ballast, ties, and, of course, line and surface. Their remaining in excellent condition is in large part dependent on drainage and climatic conditions.

Good track geometry requires tangents (straight track) with no "wiggles" or short or abrupt variations in the alignment. Long swings, however, usually have little or no adverse effect on ride qualities or life of track elements. Curves should be equipped with transition curves or spirals long enough to accommodate superelevation changes at rates of 1-1/6 to 1-1/4 in. per second for speeds through 79 mph, and 1-1/8 in. per second for speeds above 79 mph. The outside rail is superelevated above the inside rail by an amount based on the prevailing speed to permit equal load distribution on each rail (equilibrium speed). Superelevation $e_c = 0.0007DV^2$ inches where D is the degree of curve and e is the speed in mph. A safe comfortable ride can be had with $e_c = 0.0007DV^2 - 3$ in. of unbalanced superelevation to accommodate trains moving at other than equilibrium speeds.* Even this may not suffice on certain curves, so speeds must be reduced.

If a curve is in good alignment, the midordinates to a chord of fixed length should be uniform throughout the main body of the curve and decrease at a uniform rate from curve to tangent throughout the spirals. Departures from uniform midordinates and superelevation require adjustment: tamping and lining.

Cross level is the height relation of one rail to the other. The rails must be exactly the same elevation at any one spot. A track out of cross level causes rock and roll; and can, if considerably out of level, derail a train. The worst condition is that of warp, where a low spot exists on one rail and another low spot is in the opposite rail a car length away.

Sags and low spots may cause train handling difficulties and break-in-twos, setting the stage for derailments. Sinks and soft spots may require slow orders until good profile and surface can be restored.

Geometry Measurement. The measurement of track geometry is a challenging problem. It involves establishing standards of allowable departures from ideal conditions and ways of measuring these departures. United States railroads have sometimes been referred to as "1/2 inch" railroads. That is, allowable departures of 1/2 inch from the ideal are permitted in gauge, cross level, alignment, etc. per 39-foot rail length or some similarly common measure. Track for speeds in the 90+ mph range should probably be maintained to "1/4 inch" standards. It should be noted that requirements for smooth riding and engineering economy may or may not be more exacting than those for safety where the avoidance of an accident is the prime consideration.

In the past, track geometry measurement was largely a function of subjective observations of ride conditions, i.e., a track supervisor notebook in hand, on the rear of a passenger train. His findings would be correlated with reports of rough track from enginemen. The trained eye and day-by-day knowledge of the territory of the section foreman coupled with motor car and walking trips of assigned inspectors and supervisory personnel were also used. All of these added up to field observation and subjective judgment.

Maintenance cycles, established on a statistical basis, might be considered an improvement or at least an aid to the foregoing. But these,

* The advent of high-center-of-gravity cars has led to the necessity of limiting unbalance to 2 in. where the newer equipment is used in quantity.

too, have been based on judgment and/or on statistics that had meaning only in reflecting variations in budget allocations on individual railroads.

Within the past decade, several track inspection cars have been developed that measure variations in gauge, cross level, warp (track level measured diagonally), curve and tangent alignment, and profile. Departures from ideal conditions are recorded on a tape and, in some cars, compiled and accumulated by on-board computers. Lines drawn on the tape indicate acceptable limits of variation. Recordings falling outside those lines represent deficiencies requiring attention. A major advantage of the inspection car is the ability to measure the track under load. A track with apparent perfect geometry in an unloaded state may respond quite differently when a heavily loaded car or locomotive is superimposed, causing settlement and deflection of the track.

Maintenance Cost Factor. As noted earlier, good maintenance of track geometry begins with good subgrade and drainage design and construction, and continued attention to these factors. Tie renewals must proceed at a rational rate per mile per year. Proper attention to rail and rail joints and use of clean, stable ballast, cleaned and/or renewed at reasonable intervals are also important requirements for proper track geometry maintenance. Added to the foregoing are the spotting, smoothing, and surfacing operations conducted at periodic intervals to restore correct surface, profile and alignment to the track. These activities may be coordinated at times with tie, ballast, and rail renewals.

Spot work consists of restoring small, isolated, irregularities. The most common activity is tamping joint ties (or, with CWR, the place where joint ties used to be and which still retain a measure of instability). Section gangs, where used, perform this task along with lining bad kinks from curves and tangents and performing other housekeeping duties. Where section gangs are not used, a spotting gang is sometimes moved from place to place on a subdivision; but the work often is left undone until a smoothing gang is scheduled over the territory.

Smoothing gangs restore detail line and surface by raising and tightening on an out-of-face basis low spots in the track that are in reasonably good surface. Smoothing gangs may work on a 2- to 3-year cycle.

Surfacing gangs make 2- to 4-inch lifts out of face, the heaviest raises being made where low spots and sags have developed. New ballast must be added to fill in those places where existing ballast has been used for raising. The gang does not raise track as such, but only corrects those locations where the track has settled below grade. For the rest, they tighten the compaction under the ties where needed. The ultimate value of repeated smoothing and surfacing operations is in some question because of adverse effects on ballast materials and long-term track stability. The raises are not always high enough to permit forcing and compacting ballast particles far under the ties. Also, repeated working of the ballast causes breakage and abrasion. Dust and fines are formed that interfere with the free-draining qualities of the material.

Ballasting, and the surface and line work that go with it, are performed at intervals of 6 to 10 years on main line tracks, much less frequently on branch lines. The old ballast may be plowed to a depth of 2 to 4 in. beneath the tie (some roads plow only to the bottom of the tie) and replaced with new ballast, old ballast after cleaning, or a combination of both.

An alternative is to raise the track 4 to 6 in. on new ballast. This procedure is simple to perform and works well, especially where low grade ballast is used and where subgrade is wide enough to accommodate the new ballast section. It leads, however, to profile difficulties where there are many points of fixed elevation--bridges, overhead clearances, tunnels, railroad and major highway crossings at grade. Track settlement may not be sufficient to accommodate the raise so that a series of high and low spots (at the fixed locations) appear in the track profile.

EFFECTS OF MODERN EQUIPMENT ON TRACK MAINTENANCE COSTS

The loads and forces that act upon the track structure, with the exception of thermal effects--frost heaves and rail expansion and contraction--come from traffic loadings, i.e., from wheel loads that produce vertical, lateral, and longitudinal loads; also from train speeds and from the frequency and duration of load application and repetition. The track-train combination acts as a system with track support and reaction forming a response to train loadings and the track, in turn, affecting train movements.

Track maintenance costs arise from track instability and the effort expended to restore the desired track geometry; and from the renewal of track component material--ballast, ties, rails, and other track materials.

Modern equipment exemplified by long, hi-cube, high-center-of-gravity, roller bearing cars with wheel loads of 30,000 to 36,000 lbs. or more apply loads of all types with maximum intensity. Specific effects are summarized as follows:

Wheel Loads. The life of track surface and line, i.e., the duration of its degree of geometric conformation, is represented by the frequency of surfacing, smoothing, spot tamping, and ballasting operations that must be performed. It is a function of track flexibility or deflection under load. The more deflection, the shorter the life of track, of its geometry, and the service value of its components. Track deflection is a direct function of wheel loads, as expressed in the formula:

$$p = uy$$

Where $p$ = wheel load
$u$ = modulus of track stiffness
$y$ = track deflection

More specifically, taking rail into account (it cannot readily be separated from the support system).

$$Y = p/\sqrt[4]{64\ EI\ u^3}$$

Where E = modulus of rail elasticity = 30 x $10^6$
I = the moment of inertia of the rail - $in^4$
u = modulus of track elasticity in lbs. of load per inch of rail length per inch of track deflection

Thus, for a given rail and track modulus, the deflection (and life of track) is directly proportional to the wheel load and to the number of times the load is reapplied.

Prior to 1960, 26,000 lbs. was considered the maximum acceptable wheel load. This was based not on track considerations, which were generally ignored, but on the AAR Mechanical Division's limits on journal bearings. In light of the foregoing, the 35,000 lb. wheel load of a 100-ton car with 137 tons gross weight on rails represents a 35 percent increase in wheel load P. Therefore a similar reduction in the life of track line, surface, and component materials is a reasonable expectation.

Wheel loads also contribute to rail wear and defects. The heavier loads accelerate abrasion, and the increase in bending stress can shorten the life in bending (flexure). Corrugations, head checking and spalling, flaking, shelling, horizontal fissures, vertical split heads, and other defects in rails develop more rapidly under heavy wheel loads and the contact and shearing stresses resulting therefrom. For jointed track, battered rail ends add to car maintenance and require more surfacing of track (especially at the joint location), more rail-end welding to restore the battered surface, more frequent renewals of joint ties, and more joint bar renewals.

Experience has shown that rail life for 10 to 20 million gross tons annually under continual loadings of 34,500 lbs. per wheel have shortened the life of 132 lb. rail from the average of 600 mgt to half of that or less.

Breakage of rail and joint bars is a major problem with heavier wheel loads, especially on branch lines laid with light rails, where many heavy loads originate. Incipient cracks and failures, which would have remained stable for much longer periods under normal traffic, grow and fail soon after the introduction of the heavy loads.

Heavy wheel loads further provide a high lateral component that contributes to failure in track alignment, surface, and superelevation.

Three-Axle Trucks. Three-axle trucks, especially those under modern locomotives, are stiff and unyielding, a condition further exacerbated by the use of roller bearings that allow little or none of the lateral play that is found in the older "brass" journal box type bearing. The effect is especially noticeable on high-degree curves ($6^\circ$ or over), but even tangent track is experiencing wide gauge and plate-cutting of the ties. Double-spiking of curves, and the use of longer ties and tie plates (at least on high-degree curves), and more frequent need for regauging and lining are cost items associated with these trucks. It should be noted that an effort is under way to introduce a greater degree of elasticity into the frames of roller bearing cars.

Car Length/Height of Center of Gravity. Long cars have several adverse cost effects on track maintenance, especially when length is combined with high centers of gravit. Hi-cube box cars, high-capacity hopper cars, and loaded TOFC flat cars have centers of gravity up to 96 in. or more (above top of rail)--compared to conventional heights of 72 to 84 in. Tri-level rack cars and some ore cars are less of a problem.

The truck centers of 85-foot cars correspond roughly to the staggered joint spacings of 39-foot rails (39 ft. + 19-1/2 ft. = 58-1/2 ft.). Shorter truck centers for 65'± cars respond in similar manner to the 36-foot ± lengths of cropped rails often found in branch and yard tracks. If the joints are poorly maintained, i.e., battered and/or out of cross level, a rock and roll motion is imparted to the car, establishing a wide roll angle, which is accentuated by a high center of gravity. Such conditions often prevail on slow speed yard and branch line tracks. The intensity of rockings seems to maximize at speeds of 15 to 18 mph. Some railroads will no longer permit slow orders within this range to be placed on poor track.

Three principal cost effects are:

a. Cost of track repairs from derailments caused by rock and roll.

b. Accelerated deterioration of the track due to impact at low joints.

c. A need to maintain a higher level of maintenance than would be required for cars of conventional size.

Note that the use of continuous welded rail does not always eliminate the problem. The roadbed may retain uneven spots at the old joint locations which will not disappear until a major surfacing or ballasting operation is performed.

The excessive roll angle created by rock and roll, combined with the large dimensions of modern equipment, may also create clearance problems with the following:

a. Trains and cars on adjacent tracks, especially on high degree curves.

b. Tunnels and tunnel portals.

c. Bridges and bridge portals.

d. Other surroundings where clearance is for any reason close.

A second major problem is the high lateral forces long cars exert on the track, especially on the inside rail of high degree curves, particularly when a long car (85 ft. ±) is coupled to a short car (40 to 50 ft. ±). (The problem is somewhat alleviated by use of a longer than customary coupler shank on the long car.) The inward lateral forces create an overturning moment about the point of contact of the wheels with the inside rail. The outside wheels may rise off the rail on curves of 6° or more, and the load is concentrated on the inside rail. The general result is gauge widening, plate cutting, and distortion of alignment. The L/V ratio (the ratio of lateral to vertical forces of the wheel) may pass the overturning point and/or the inside rail may spread allowing wheels to drop inside the track or overturn. In either case, derailments occur and costly track repairs must be absorbed. The cost effects become:

a. Repairs to track following derailments.

b. Costs of more frequent adjustment of alignment, of regauging, and of maintaining (adzing and oiling) and renewing cross ties; also loss of rail life due to more wear on the inside rail.

Cars Without Center Sills. Certain car types, especially high capacity (100 tons +), long tank cars, are being built without the conventional center sill. The cylindrical tank shell serves to provide structural rigidity and to transmit forces of draft and buff between adjacent cars. Unfortunately, there may be so much rigidity that the car does not adjust readily to track curvature, changes in superelevation, or to track irregularities. The effect is similar to the relative flexibilities of a mailing tube vs. a shoe box when subjected to tortional forces. Without a center sill, coupling impacts in buff and draft are not transmitted in a "straight line" through the center sills at approximately the same height above the rail, but must be detoured upward from the couplers through the longitudinal centroid axis of the car with offset moment effects. The track costs attributed to these cars include:

a. Damage to track from more frequent derailments.

b. Accelerated wear on the track: wide gauge, plate cutting, distortion of surface and alignment, etc.

c. Need for a higher level of maintenance to accommodate the cars than would otherwise be required.

Train Length. Although not directly related to the size and loading of modern rolling stock, train length contributes to the cost of track maintenance as briefly described below:

a. Derailments, with attendant track damage, are the result of the train buckling during braking operations, pull-outs from sags over an undulating profile, or from general draft and buff effects, especially when one or more lightly loaded or empty cars are placed between heavily loaded cars.

b. The foregoing buckling forces may distort the track, leading to poor alignment and wide gauge, etc., even when derailment does not occur. A subsequent train might become derailed before the track condition is detected and corrected.

c. The resilient return of rail and track to the unloaded position between car truck passage and between the passage of trains does not occur as rapidly under long trains. By the time 2/3± of the train has passed, that resilient recovery has been delayed and retarded, leading in turn to a greater degree of surface distortion and the need for more frequent adjustment of line and surface. This effect becomes most pronounced with trains of more than 80 cars.

In summary, it can be seen that the roadway track structure is in reality a complex "system" when its behavior is viewed as a function of all of the elements and conditions described above. Determination of the costs associated with this system and the proper allocation of these costs to the services utilizing it constitutes the most significant task in roadway cost analysis for pricing purposes.

# V. ROADWAY COST ANALYSIS

## General

Roadway costs as considered in this project include all those associated with the provision, operation, and maintenance of railroad right-of-way, roadbed, track, structures, and all attendant facilities, systems, and equipment. These costs generally correspond (in theory) to those expenses reported in the ICC Road Property and Maintenance of Way and Structures Accounts (Accounts 1-54 and the 200 Series Accounts). It should be noted, however, that several cost items or categories currently reported in ICC 300 Series Accounts (Equipment) and 400 Series Accounts (Operations) are herein considered "roadway" costs. Examples of these would include maintenance of roadway work equipment and signal operations.

Expenses associated with the maintenance of railroad roadway approximated 18 percent of total railroad operating expenses in 1974. While the "variable" portion of roadway expenses was necessarily smaller, roadway costs clearly play an important role in the determination of railroad costs for rate-making purposes.

Accurate costing of railroad roadway gains even greater significance when rail-highway competition is considered. Nowhere in their operations do the cost structures encountered by the highway and rail mode operator differ more greatly than in the category of roadway expense. The highway user has roadway expenses that are 100 percent variable with his traffic volume, whereas the rail carrier's roadway expenses can sometimes approach 100 percent fixed. This fact obscures the inherent cost relationship between highway and rail, since the average roadway cost per unit of output necessarily changes with each change in volume of rail business.

Over the years, railroad roadway cost analyses have had as their primary objective(s) one or more of the following:

- Preparation and allocation of roadway capital and operating budgets.
- Analysis of investment and/or plant relocation alternatives.
- Calculation of avoidable costs for abandonment and/or service cost sharing proceedings before regulatory bodies and the courts.
- Calculation of participation in joint facility operations (joint track agreements, etc., - somewhat related to the above).
- Calculation of the cost effects of changing the operating demands placed on the roadway (e.g., running longer, faster, heavier trains; higher unit loadings, etc.).
- Development of unit variable costs for pricing purposes.

While the objective of this study is explicitly the development of methodologies and procedures for analyzing roadway costs for pricing purposes, there is no reason that such methodologies and procedures would be inapplicable to any or all of the other costing objectives. Required accuracy or level or detail and limitations upon data availability, integrity, and manageability may vary for individual cases within each of these objectives. However, the proper procedural approach should, given comparable levels of effort and detail, yield comparable results regardless of the costing objective.

Inherent in each of the above costing objectives and, in fact, the major thrust of most roadway costing work to date is the separation of Maintenance of Way and Structures costs into their fixed and variable components, i.e., the determination of those costs which are plant-type and size related vs. those which are traffic related. Since economic theory strongly supports the use of railroad variable costs as the rate "floor," it is the determination of these traffic-related (variable) roadway costs which is important to the accurate assessment of service profitability.

Roadway Costing Methodologies and Studies -- Past and Present

Over the years, analytical techniques ranging from rule-of-thumb "guesstimates" to relatively complex and sophisticated simulation models have been applied to the determination of roadway costs and cost function variability. Among the more notable pioneering efforts in the field were those of Wellington,[1] Louis Yager, Ford K. Edwards, and Poole.[2] Meyer et.al. provided a rather comprehensive treatment of roadway costs in The Economics of Competition in the Transportation Industries.[3] Roadway cost analysis has long been the subject of studies by Committee 16, "Economics of Plant, Equipment and Operations, as well as other committees of the American Railway Engineering Association (AREA) and by the Association of Railroads (AAR) through its cost research program. Industry roadway costing procedures for use in regulatory proceedings in the U.S. are prescribed in the Interstate Commerce Commission's Rail Form A Cost Finding Techniques.[4] Similar yet more detailed procedures are used in Canada under Canadian Transport Commission regulations. Several individual railroads in the U.S. have developed variations in the Form A procedures or, in some cases, completely unique roadway costing methods for their internal purposes. Other work has recently been conducted in conjunction with Penn Central-AMTRAK service cost-sharing proceedings.[5] Most of the aforementioned studies or methods are more completely described below. While each has been used, it may be said that none has proved entirely satisfactory for the economic analysis of roadway costs, on a service-specific basis, for pricing purposes.

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1. Wellington, A.M., The Economic Theory of the Location of Railways, 6th Edition, 1914, John Wiley & Sons, Inc.

2. Poole, Ernest C., Costs -- A Tool for Railroad Management, Simmons Boardman Publishing Corporation, New York, 1962.

3. Harvard University Press, Cambridge, Massachusetts, 1959.

4. Rail Carload Cost Scales by Territories for the Year 1970. Interstate Commerce Commission, Bureau of Accounts, Washington, D.C., May 1973.

5. A Methodology for Service Cost Sharing, De Leuw, Cather & Company in association with Haskins & Sells, December 1972.

Some of the more notable costing procedures used both in the past and under present-day conditions are described below. They include the work of A. M. Wellington, Yager, the AREA and AAR, as well as current methodologies of the ICC, and five Class I railroads.

A.M. Wellington's Method of Statistics, Records, and Engineering Judgment

Wellington sets forth his costing procedure incidental to the determination of train mile costs in The Economic Theory of the Location of Railways, 6th Edition, 1914, John Wiley & Sons, Inc., pp. 118-132, 199, 569, 319-321.

Wellington uses statistical averages of costs from various railroads to determine the cost for various maintenance of way items. He then determines how these costs vary with traffic, basing this estimate on experience and judgment. For example, in evaluating the estimated maintenance cost per train mile of 600° of central angle of curvature, he tabulated the following as the maintenance of way portion of train mile costs of curvature.

| Item | Average Cost of Item--Cents | Percent Added by 600° of Curvature | Cost Due To Curvature |
|---|---|---|---|
| Rail Renewals | 2.0 | 300 | 6.0 |
| Adjusting Track | 6.0 | 50 | 3.0 |
| Renewing Ties | 3.0 | 50 | 1.5 |
| Earthwork and Ballast | 4.0 | 50 | 2.0 |
| Yards and Structures | 8.0 | Unaffected | --- |

In determining the costs of rail per train mile, the procedure is the following:

a. Determine cost of one mile of steel rail.

b. Reduce this by its scrap value.

c. Divide the foregoing net cost by the number of trains the rail can carry. (He estimates this to be 300,000 to 500,000 based on records, experience, and judgment, to obtain 0.30 to 0.50 cents (3 to 5 mills) per train mile as the cost of the rail.)

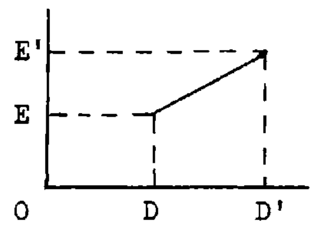
d. Rail life was further modified by considering increased wear due to curvature at a rate of 1/2 lb. per 10 million gross tons per degree of curve.

Ties are similarly handled, i.e., he sets up a tie life table of 9 years life in tangent track, 8 years for a $2^o$ curve, 7 years for a $6^o$ curve, 6 years for a $10^o$ curve, and 5 years for curves of $14^o$ to $16^o$.

The Yager Formula

The Yager Formula is an heuristic or "rule-of-thumb" model developed in the early 1920's by a subcommittee of AREA Committee 16. Louis Yager was the subcommittee chairman. The model is based on a technique first used in 1918 to study the level of railroad maintenance during the period of Federal control. These procedures in turn were based on procedures first suggested by Wellington. The so-called Yager Formula was approved for inclusion in the AREA manual in 1925.

The formula is fairly simple. The maintenance expense at a given traffic level can be determined by knowing the maintenance expense and traffic density for some base period. The new expense level is determined by multiplying the base period maintenance by 1.00 plus the product of the ratio of the increase in traffic to the base period traffic and the portion of maintenance expense affected by traffic.




$$E' = E\left(1 + \left(\frac{D' - D}{D}\right) A\right)$$

E' = maintenance expense for new period
E = maintenance expense for base period
D' = traffic density in new period in equated gross ton miles/ equated track mile
D = traffic density in base period in equated gross ton miles/ equated track mile
A = portion of maintenance of way and structures account affected by variations in traffic

Thus, a straight line relationship exists between increased use and maintenance expense. The slope of the line is determined by the portion of maintenance expense affected by traffic. The Yager group recognized that the relationship is probably not linear over the entire range. They limited the curve to traffic variations of 1/3 more or less than the base period.

The major weakness of the model is the determination of "A" in the formula. The explanation of the model as adopted by the 1936 AREA convention states, "The relation of maintenance expense to use is incapable of exact determination, but can be approximated by studying in detail properties as a whole and consists simply in separating maintenance charges not affected by use from those that are affected by use." Therefore each maintenance of way and structures account must be examined, and a rule-of-thumb estimate of the portion of each account affected by use must be made. The example shown in the AREA manual (based on ICC records of all Class I railways for the three year period ending June 30, 1917) indicated that expenses vary 33.13 percent with traffic. The Yager group suggested that each railroad modify this percentage to account for local conditions, especially tie costs. The model makes the unlikely assumption that similar maintenance methods and priorities will prevail over the test period.

The formula requires that traffic density be computed in Equated Gross Ton Miles/Equated Track Miles. To compute EGTM, the following weighting of ton miles was suggested:

| | |
|---|---|
| Freight car gross ton miles . . . . . . . . | 1.00 |
| Passenger car gross ton miles . . . . . . . | 1.00 |
| Freight locomotives gross ton miles . . . | 2.00 |
| Passenger locomotives gross ton miles . . | 3.00 |

The computation of equated track miles utilized a similar weighting scheme:

| | |
|---|---|
| 1 mile of first main track . . . . . . . . | 1.00 mile |
| 1 mile of each additional main track . . | 0.80 mile |
| 1 mile of sidings . . . . . . . . . . . . . | 0.50 mile |

The Yager Formula also provides allowances for increased investments. Investments are divided into two categories, way and structures. Increased investment in way will require additional maintenance costs in direct proportion to the equated track miles added, provided that traffic density remains equal. The user is cautioned, however, to correct for varying price levels and changes in maintenance practices.

Increased investments in structures is handled in a similar manner. The Yager group assumed that the cost of construction material and labor will vary from year to year at the same rate as the labor and material used in maintenance. Thus once a relationship between the reproduction cost of base period property and maintenance is determined, the additional maintenance costs for a given level of increased investment will be proportional to the increased reproduction value of the property. However, since additions to the property are unlikely to be distributed between classes of structures in the same proportion as they were during the base period, the relationship between reproduction value and maintenance should be estimated for each of the ICC primary accounts. The user is warned that some investments may have no effect upon maintenance and should be eliminated from consideration. Further, when an intensive betterment program is involved, the new facilities may differ greatly in their relationship to maintenance costs than the facilities they replaced. All costs used in this procedure must be adjusted for changes in price levels.

After some misleading projections, the model was deleted from the AREA Manual in 1955. Discussion by Committee 16 seemed to indicate that these errors were primarily due to misinterpretation of the requirements of the model than any other single reason. However, the determination of "A" offers a broad possibility for error.

Summary of AREA Involvement in MofW&S Costing (to 1971)[2]

Committee 16 of AREA (Economics of Plant, Equipment and Operations) has been concerned with track maintenance costs since 1936 when the Yager formula was accepted and included in the Manual after much investigation and consideration.

Continued use of the Yager formula brought out its deficiencies, especially its composite example that cited expense varied 1/3 with traffic; which by test, varied 1/2 with traffic. It was in 1948 that Committee 16 started revision of the basic formula. The experience of a heavy increase in traffic during and subsequent to World War II indicated that maintenance expense was affected to a greater extent by usage than by mileage. Four revisions of the formula were drafted and tested; none was found satisfactory. In June 1955, Committee 16 joined Committee 11--Engineering and Valuation Records (now Engineering Records and Property Accounting), to "Remove Yager Formula from Manual of Recommended Practice."

By this action Committees 11 and 16 were committed to the development of a new formula or model that could answer the basic needs, as follows:

a. A budget for management to allocate funds in future periods for men, material, and equipment to produce adequate track for definite usage.

b. Development and division of rates to yield adequate revenues.

c. Analysis of railroad networks and routes to determine means and methods for simplification and modification for merger and consolidation.

Using the above as a goal, Committee 16 proceeded to seek out all existing data, past research, and availability of new tools to further the development of a new model. Over the years several studies had been made on the economical size of rail for different traffic conditions. This introduced two principal considerations: (1) the characteristics of the traffic and (2) the characteristics of the track structure. Considering first the characteristics of the many types of rail car traffic, there are several that have an influence on track maintenance requirements. Some of these are: poorly lubricated center plate, tight side bearings, wheel condition, eccentric wheels, wheels with flat spots, ratio of loaded cars to empty cars, etc. However, it was felt that all of these would not have any great direct significance and would average out over a year's time; therefore, considering the track structure only was deemed necessary. Of course, a double track ore line or similar operation would be an exception to the above.

Collecting of data had been started and a considerable amount collected from twenty-six Class I railroads. Finally, in 1954, the Formula $Y=0.9995+0.3810X$ (X and Y are defined below), was developed using the data collected. Then in 1956, using the least squares method to analyze this data of twenty-six railroads collected over the 8-year period, the Formula $Y = 1.1876 + 0.4045X$ was developed. This then evolved further to other work being done; and in 1957 Committee 16 issued a progress report proposing a straight

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2. Extracted from AREA Proceedings, Volume 72 - Bulletin 635, 1971.

line formula to measure the changes in cost with the changes in traffic volume by:

$$Y = a + bx$$

Where $Y$ = maintenance per mile of track excluding depreciation and amortization
$x$ = density in total gross ton miles per mile of track, freight and passenger
$a$ = a constant to be determined, or the maintenance cost if no traffic
$b$ = the rate of change in maintenance cost with changes in traffic density

Following, in 1958, a regression analysis was made of the 1956 formulas which yielded the following:

| | |
|---|---|
| Not Weighted . . . . . . . . . . . . | $Y = 1.3190 + 0.4800X$ |
| Weighted on GTM . . . . . . . . . | $Y = 1.4229 + 0.4496X$ |
| Weighted on Miles Track . . . . . | $Y = 1.3009 + 0.4723X$ |

All of these formulas indicate a uniform constant plus a variable linear with density. However, cost studies being made found that a parabola fits an empirical cross-section and time-series data better than it does a straight line. Another aspect of this concept is given in the form of a parabolic curve as follows:

$$X = 0.48\ (Y + 1)^{1.7}$$

Again the subcommittee submitted a progress report which was included in AREA Bulletin, Vol. 64, No. 574, pages 113 through 115, and introduced a formula that had been derived from cost information collected over a period of years. The formula proposed was:

$$A = F\ (0.5 + D^{0.435})$$

Where $A$ = amount of annual track maintenance cost per mile of track
$F$ = constant based on labor costs, productivity and material prices
$D$ = traffic density in millions of gross tons per year

In 1961 funds were authorized by the AAR Board for a research project investigating maintenance of way costs. A contract was entered into for analysis and development of a cost formula. The problem of constructing an econometric model for track maintenance requirements was studied during the early years of the project. As a result of this investigation it was proposed to study 42 test sections on the C&O Railway. The work plan involved analysis of the relationship of track characteristics to maintenance costs. The C&O was to forward monthly expense reports of maintenance performed on the test sections. Each expense report used C&O's 151 classification roadway accounting system. The 42 one-mile test sections varied widely in their geographical location, traffic density, curvature, grade and track material. The original plan anticipated applying these figures to empirical formulas developed elsewhere around the world.

Analysis procedures deviated from the above plan. A preliminary report outlined the following research procedures. Each test mile was categorized according to the following characteristics: average weighted curvature, absolute average weighted gradient, gross tons/year, year the rail was laid, and rail weight. A computer program was then used to derive simple correlation coefficients between these characteristics and total maintenance expenditures for each test mile. AREA Committee 16 was very critical of the report and suggested that a number of changes be made. First it was felt that more than the five "independent" variables selected should have been studied. Train speed, unbalanced superelevation, moment of inertia of the rail and track modulus were some of the additional variables suggested for consideration. Secondly, members of the Committee felt the simple correlation analysis was not adequate; nonlinear aspects of the problem should have been considered. The averaging of curve and grade data was thought to obscure the real effect of these very important factors. The curvature is thought to have been determined simply by averaging the degrees of curvature. Finally, the lack of application of the data to any existing hypothesis was severely criticized.

Later some of the suggested changes were incorporated in a report entitled, "Preliminary Econometric Modeling for Track Maintenance," which was intended as a final report. A multiple regression computer program was applied to six track characteristics to correlate them to eight categories of maintenance costs. The six track characteristics considered were: curvature, gradient, traffic density, rail moment of inertia, train speed, and surfacing age. Transformations of these characteristics (i.e., characteristics and/or squared products of two characteristics) were also considered. The eight cost categories considered were tie costs, rail costs, surface and ballast costs, miscellaneous maintenance costs, other costs, a combination of tie rail and ballast costs, a combination of miscellaneous and other costs, and total maintenance costs. Committee 16 again criticized the report for the "independent" variables chosen, for the curvature and gradient computation procedure, for looking only at the first and second power of the track characteristics, and again for ignoring existing hypotheses. Finally, some of the test sections were found to have data missing for surfacing costs, but these sections were not eliminated from consideration. As a result, Committee 16 rejected the report.

Committee 16 hoped that the data already collected and work already done could provide a useful basis for further studies. Therefore, the research was continued. The AAR research center was given the task of estimating the missing maintenance costs.

The final consultants' report actually varied little from the previous reports. In this report 5 track characteristics--maximum train speed, traffic density, rail weight, weighted average curvature, and rail type (jointed or welded)--were related to maintenance expenditures for material, labor, and total costs. A "stepwise regression" computer program was used to obtain second order and multiplicative regression equations for the 5 track characteristics and their transformations. The expenditure figures were the expected annual expenses as determined by the AAR. Again, because the C&O data was not used to test existing hypotheses, the Committee rejected the report.

AAR Research Center Costing Procedure

In connection with the research conducted on maintenance of way costs on 42 one-mile test sections established on the C&O Railway, maintenance expenditures on these sections were to be reported on a monthly basis. After almost two years of data collection, it was discovered that some expenditures had gone unreported and others were reported incorrectly. The AAR Research Center was given the task of correcting the C&O data. A report of the methods used to correct this data was published in AREA Bulletin 615, September/October 1968, pp. 75-94, under the title "Preliminary Study of Maintenance of Way Costs."

The first step in determining the expected annual maintenance costs involved a personal inspection of each of the test miles by a member of the AAR staff. A local maintenance officer was contacted and data was obtained concerning work normally scheduled and performed on each test mile each year. Those operations which applied directly to track maintenance only were considered. Early in the study it was planned to separate regular or day-to-day maintenance from cyclic or periodic type maintenance. It was found, however, that in many cases the dividing line between the two types was hard to define and many operations could be interpreted as either type.

A number of different methods were used to estimate maintenance expense, each category of expense receiving a different treatment. Many of the estimates are simple rule-of-thumb judgments combined with some cost data. Others involve some rather sophisticated adjustments for track conditions. Each general type of estimating procedure will be reviewed along with the expenditure classes for which they are used.

The first general class was simply to set forth an annual cost for certain types of maintenance on a per-year basis. Costs were usually average costs reported in areas where the maintenance work was performed. This was used for estimating the costs of ditch cleaning and rail-end build-up.

The next level of sophistication was to establish costs for certain maintenance procedures and to use the field survey data to estimate the frequency of occurrence of this procedure. The method was applied to weed control costs where standard costs were developed for three types of weed control. The frequency of occurrence of each of the three types was based on the judgment of maintenance officers familiar with each track mile.

The next higher category of estimation took one track characteristic into account. This procedure was applied to ballast cleaning costs. It was assumed that the frequency of ballast cleaning would depend on traffic density. From one representative cost figure it was assumed that $5/mile/million gross tons would represent a realistic cost. A similar procedure was used for supervision costs. A base cost of $27 per track mile per year with no traffic was derived from the average foreman's salary and track miles supervised. The average costs for supervision were then plotted against traffic density. The expression $y = 27 + 19.8\,(x)^{0.3}$ was fitted by the least squares method.

For other estimates, two track characteristics were considered. A per-mile cost was computed for detector car rental, track patrols, and bolt tightening operations. The frequency of these operations was then estimated on the basis of train speed and annual traffic density for each test section. The cost of curve lubricator maintenance also used two characteristics but in a different manner. Two test lubricators showed an annual cost of $0.025 per MGT per degree of central angle.

Annual tie costs were also related to two track characteristics. Average tie life was related to horizontal alignment and traffic density. No mention was made of how the tie life was estimated. Tie costs were then simply the average number of ties required annually, multiplied by the costs of purchase, handling and placing each tie.

Rail costs were computed in a manner not too dissimilar from those used to determine tie costs. Annual costs are simply the cost of rail replacement divided by the life of the rail in years. Rail life is determined by the following formula:

$$T = 0.545 W D^{0.565}$$

Where
- T = rail life in MGT
- W = rail weight (lbs/yd)
- D = traffic density in MGT per year

Rail life and cost is further adjusted for the effects of curvature. Cost figures are further affected by assumptions made concerning the value of usable and scrap material released and the proportion of each.

The highest level of sophistication was reached in estimating the cost of ballast and labor costs of cyclic lining and surfacing. Estimates were made of the number of major and minor ballast lifts required in one cycle for traffic densities of 3, 5, 10, 15, 20, and 25 million gross tons annually. Secondly, an estimation of the number of years in the maintenance cycle was made for each traffic density yielding an annual cost for ballast and lining and surfacing labor. Next the estimates were adjusted to represent costs for a standard 115 lb. rail section and standard speed of 50 mph. The rail section adjustment is made by multiplying the annual cost estimate by the following ratio:

$$\frac{\sqrt{I_x}}{\sqrt{I_{115}}}$$

Where $I_x$ is the moment of inertia of the rail section corresponding to a given traffic density and $I_{115}$ is the moment of inertia of a 115 lb. rail. This is then further adjusted to 50 miles per hour train speed by multiplying annual cost estimates by 100 over the speed adjustment for the speed corresponding to a given traffic density. No mention was made of the assumed rail sections and train speed for each traffic density. The source of the data on the relative effects of speed is not cited either. The report does state, however, the speed factor assumes 100 percent cost at 50 mph for a traffic density of 20 MGT, and that the expression $y = 64e^{0.00937\,(x)}$ was developed by the method of averages. (y=$/Mile/Year).

The normalized costs for ballast and surfacing labor were then plotted. A regression curve was fitted to each figure by the method of least squares yielding the following results:

Ballast Material: $y = 60 + 25.47\,(x)^{0.586}$

Lining and Surfacing Labor: $y = 240 + 286\,(x)^{0.3}$

The actual estimates of costs for the test sections were then made by adjusting a cost from the above equations by the rail and speed characteristics on that section. The same methods were used to compensate for these characteristics as previously used in setting up standard costs.

## AAR Costing Work Under Phase II of the Railroad Cost Research Program[3]

a. Background. The AAR's cost research program had its inception in 1961. Phase I of the program led to a policy statement by a group of renowned economists regarding the relevant concepts in determining costs for ratemaking. The conclusions to which this entire panel subscribed are as follows:

1. In the determination of cost floors as a guide to the pricing of particular railroad services, or the services of any other transport mode, incremental costs of each particular service are the only relevant costs.

2. Rates for particular railroad services should be set at such amounts (subject to regulation of maximum rates and to legal rules against unjust discrimination) as will make the greatest total contribution to net income. Clearly, such maximizing rates would never fall below incremental costs.

3. Pricing which is not restricted by any minimum other than incremental cost can foster more efficient use of railroad resources and capacity and can therefore encourage lower costs and rates. This same principle applies to other modes of transportation.

4. The presence of large amounts of fixed costs and unused capacity in railroad facilities makes it especially important that railroad rates encourage a large volume of traffic.

5. Reduced rates which more than cover incremental costs and are designed by management to maximize contribution to net income do not constitute proof of predatory competition.

6. "Fully distributed" costs derived by apportioning unallocable costs have no economic significance in determining rate floors for particular railroad services. The application of such a criterion would arbitrarily force the railroads to maintain rates above the level which would yield maximum contribution to net income and would deprive them of much traffic for which they can compete economically. For similar reasons, restriction of railroad minimum rates according to the "full cost of the low-cost carrier" is economically unsound.[4]

With the completion of Phase I of the cost research program, the Board of Directors of the Association of American Railroads authorized the study described herein, designated as Phase II, to apply the principles of the Phase I statement in improving methods of railroad cost analysis.

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3. Extracted from A Guide to Railroad Cost Analysis, Bureau of Railway Economics, Association of American Railroads, Washington, D.C., December 1964.

4. Wm. J. Baumol and others, "The Role of Cost in the Minimum Pricing of Railroad Services," The Journal of Business of the University of Chicago, Vol. XXXV, No. 4, October 1962, pp. 357-366.

The paramount need was and is for specific analysis of railroad costs in relation to conpensatory rates. Accordingly, the primary purpose of the study was to foster cost analysis and estimation which could serve as a significant floor in the pricing of specific railroad services. Such analysis was focused on the extent to which costs vary as a consequence of changes in volume of output. It was not the purpose of the study to provide cost answers for general application to differing situations.

Maintenance of Way and Structures Costs -- A summary of the treatment of these costs and findings under Phase II of the cost study.

Since maintenance of way and structures accounts exhibit (as do many others also) different proportions of fixity and variability, they require analysis separately or by reasonably homogeneous groups. The cost characteristics may range from relatively high variability in some of the track accounts to almost total fixity, e.g., depreciation, retirement, and snow removal.

Statistical analysis indicated the following general conclusions: (1) fixed maintenance of way cost per mile of track is about the same regardless of the number of track miles owned, (2) use-related variable unit costs (per gross ton-mile and per switching locomotive-mile) are higher on the average for smaller roads (short mileage) than for larger roads, and (3) estimated incremental cost as computed for demonstration purposes reflects a much lower cost variability than densities, it was expected that variability would be even lower, i.e., more a function of time and natural conditions and less a function of traffic volume (use).

A study of cost variability was made limiting the analysis to joint track arrangements. This approach localized the area of study and thereby attempted to hold constant the effect of non-traffic factors such as weather, grades, etc. It was felt that use of this technique would permit more accurate estimation of the variability of maintenance costs with traffic volume.

The reader is directed to Chapter Five of footnoted Reference No. 3 on page V-12 for a complete description of the M/W&S costing work of the Phase II Cost Study.

## Current ICC Form A Maintenance of Way and Structures Costing Procedures

### a) The ICC Uniform System of Accounts

The currently prescribed system for accounting for railroad maintenance of Way Expenditures contains the following structure of accounts:

| Account No. | Account Description |
|---|---|
| 201 | Superintendance |
| 202 | Roadway Maintenance |
| 206 | Tunnels and Subways |
| 208 | Bridges, Trestles and Culverts |
| 210 | Elevated Structures |
| 212 | Ties |
| 214 | Rails |
| 216 | Other Track Material |
| 218 | Ballast |
| 220 | Track Laying and Surfacing |
| 221 | Fences, Snowsheds and Signs |
| 227 | Stations and Office Buildings |
| 229 | Roadway Buildings |
| 231 | Water Stations |
| 235 | Shops and Engine Houses |
| 237 | Grain Elevators |
| 239 | Storage Warehouses |
| 241 | Wharves and Docks |
| 243 | Coal and Ore Wharves |
| 244 | TOFC/COFC Terminals |
| 247 | Communication Systems |
| 249 | Signals and Interlockers |
| 253 | Power Plants |
| 257 | Power Transmission Systems |
| 265 | Miscellaneous Structures |
| 266 | Road Property; Depreciation |
| 267 | Retirements; Road |
| 269 | Roadway Machines |
| 270 | Dismantling Retired Road Property |
| 271 | Small Tools and Supplies |
| 272 | Removing Snow, Ice and Sand |
| 273 | Public Improvements; Maintenance |
| 274 | Inquiries to Persons |
| 275 | Insurance |
| 276 | Stationary and Printing |
| 277 | Employee Health and Welfare Benefits |
| 278 | Maintaining Joint Tracks,Yards and Other Facilities-Dr |
| 279 | Maintaining Joint Tracks,Yards and Other Facilities-Cr |
| 280 | Equalization; Way and Structures |
| 281 | Right-of-Way Expenses |
| 282 | Other Expenses |

In the replacement of track structure assets which include ties, rail, other track material, ballast and track laying and surfacing, retirement accounting is not observed but rather operating expenses are charged with the cost of labor and material used to replace the track structure in kind and allowed credit for value of secondhand or scap material recovered. In this process the asset accounts remain undisturbed, except improvements in the rail or track structure which cost more than direct replacement. In such case the asset account is debited with the value of upgraded improvement only and funds used in replacement are charged to operating expenses. Concurrently, when lighter rail is laid in replacement, the asset account is credited with the retirement representing the difference in cost from the heavier replaced rail.

Depreciation is computed by applying to the cost of the property such percentage rates as will distribute the service value by the straight-line method in equal annual charges during the estimated life of the property.

b. Costing Procedures

Results of the most recent ICC study of maintenance of way and structures costs are published in 1970 Carload Cost Scales, ICC Statement No. ICI-70.

Percent variability factors for maintenance of way and structures expenses were developed from second degree curvilinear regression equations of the form:

$$y = a + bx + cx^2$$

where:

$y$ = expense per mile of road

$x$ = output per mile of road

The percent variable factors were computed for a 5-year average of 1966-1970 Form A-reported expenses and outputs using the mean output level in the expression for elasticity:

$$\frac{b + 2c\bar{X}}{a/\bar{X} + b + c\bar{X}}$$

Maintenance of way expenses per mile of road for running tracks, Accounts 202 through 221, were found to be 57 percent variable (on average) with gross ton miles deflated by road miles. Percent variability ranged from 49 percent to 62 percent during the 5-year period. Coefficients of determination ($r^2$) ranged from .297 to .484.

Maintenance expenses of yard and way switching tracks, Accounts 202 through 221, were found to be 55 percent variable (on average) with yard and train switching hours. Percent variability ranged from 20 percent to 96 percent during the 5-year period. Coefficients of determination ranged from .682 to .818.

Superintendence and all other way and structures expenses, Accounts 201 and 227 through 279, as a group, were found to be 60 percent variable (on average) with tons of revenue freight. Percent variability ranged from 55 percent to 64 percent during the 5-year period. Coefficients of determination ranged from .665 to .716.

Although the analyses were conducted separately for large and small roads, results were grouped together for use in 1970 Carload Cost Scales, ICC Statement No. 1C1-70.

Current Roadway Costing Procedures of Five Railroads

The following are summary reports on reviews held during October 2 through 5, 1973, with the Costing groups of the Southern, Chessie System, Canadian National, and Canadian Pacific railroads. The purpose of these reviews was to ascertain the primary techniques currently in use in the industry to develop roadway costs for internal costing purposes. In addition, information was obtained regarding current efforts within these railroads to develop refined roadway costs. Also presented is a summary description of present roadway costing methods of the Southern Pacific Transportation Co. (prior to completion of this study).

- Southern Railroad. The Southern's current roadway costing procedures utilize the ICC Form A techniques in use prior to the Commission's June, 1973, revisions. Southern is currently evaluating the revised Form A procedures (percent variable factors) for application on the Southern system. It was indicated that the Southern's future cost system would eventually be tied to cost center data captured at the section gang level, with roadway maintenance expense ultimately related to train crew district to coincide with other train operating expenses. Maintenance cycles and related costs for new line segments would be developed from the extensive engineering and maintenance data base accumulated by Southern's program of track inspection and defect recording.

  The Southern is currently conducting a study to develop surfacing and tie renewal costs for main and branch lines by specific track segment.

These would eventually lead to substantial refinement of traffic-related costs for segments of different traffic densities on the Southern system.

- Chessie System. As a result of an engineering study to determine the economical rail section for use on the C&O/B&O system, relationships (based on empirical formulas and engineering judgment) between rail renewal, cyclic maintenance, and spot maintenance costs and economic service life of track were established for a range of "speed-tonnage" densities relevant to the C&O/B&O system. System average gradient and curve factors are used. Cost multipliers were developed to adjust incremental renewal costs for the effects of heavy axle loads. These were also the results of a special engineering study. For Chessie System internal costing purposes, only rail, tie, ballast, and other track material costs are considered variable with traffic.

  Internal branch line studies on the Chessie include all relevant opportunity costs. Required incremental roadway investment is not considered in the pricing of its services.

- Canadian National Railway. One or more of three costing techniques are used for proceedings before the CTC (Canadian Transport Commission). These are: (1) direct assignment, (2) direct analysis, and/or (3) regression analysis. Direct assignment is the process of assigning to an operation an amount of expense which corresponds to that recorded on an accounting document. Direct analysis is used when the expense under study is or is assumed to be 100 percent variable with some service unit or units. Regression analysis is used when an item of expense is not known to be 100 percent variable with the service units and/or when the item of expense is related to more than one variable. The data used are the expenses and service units for each of the 18 operating areas or 5 regions of the CN system. The regression method consists essentially of observing actual variations in traffic and concomitant variations in expenses to determine whether variations in expense accompany variations in traffic with such consistency that they cannot be ascribed to chance. If so, an equation relating expenses to service units is developed based on the actual experience contained in historical data.

  Roadway maintenance unit costs are developed by regressing the sum of expense dollars contained in the track, tie, rail, OTM, ballast, roadway buildings, roadway machines, small tools, public improvements, and right-of-way expense accounts on the independent variables of miles of road, gross ton miles, yard and train switching miles, and gradient index. Five-year data are used in the development of regression models.

  The gradient index is developed as follows:

  > The gradient index is used as a substitute for curvature and ruling grade until an index for the latter can be obtained. It is developed as follows: the operating timetables show, for each direction of each subdivision, the maximum tonnage which can be hauled by an 1800 H.P. locomotive. The lower tonnage in either direction serves as a rating of the gradient characteristics of the subdivision, in the sense that

it is high when the maximum grade on the subdivision is low, and low when the maximum grade on the subdivision is high. For each area, the reciprocal of the weighted average of all subdivision ratings is calculated. This yields a variable which increases with grade.

The coefficient of the gross ton-mile variable is not applied directly to locomotive and caboose gross ton-miles, but is converted to costs per locomotive-mile and a cost per caboose-mile, on the basis of the average weight of the equipment.

Both the road mileage and gradient factor are considered "fixed" in the regression equation for each region, and hence such expenses are treated as plant-related, and not traffic-related. Thus the CN/CP costing procedure (see below) is essentially a two-variable correlation based on normalized regional expense data. The effects of speed, axle loads, and unit trains upon roadway maintenance costs have not been quantified by CN at this time. Maintenance of tunnels, bridges, fences, snowsheds, and several other facilities are not considered in variable cost calculations.

In all actual loss calculations relative to branch line abandonment and subsidy applications, the on-line portion of roadway maintenance expenses is obtained by direct assignment.

With respect to allocations between capital and expense monies, procedures differ from those prescribed by the Interstate Commerce Commission. For example, all rail and ties laid in excess of 1,000 feet are capitalized on Canadian lines. On the theory that every line is susceptible to an increase in traffic, CN believes that costing should be conducted in anticipation of the necessity to increase capacity, e.g., the marginal cost of road property investment above a minimum line should be charged to the traffic on that line.

- Canadian Pacific Railway. CP roadway costing procedures are essentially identical to those of CN, as CP is also under CTC jurisdiction. No distinction is made between yard and running track maintenance expense for those procedures. Roadway variable costs are calculated on a system basis only, with no attempt made to utilize division or subdivision costs for internal pricing purposes. Under CTC procedures, the cost of capital appropriate to CP is also applied to CN in matters before the Commission.

- Roadway Costing Procedures of the Bureau of Transportation Research, Southern Pacific Transportation Company

  Overview. Most rail cost calculations made by the Bureau of Transportation Research are variable costs. Thus, for decision-making purposes, the attempt is made to identify only the change in total cost which would result from a particular change in traffic volume.

Specifically, the so-called "directly assigned and unit cost" method is used to determine variable costs. This method has six categories of costs:

(a) Directly assigned to engine districts (train and enginemen, road fuel).

(b) Directly assigned on a car count, car mile, or car day basis (car rents, joint terminals).

(c) Directly assigned on a shipment basis (loss and damage, protective service, LCL service).

(d) Payroll additives assigned on a labor basis (health and welfare, payroll taxes, injuries to employees).

(e) MofW&S, MofE, and Transportation expenses assigned on a unit cost basis.

(f) Overhead expenses assigned on a percent additive basis (traffic, general, use taxes, etc.).

Train and enginemen wages, fuel, etc. are associated with or "directly assigned" to the specific engine districts over which traffic under study moves. Certain other costs, such as rents of privately-owned freight cars, joint yard expenses, and loss and damage are also directly assigned to the particular traffic movement under study. In special cases, such as unit train studies or freight car studies, a greater amount of direct assignment is used than in ordinary traffic studies.

The bulk of the remaining variable costs associated with a traffic movement fall into a category called unit costs. These are costs which can only be allocated at the system level. The allocation is made on a unit basis in accordance with the amount of work done. The service units are the following: gross ton miles, locomotive ton miles, gallons of fuel consumed, yard or train switching hours, train miles, car miles, and carloads.

The final group of variable costs can neither be directly assigned nor allocated to service units. These include traffic and general expense, use taxes, and haul of company materials. These costs are applied to a specific traffic movement as a percentage markup on the other variable costs.

SPT freight expense accounts and service units, as reported to the Interstate Commerce Commission, form the basis for the BTR cost calculations. Direct expenses billed to Amtrak are not contained in SPT accounts, and uncompensated Amtrak expenses are not charged to freight service. Suburban service expenses are based on specially maintained records and are not allocations based on ICC Rules of Separation. Suburban service expenses are deducted from total expenses to obtain freight service expenses.

Although total variable expenses in the BTR's Freight Formula are about 78 percent of total operating expenses, taxes, and rents, the application of these variable expenses to individual traffic movements often results in a lower variability ratio.

Maintenance of Way and Structures Costing. Given this overview of current BTR costing procedures, the following discussion will describe the **current derivation of the M/W&S cost element, the method by which M/W&S costs are allocated to appropriate work or traffic units, and the theoretical rationale underlying the procedures.**

Total, yearly, direct MofW&S expenses for freight service for SPT Co. (including NWP) are derived by subtracting the following indirect expenses from the total charges to Account 200: TOFC packer and crane repairs, road property depreciation, retirements, dismantling of retired property, public projects, injuries to persons, health and welfare, joint yards, extraordinary damages, and storm damage. The total direct freight service expenses thus determined are then apportioned to (1) running tracks, (2) yard and way tracks, and (3) all other expenses (structures, signals, etc.). Each of these three categories is assigned a percent variability factor representing the degree to which each expense category is felt to vary with a measure of traffic volume. Running track expenses are considered to be 80 percent variable with traffic volume which is expressed in gross ton miles. Yard and way tracks are considered to be 20 percent variable with yard and train switching hours. "All other" expenses are considered to be 20 percent variable, and are then apportioned to road and yard on the basis of the track accounts.

Variable MofW&S expenses for running tracks are allocated to traffic on a gross ton mile basis. Variable MofW&S expenses for yard and way tracks are allocated to traffic on a yard and train switching hour basis. Gross ton miles and yard and train switching hour statistics are taken from Form OS-A reports. The resulting unit costs are used on components of linehaul gross ton mile costs and yard switching hour costs.

Basic to the development of variable MofW&S costing is the assumption that some portion of total direct MofW&S expenses vary with (measures of) traffic volume. Until 1971, the percent variability of MofW&S expenses for running track was determined by regression the total of such expenses (per mile of track) for 23 Class I railroads (including SPT) on total gross ton miles (per mile of track) and total miles of track operated for these roads. The level of variability of SPT MofW&S running track expenses was taken from the resulting regression line based on the SPT level of operation (GTM) for a given year. Percent variability of structures, signals, and all other expenses was assumed to be the same as for running tracks. Percent variability of yard and way tracks was estimated at 20 percent based on a 1954 regression analysis using yard and train switching hours.

Since 1971 the variable portion of MofW&S running track expenses has been estimated based on judgment resulting from a combination of regression studies and joint track studies, while the variable portion of "all other expenses" is based on the conclusion that it cannot be more variable than yard track maintenance.

Underlying the application of these variability factors (admittedly inadequate for any purposes other than correlation of system average of MofW&S costs with traffic factors) has been the problem of relating accounting data to specific units of rail service output and their respective roadway maintenance expenses.

Service Units for Individual Variable Cost Calculations. The calculation of an estimated variable cost requires the determination of those service units (or work units as they are sometimes called) associated with the carload movement and which represent the same service units used in the calculation of the formula unit costs. Determination of the proper service units requires knowledge of the particular operating pattern to be followed. Service units are items such as gross ton miles, train miles, car miles, gallons of fuel consumption, and yard and train switching hours.

There are two types of gross ton miles (GTM's), total and trailing. The two differ in that total gross ton miles include the locomotive and caboose, while trailing GTM's include only cars and their contents. Total GTM's are used in connection with the maintenance of way MGTM unit cost and fuel costs. Trailing GTM's are used as a divisor in connection with composite linehaul MGTM costs, so that revenue carloads will reflect total train costs.

Ton miles are a function of weight and distance whether a train or a single car is involved. In the case of the movement of a car, the empty return must be considered as well as the loaded move.

The unit weights of locomotives and cars are available through various lists provided by the Mechanical Department, AAR and ICC. The weights of the car's lading come from actual waybill information, Traffic Department projection, or commodity density tables.

Switching for specific moves is divided between origination, intermediate yard, en route, and destination switching. The time estimates for these functions are based on BTR switching studies of varying complexity and sophistication. These studies usually covered one week of activity in a particular terminal. The study procedure distributes all the engine time during that week to elements constituting the various types of moves a switch engine can make; for example, the total yard engine time during the sample week spent classifying cars is determined. Other elements or "building blocks" include transfer moves, industry switching, interchanges, weighing cars, switching to repair tracks, etc. The car movements through the yard during the sample week, based on terminal records, are converted into element counts and divided into the corresponding time for each element. The resultant times per element are combined into complete car cycles through the yard. Similar studies, combined with judgment, are used to develop estimates of the remaining components of yard and train switching hours.

The previously established unit MofW&S costs ($/GTM and $/switching hour) are then applied to the estimated service units, determining the MofW&S contribution to the total variable cost of a specific carload or train movement.

Review of an Internal Study of the Canadian Pacific Railway to Determine Roadway Costs for Budgetary Purposes

The purpose of this review was to investigate the costing methodology and procedures developed and employed by the CP study team during a recently completed 18-month study of roadway costs on the Canadian Pacific system.

The CP study was initiated to accomplish three basic objectives: (1) to determine an adequate level of roadway expenditure to meet current and future traffic and operating requirements, (2) to recommend the required allocation of total system expenditures by operating region, and (3) to determine the effect(s) of capital investment on roadway maintenance expense. The study proceeded under the two basic precepts that roadway expenditures can be predicted by considering levels of traffic and other cost-causal factors and that capital and maintenance expenditures must be considered jointly.

Because of the historic dollar significance of the track labor account, the budgetary system was initially developed for a track labor account "model". For this and subsequent expenditure models, four basic tasks were accomplished: (1) significant expenses were identified, (2) similar work areas (roadway segments) were classified according to their basic physical and operating characteristics, (3) work activities were categorized relating to the significant expense items previously identified, and (4) the frequency and cost of work activities (maintenance functions) was estimated based on the judgment of CP engineers as to "what should be done" for a given classification of roadway. The CP system was broken into four classifications requiring differing levels of maintenance. These classifications were developed by considering four basic associated factors or characteristics: (1) gross tons handled, (2) train speed, (3) physical characteristics of the track, and (4) service characteristics of the traffic. The resulting classifications to be applied to system lines for cost estimating purposes were designated in equated tonnage terms, i.e., CP Class I lines are all those with a minimum of 12 MGT/yr ± 2 MGT/yr, depending on the "effect" of the remaining factors. Class III lines are those with a maximum of 2 MGT/yr ± 1 MGT/yr, depending on the extent of passenger operations. Class II lines are those with tonnages falling in a range between those mentioned. Class IV lines are those lines with minimum traffic--those which are candidates for abandonment. An inventory of system lines was conducted to develop the necessary criteria for cost estimates by CP engineers.

Cross sectional analyses of the cost estimate responses were performed; the results were reviewed with regional engineers; and final adjustments were made as necessary. This process, with some variations, was carried out for the remainder of accounts (track material, buildings, bridges, signals, snow removal, joint facilities, etc.). As a result, a system measure of what the economic roadway costs "should be" was inductively developed essentially independent of historic accounting data.

Overall results pinpointed regional deficiencies, or in some cases, overexpenditures for each major maintenance and renewal function. A responsibility accounting system is currently being designed to capture roadway expenditures in a manner which will allow future comparisons with the judgemental cost estimates developed by the current study.

The overall results of the budgetary study will eventually be used to develop maintenance programs more closely tailored to regional operating plans and will serve as the basis for refined internal costing procedures.

The basic techniques applicable to the analysis of roadway costs together with the complexities inherent in roadway cost analysis are described below.

Cost Analysis Techniques. Without question, statistical analysis has been the most widely utilized analytical technique applied to the determination of roadway cost functions. Such analysis has almost always taken the form of recorded measures of expense regressed on one or more recorded measures of service output. In addition, such techniques are applied at the "micro level," in the development of engineering production functions which attempt to describe the physical behavior of various components of the roadway based on empirical research data. Setting aside, for the moment, the myriad of problems associated with statistical analysis of railroad roadway costs, there are several intrinsic limitations to statistical analyses in general which should be mentioned.

Statistical cross sectional cost analyses (relationships determined from a number of observations at a fixed point in time) do not reflect the behavior of firms under long-run equilibrium conditions. In addition, costs which are currently observed have been biased by past decisions, policies, and operating conditions. Conversely, time series analyses (relationships determined by observation of a single operating entity over a specified span of time) yield results which combine the effects of the independent variables with those of policy changes, improved technology, price changes, or other "structural" modifications in a manner which often defies further separation.

In addition to these basic pitfalls in statistical anlyses, there exists the problem of specifying the form of a cost function before the function can be estimated. In many cases, the data will not predetermine which form is correct. Given the sensitivity of estimated variable costs to the form of the equation or cost function, this may prove to be a serious drawback in the use of statistical techniques in cost analysis.

In summary, the function estimated by statistical means is likely to be quite aggregate in nature and a description of current operations. Where no structural change is involved, and where there is no need for really detailed costs, it has major advantages. In addition, it provides estimates of indirect costs, those, for instance, which are not actually a part of the provision, operation, or maintenance of the roadway per se.

A second widely used costing technique involves the derivation of cost functions from engineering production functions. The data on which these production functions are based consist either of technological information from scientific theory or from empirical analyses of controlled experiments. This represents the so-called "engineering" approach to costing.

There are several advantages to estimating production functions from engineering data and principles. The range of applicability of the function is known in advance; it is not subject, in general, to data limitations. Unlike the information used in cross-section and time series statistical analyses, engineering data may be available over a wide range of observations. Moreover, the results of production investigations do not depend on the pattern of plant investment. For these reasons, engineering production functions conform more closely to the production functions of economic theory. The cost functions derived from such production functions also better approximate their theoretical counterparts than do statistical cost functions.

These engineering cost functions also have disadvantages. Since they are theoretical, there is no assurance they could be realized in an actual operation. Other difficulties also arise for the estimation of the production function. This function is typically represented as the sum of functions describing individual processes. Unless these processes are additive and independent, estimation may be extremely difficult. This problem can be avoided, however, if interaction effects are dealt with in the specification of individual process functions. In addition, it may be difficult or impossible to include non-technical processes, which result in indirect costs, in an engineering production function.

A third method of deriving or estimating cost functions involves the use of what some may term "guesswork" and others "informed judgment." Where there is an immediate need to determine cost functions in the absence of existing statistical analyses or empirical data, this may indeed be the only means to include many items or categories of relevant cost. This "judgment methodology" may vary widely in credibility for a number of rather obvious reasons. However, if judgments are thoughtfully formed, reviewed and perhaps modified by wider domains of expertise, and then tested to the extent possible against actual experience or "field conditions," they may become valuable analytical tools. No single costing technique may be applicable to a broad cost area, such as railroad roadway costs. However, the techniques described above may be used in combination to develop the total roadway cost function if the inherent strengths and limitations of each are clearly realized, if all relevant costs are included in the analysis, and if each relevant cost is included only once.

Complexities and Constraints in Roadway Cost Analysis

Using Reported Expenses and Output Units in the Development of Roadway Costs for Pricing Purposes. It is generally conventional railroad accounting practice to maintain the accounts of a company in total for reporting in the ICC's Form A annual reports. Expenses recorded in ICC accounts are aggregated over large areas within which the factors influencing roadway costs may vary substantially. The individual ICC accounts themselves represent such broad areas of roadway expense that almost any effort to determine specific service, work activity, or functional costs therefrom is futile, especially because they are also rarely refined to divisions or districts below the system level. Measures of service output, such as gross ton-miles or switching hours are also aggregated under reporting procedures in a similar manner. Thus, calculated results for any procedure, either statistical or arithmetical, which utilize the expense and output data as reported in Form A reports, can at best reflect only national or system average unit expenses for broad categories of roadway maintenance and operation. This problem is further compounded by the flexibility which exists in the manner in which expenses are recorded. The treatment of various expenses, i.e., as to which accounts are affected by various types of expenditures, may differ from railroad to railroad and even within individual railroads at different periods of time.

While the conditions described above represent significant obstacles to service-specific roadway cost analysis using reported expenses, there are other problems with such data.

Any meaningful analysis relating cause to effect requires that the data measuring cause and effect are matched with reasonable accuracy. While the expenditures recorded in the accounts are a fair reflection of the monies actually spent for maintenance during a given year, there may be some question that the traffic factor service unit figures reported for the year reasonably reflect the levels of traffic which caused the traffic-related maintenance expenditure. This occurs because a substantial portion of roadway expenses are incurred on a cyclical program basis and the tonnage, for example, which caused the traffic-related expenses may have been moving over the road for long periods of time. Where substantial year to year changes in traffic volume are experienced, the use of a year's maintenance expense and its measure of traffic volume raises the probability that the data are not matched. This problem can be reduced to some extent by averaging data for a term of years. However, if there were not only normal cyclical fluctuations of traffic but also secular increases or decreases in volume, averaging of several years's data probably does not correct for errors introduced by the long-term trend.

Finally, although railroad accounting systems can and should be devised to record roadway expenses on a basis more applicable to service-specific costing, such systems can only, at best, provide a more precise and useful record of monies actually spent. However, the increasing budgetary constraints facing railroads today have rendered the operating expenses recorded for deferrable roadway investment and maintenance functions inadequate for cost analysis purposes. The notion that this condition can be taken into account by averaging expense data over some extended period of time is becoming less and less true as these deferrals continue. American railroads are today often forced to deplete their fixed plant resources in order to reduce expenses, and in some cases in order to merely survive. The true economic costs associated with service-related deterioration of roadway may thus not be visible in the railroad charts of account. A report on national rail system deficiencies in annual track and roadway renewals has estimated that an additional annual expenditure of nearly $270 million for rail and tie programs alone will be needed to help restore the nation's rail roadway system to a level adequate for current and forecast demands.[6] A more recent study conducted for the Federal Railroad Administration resulted in an estimate of nearly $5.3 billion in track structures and signal maintenance deferrals for 25 selected Class I railroads.[7] When the compound effect of a deficiency of this magnitude is considered, there would appear to be little doubt that an economic analysis of rail roadway for pricing purposes which relies totally on records of current and past expenditures may fall far short of a determination of true costs.

Inadequate Empirical Data and Other Scientific Information. As stated previously, there is less research-supported data describing the physical and economic behavior of railroad roadway under the wide spectrum of day-to-day operating conditions than exists for the "fixed plant" of other transport modes. Important research is underway or planned in the areas

6. Decade of Decision, A Report on Railroad Track and Roadway. Task Force II, Labor and Management Committee, Federal Railroad Administration, U.S. Department of Transportation, April 1971.

7. Maintenance of Way Studies. T. K. Dyer and Associates, Lexington, Mass. 1975.

of vehicle-track interaction and roadbed stability which should lend considerable refinement to the methodologies currently used to estimate the cost effects of these factors. While the importance of this and other research cannot be emphasized too strongly, it must be realized that there are, and will continue to be, roadway cost factors the analysis of which must proceed without even the scientific theory necessary to derive hypothetical relationships. If the cost analyst is to quantify the effects of these factors, some of which include climatic/atmospheric conditions, the areal nature (urban, suburban, or rural) of the roadway in question, traffic interference with roadway maintenance programs, and the accelerating effects of deferred maintenance on roadway cost, they must either be set to zero or estimated out through the use of the best judgement available.

Influences of Railroad Management's Policies. The discretionary policies of individual railroad's managements may severely inhibit the accurate determination of unit roadway costs based on analyses of aggregated data for several railroads. The effects of differing policies upon roadway costs can be seen acting in several ways. Management perception of the "level" or "standard" of maintenance required for various system lines will obviously have a marked effect on roadway system costs. Inherent in this perception of required level of maintenance effort is the risk to which individual managements are willing to be exposed as the result of roadway related defects or failures, the degree of coordination between maintenance and operations planning functions, and the extent of management's knowledge of the existing condition of the roadway.

Another important aspect of management policy relates to the programs of individual railroads to optimize the tradeoffs between track condition and total cost through the use of various rail relay or "cascade" alternatives. These policies determine the effective service lives of many elements of the roadway and cannot be ignored in a comprehensive cost analysis.

While individual management policies can significantly affect unit cost development based on roadway aggregate industry data, when developing costs for a given railroad, these policies may be reasonably discernable and their effects reasonably well quantified.

Roadway Capacity Costing. Much economic and competitive significance is accorded to the excess plant capacity which the railroads maintain, and the utilization of that capacity clearly has a major impact on railroad profitability. However, little effective costing of railroad plant capacity has been completed, probably because capacity costs are influenced by a number of factors, and their precise identification thus becomes difficult. In general, however, the extent to which the total cost of providing capacity changes with the provision of an additional block of service will largely determine the importance of the various factors.

a. Roadway Capacity and Utilization. Capital intensive industries, such as public utilities or railroads, have substantial funds invested in providing the capacity to serve their customers. For a railroad, roadway capacity is a measurement of a facility's capability to produce output. A number of factors determine production capability. Some of these include:

1. Availability of rolling stock and motive power.

2. Policies concerning scheduling and operation of trains in yard and linehaul movements.

3. Delays caused by equipment and plant failures, weather conditions, and maintenance.

4. Plant and equipment restraints limiting train speeds, length and loading.

5. The desired level of service.

The costs of providing capacity to serve include income and property taxes, depreciation, insurance, rents, and return on investment. The problem arises in efficiently generating revenues to cover these costs. If revenues do not cover costs, including a reasonable rate of return on investment, then a rational firm will shift its resources to more promising enterprises.

Closely related to the capacity cost concept is roadway utilization. A roadway utilization factor can be determined by calculating the relationship of average output to peak or capacity output.

Present ICC cost data do not include measurements of the degree of utilization of a firm's facilities. Because ICC costs are basically average costs, no accurate conclusions can be drawn concerning the effects of changes in a railroad's pricing, equipment, or service policies.

A difference exists between absolute physical capacity and economic capacity of rail roadway facilities. At the extreme limit, the saturation point of physical capacity on a given route would be the condition where each train is directly adjacent to the train ahead of it, or more realistically, for say, single directional movement on a double track line, when each train is spaced for minimum headway.

Economic capacity, on the other hand, is based on the law of diminishing marginal returns, and is the point at which additions to traffic bring about increasing marginal costs. As congestion develops due to increasing traffic volume, the productivity of additional facilities increases at a decreasing rate. Costs, in this case, increase at an increasing rate. The optimal position would be some level of traffic where the marginal cost of adding traffic is equal to the marginal revenue received from the added traffic. Where marginal cost is greater than marginal revenue, traffic should either be cut back or additional capacity added. From a profitability standpoint, it is this economic capacity which is the relevant capacity to consider.

b. Investment in Capacity. The appropriate level of investment in capacity is difficult to determine. A number of problems arise. First, rail management must determine the appropriate track segment to consider when investing in roadway. Is one mile of track, a route, or the entire system the proper length?

Second, a determination of the proper investment time period must also be made. This time period will depend on the route and the traffic expectations on that route. Consideration of the dollar amount as well as the timing of the expenditures on capacity need be considered when projecting what capacity will be needed in the future. Three basic possibilities arise: one may expect traffic growth, stability, or decline. Thus, a route expected to realize rapid increases in traffic will have a shorter relevant investment time period than a route where traffic is expected to remain stable.

A hypothetical example may help clarify this concept. Assume a particular railroad route presently handling 20 trains per day has an economic capacity of 30 trains per day. Traffic has been increasing rapidly on this route and is expected to triple in the next 5 years. Even though this route is under-utilized at the present time, the promise of a great increase in traffic would justify the addition of capacity to this route. Thus, the time period relevant for investment in capacity is relatively short in this instance.

Conversely, if we examine another route, once again handling 20 out of a possible 30 trains per day, and expecting little traffic increase in the future, then the relevant investment time period to consider may be 20 to 25 years. In this situation, very little if any addition to capacity would be justified. In the case of a route where traffic is expected to decline, capacity may be reduced. One could envision the elimination of CTC, closing stations, etc., as traffic declined.

c. Capacity Costing Theory. The economic theory of capacity costing is relatively clear. If a particular type of service or capacity serves all users, capacity charges should be levied only on those users of peak period utilization. Those responsible for the incurrence of capacity costs should pay for them. Economic efficiency requires that users pay for the expansion costs which they cause. In this way, users will weigh their demand for additional capacity against the cost of that additional capacity. Unless a charge is assessed against this demand for capacity, resources used in providing that capacity will not be used efficiently. Off-peak users should not have to pay for these costs. This principle stems from the concept of true joint costs. Even in a perfectly competitive environment, the existence of true joint costs justifies differential pricing. Concerning the railroads, the same capacity is available to provide separate services. Theoretically, every freight car, locomotive, mile of track, etc. available for service in June is also available in February. In the case of true joint costs, prices are based on the varying elasticities of demand for each type of service rather than solely on the cost of providing the service.

The joint supply theory provides a relevant pricing range (minimum and maximum) rather than specific charges. The minimum rate floor would be rates that cover at least the variable costs of providing the service. This minimum rate would apply to off-peak users generally possessing an elastic or price-sensitive demand for rail service. At any rate above this minimum, the user will be contributing toward the payment of joint capacity costs.

The maximum price may be viewed as essentially a two-part price. The first part would cover the variable costs such as off-peak users pay. The second part would be a demand or capacity charge. This is a charge for the railroad's readiness to serve on demand. This readiness is made possible only by the installation of capacity. The price then distributes the cost of capacity among the buyers of that capacity. The magnitude of the charge will be dependent on the degree of inelasticity of demand for transportation service as well as the shippers' use of capacity at peak traffic times.

One must keep in mind the real world complexities of capacity costing and pricing. If too low off-peak charges are assessed, the demand may drift to the point where congestion and shortages occur at the formerly off-peak period. Capacity costing also presupposes flexibility of rates. Such flexibility may be very difficult to obtain. Nonetheless, the principle remains sound; differential pricing should be employed for peak and off-peak use of capacity.

Based on this joint capacity concept, off-peak users will contribute little toward paying capacity costs. Peak users, however, as dictated by their respective demands for rail service, will pay for the capacity. Combined revenues received from peak and off-peak users (total) revenue must cover the costs of providing the service (total cost), including required profits.

# VI. STRUCTURING THE APPROACH TO ROADWAY COST ANALYSIS - - OBJECTIVES, RATIONALE, PRIMARY CONSIDERATIONS, METHODS

## Cost Analysis Objectives

This study was conducted with the following set of objectives in developing railroad roadway costing procedures for pricing purposes.

- The procedures should yield relevant, accurate and service-specific economic costs of providing, operating and maintaining railroad roadway; costs which can serve as the basis for evaluating rail service profitability.

- The procedures must have the capability to be modified to meet the specific needs of individual railroads, i.e., the procedures must be flexible enough to assimilate different policy assumptions, roadway maintenance standards and practices, and levels of resources.

- Resulting specific roadway costs should relate, to the extent possible, to the basis upon which other railroad operating costs are calculated, e.g., linehaul costs for a specific movement should reflect the costs of the specific linehaul trackage associated with that movement.

- The procedures should be developed with an understanding of overall costing system application, i.e., calculation and assignment of roadway costs developed from these procedures should be manageable when considered in the context of the overall costing effort required for each traffic movement.

- Roadway costs derived under these procedures should exist, to the extent possible, in a format which can eventually be compared with actual service-specific expenses as recorded under refined accounting procedures.

- The procedures should have the capability to reflect changes in roadway costs brought about by changes in operating requirements or roadway capacity and should in fact be the vehicle for insuring that the full impacts of such changes are clearly recognized.

- The procedures should have the capability for refinement based on results of current and future research into the physical behavior of the various elements of the roadway.

- The costs associated with the implementation and continued utilization of the cost analysis procedures must generate adequate returns for doing so.

These objectives have served both as the guidelines for, and the principal constraints to the work reported here.

Primary Improvements Sought

Current procedures for analyzing roadway expenditures assumes that economic depletion of the roadway under service conditions will be adequately reflected in the maintenance charges reported. This would be true, on a system average basis, if renewals (treated as maintenance expenses) were always performed at an adequate level. Where these renewals have been deferred, or where other than system or regional costs are needed, these reported maintenance expenses cannot reflect the actual consumption of railroad fixed plant. On a route and service-specific level, roadway renewal/replacement costs developed from expenditure records can never be expected to adequately reflect the cause and effect relationship between current types and volumes of traffic and the depletion of long-lived components of the roadway, i.e., the true economic and "variable" costs of providing rail service. It is this deficiency in current roadway cost analyses which receives predominant attention in this study. It will be seen that application of procedures developed herein yield results which indicate that cost levels determined utilizing system average historical expenses may have understated, or overstated, the unit variable roadway costs associated with specific types of railroad service by as much as 300 percent.

Beyond the competitive implications of such variations in roadway service costs, it can be seen that cost information of this nature can and must begin to play a more prominant role in the coordination of railroad marketing, equipment acquisition, and operations and engineering planning decisions.

As important as relevant roadway investment, operating, and maintenance cost information may be for improving pricing decisions, it is felt that such information must serve these other areas of management control and, in fact, can be made to be one of the mechanisms to insure proper coordination of railroad service planning on a consistent basis.

Notions About Roadway Cost "Variability"

What is a "variable" cost with respect to railroad roadway? Which of these costs are "variable" in the "short-run," the "long-run?" Indeed, what is the "short-run," the "long-run?" Which of these costs are "continuously variable" vs. those which change only at some specific level(s) of output service? What are the different types of service output "units" which cause roadway costs to vary? Which roadway costs are theoretically "variable" but never seem to exhibit this behavior? Does the phrase "% variable" have any meaning whatsoever? How can a specific type of roadway cost be proved to be "variable?" In short, just what is the "reality" of roadway cost behavior and how does it affect roadway cost analysis?

These are all difficult questions arising from the complexities surrounding roadway cost analysis discussed earlier. They have all been asked before. They are also questions for which there are no single, universally correct answers which would apply to all railroads.

How, then, should this problem of determining and allocating variable roadway costs in a systematic manner be approached in order to provide the best generally attainable measures of such costs for rail service profitability analysis?

We believe that such an approach must consist of the following basic elements:

1. Separation of railroad roadway into categories generally descriptive of the differing functional service areas provided or performed by the roadway, hence the development of the five roadway "service functions" previously described.

2. Separation and description of all the activities and resources attendant to the provision, maintenance, and operation of these roadway service functions down to a level facilitating adequate managerial control over such activities. This means being able to attain adequate knowledge of the expenditures required for these differing activities, using a variety of differing methods, on a basis sufficiently refined to permit the development and allocation of service-specific variations in roadway economic (variable) costs by being able to clearly recognize or at least reasonably hypothesize which of these activities are wholly dependent upon type and volume of rail traffic. This means describing these activities in sufficient detail to substantially increase our ability to treat related costs by direct analysis wherever possible, i.e., to determine or reasonably assume that either all or none of the costs related to a particular activity are traffic type and volume dependent.

3. Analysis of the resulting roadway cost control structure to select for allocation to traffic those activity costs caused by the production of incremental rail service output, regardless of when such costs are actually felt or give rise to additional cash outlays, i.e., activity-related costs constituting a sacrifice of current or future value or a current or future realization of higher costs. In most cases, statistical test of the relationships between observed or predicted costs for these activities and the output measures allegedly relating to them are never attempted. We believe that such analyses can never be adequately freed of the deficiencies noted earlier surrounding the development of specific, reliable , statistically derived roadway cost functions.

Methods, Basis for Analysis of Specific Roadway Costs

Two principle bases are utilized to determine and allocate variable road economic costs.

1. Those roadway track "maintenance" costs which in reality constitute the costs of renewing or replacing the railroad track structure are predicted, using engineering production functions assembled or developed in this study. These production functions describe the physical behavior of various elements of the roadway track structure as determined by volume and type of rail traffic. This resulting physical behavior is expressed as the portion of the track structure consumed in rendering each incremental unit of rail output service of a specific type and is "valued" for costing purposes at the current cost of replacing that portion of the track consumed.

   Justification for turning to the use of engineering relationships (production functions) as the basis for track cost analysis may be found in the need to (1) account for track maintenance deferrals which almost certainly introduce downward biases in almost any expense-based economic analysis of railroad roadway, (2) allow for quantification of the effects of specific types of rail traffic on specific types and condition of track structure for the purpose of service-specific costing, (3) to introduce into the analysis of roadway track costs the capability to utilize the results of current and future track structure research to continually improve the quantification of service-related track costs, and (4) initiate the systematic analysis of railroad marketing, equipment planning, operating, and engineering decisions in terms which will insure that the full economic consequences of these decisions, including the economic impacts upon railroad roadway, are taken into account.

   Justification for the use of current replacement costs as the proper measure of value of the track structure "consumed" by current traffic (regardless of the chronological "age" of the track structure or its individual components) is found in the need to accurately reflect the sacrifice of future value or the future realization of higher costs causally attributable to the current traffic if it is determined that the nature of the rail service is such as to give rise to continued (sustained) operation and eventual replacement of the roadway track structure. It may be said that current treatment of the replacement/renewal of roadway track structure by the Insterstate Commerce Commission, i.e., consideration of both replacement costs and routine maintenance costs as annual operating expenses, also gives rise to the valuation of current consumption of the track structure at present-day costs.

   The specific roadway track structure costs treated on this production function basis are as follows:

   Rail renewal costs
   Tie renewal costs
   Track surfacing and ballasting costs
   Other track material (OTM) costs

Specific procedures for analyzing these cost areas are contained in Section VII.

2. The analysis of the remainder of roadway variable costs is accounting-system based, i.e., it is based on the examination of expenditure records for cost areas other than track structure renewal/replacement. There are four principle reasons for structuring the analysis of the remainder of roadway costs on this basis:

   - The incidence of expenditure deferrals in other roadway cost areas is generally not as extensive, nor the resulting economic discrepancies nearly as severe as with the shortfalls associated with deferred replacement/renewal of the track structure.

   - The capability does not exist to adequately develop production functions describing the varying behavior of many of these other components, facilities, systems and activities in the manner undertaken for track structure-related costs.

   - In several cases, the system or regional average costs resulting from this type of analysis are both adequate and/or appropriate for evaluation of rail service profitability.

   - In several other cases, there is simply no better data available nor would the development of such data prove feasible.

## Engineering Aspects and Requirements

The procedures for determining and allocating roadway variable costs as developed in this study have several substantial implications for railroad engineering departments and forces.

In the case of procedures developed for analyzing variable track structure replacement/renewal costs, there are requirements for the integration of track characteristics and condition data into a data base for the purpose of predicting the economic behavior of track. Today many railroads are developing new techniques for assembling and utilizing such data for track structure analysis and maintenance planning purposes. Many of these railroads have developed methods of "classifying" or categorizing differing types of track structure and operating conditions similar to those contained herein. These are finding increasing use in rail defect and failure analyses, track geometry analysis, and maintenance policy formulation. More and more information is being developed regarding the effects of different equipment types and configurations and service levels on program track requirements. These resulting expanded track and traffic data bases are proving to be invaluable tools for the optimum allocation of scarce maintenance funds.[1,2,3] Implied throughout this study is the contention that this expanded and refined engineering-based data can and should be utilized for the economic analysis of railroad track structure for rail service profitability analyses. While requirements and resources may vary from railroad to railroad, the development and utilization of such data for both engineering planning and service pricing will serve to improve the coordination between rail service planning, pricing, and operating and engineering planning activities.

In addition, the proposed requirements for more specific and service-related roadway maintenance expense data will have varying implications upon engineering expenditure reporting and control systems. While procedures and systems similar to those described here may represent complex and costly refinements to some railroad engineering and accounting organizations, others have gone far beyond the levels of detail and sophistication described here. There can be no doubt, however, that refinements in expenditure and production reporting and control will impact engineering forces. While these impacts should be clearly recognized, they should be evaluated in light of potential improvements in many other areas of rail service planning and cost analysis as well.

Accounting System Aspects and Requirements

Detailed development of an accounting system to facilitate improved roadway cost analysis is not an objective of this study. However, no comprehensive investigation of the requirements attendant to analysis of roadway costs on a service-specific basis can proceed without recognizing that substantial changes must be made to both the ICC Uniform System of Accounts and to some conventional railroad responsibility accounting systems in order to improve both cost analysis capability and financial control. For this reason, a revised roadway cost accounting structure is presented herein, not as a proposed industry standard, but as a representative framework for the application of

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1. "Computers, Track Recorder Car Team Up in Battle Against Derailments," Railway Age, March 10, 1975.

2. "CP Rail Projects New Uses for Track Geometry Car," Railway Age, April 14, 1975.

3. "Computers-on-Track," Progressive Railroading, August 1975.

proposed procedures for analyzing the economic costs of railroad roadway. The accounting structure described in Appendix F contains the following basic information elements:

Incurring Responsibility (Cost Center)

System, operating division and maintenance district allocation of roadway maintenance operating, and investment expenditures is delineated.

Roadway Service Function

Linehaul, yard, miscellaneous trackage, service-specific facilities and systems and other facilities and systems expenditures representative of the functional service rendered by the roadway.

Location

Line, (yard) track and milepost identification for all track structure-related expenditures (rail laying, tie renewal, surfacing, turnout renewal, ballast cleaning).

Expense Identification

Specific roadway work activity designation.

Expense Description

Nature of expenditure (labor, material, supplies, services, etc.) designation for each Expense Identification.

Expense Classification

Designation of investment, program operating, ordinary operating, recollectible, and joint expenses, for reporting and control.

Expense Group

Aggregation of work activity expenses (Expense Identifications) under major operations cost groups for planning and control.

Production Output

Output statistics for program track structure renewal/maintenance activities for unit production cost development, analysis and control.

Costing System Aspects and Requirements

The impact of resulting procedures for analyzing railroad roadway costs upon the internal costing methods and systems of railroad costing departments has been one of the primary considerations in this study. The additional requirements imposed by these procedures upon the activities and resources of individual railroad cost analysis groups must be weighed against the potential benefits accruing from the roadway cost refinements and improved data bases resulting from application of the procedures. Among the significant effects of the implementation of these or similar procedures are the following:

- Requirement for specification of current or potential traffic movements in terms relevant for quantitative profitability analysis. Roadway cost analysis utilizing procedures developed here depends on current or forecast knowledge of freight traffic movement characteristics as to:

  - -train service type(conventional mixed consist or unit train service)
  - -car type and car weight
  - -net loading
  - -train or carload movement speed potential (horsepower/ton assignment)
  - -specific yardings along traffic route

- Commitment to objectives of route and service-specific cost analysis. Capability is developed and demonstrated to calculate roadway variable costs on an operating district basis, i.e., to relate roadway variable costs to train crew wage and fuel consumption costs typically calculated on a train crew district basis and to aggregate resultant costs over traffic routes.

- Requirement for periodic roadway cost reevaluation given significant changes in route specific track type and condition or traffic volume. Sufficient ties to engineering and traffic movement data bases must be maintained to insure timely recognition of structural changes in either data base and to effect required roadway cost revisions.

- Requirement for computer-based costing. Refinements in roadway cost analysis utilizing procedures proposed herein are totally infeasible without access to conventional machine processing systems. Software requirements are well within the capability of today's Class I railroads.

Management Information System Requirements

These procedures require the capability to determine or recognize significant characteristics of traffic movement in terms which bear on roadway variable costs. Whether conducted manually or with the aid of computerized traffic information systems, studies of traffic characteristics and volume are required.

Sufficient information must be accumulated to present a realistic picture of actual traffic tonnages, traffic wheel loading, and train service type mix on roadway segments designated for costing purposes. This information requires the matching of train and car movement statistics to determine the actual characteristics of service on each roadway segment. This is a difficult undertaking (regardless of whether manual or computer-based information is available) if adequate data integrity is to be obtained.

# VII. PROPOSED ROADWAY MAINTENANCE COSTING PROCEDURES

## Introduction

As stated previously, the approach to roadway cost analysis pursued in this study has as its basis two fundamental precepts:

- Meaningful economic cost analysis of the railroad roadway cannot have as its sole basis the examination of actual past expenditures.

- Relevant economic costs of maintaining the roadway track structure - those costs which should be used in evaluating rail service profitability - must be ascertained by analyzing the specific roadway segments under consideration.

The objective of roadway cost analysis for pricing purposes must be the determination of those costs which should be expected to be incurred given current track and traffic conditions, or rather, those costs which reflect the actual consumption of the roadway resulting from the provision of specific rail services.

The roadway costing procedures set forth here and in Sections VIII and IX are organized to treat the costs of each roadway service function described in Section IV.

## ● Linehaul Maintenance Costs

Linehaul maintenance costs consist of those associated with the renewal/replacement of the linehaul track structure, routine track maintenance, maintenance of linehaul signal systems and structures, plus allocations of other variable roadway systems and facility costs, equipment, and overhead costs.

1. <u>Linehaul Track Structure Renewal Costs</u>

These costs are associated with the continual replacement of the primary elements of the track structure or periodic restoration of track quality on a program basis. They account for varying portions of the expenses currently found in the following ICC Maintenance Accounts:

212 - Ties
214 - Rails
216 - Other Track Material
218 - Ballast
220 - Track Laying and Surfacing
269 - Roadway Machines
271 - Small Tools and Supplies
326 - Work Equipment Repairs

Under the accounting structure described in Appendix F, these expenses correspond with the following Expense Groups (Operations Cost Accounts) and Expense Identifications:

| Operations Cost Account | Expense Identification |
|---|---|
| 110 - Curve Rail Program | |
| 111 - Main Line Rail Program | |
| 112 - Branch Line Rail Program | |
| 115 - Other Track Maintenance | |
| | 007 - Replacing Frogs |
| | 008 - Replacing Switch Points |
| 116 - Transposing Rail | |
| | 002 - Transposing Rail, Adzing and Setting up Track |
| 120 - Cross Tie Program | |
| | 005 - Replacing Cross Ties |
| 122 - Surfacing | |
| | 011 - Surface Track Out-of-Face |
| | 012 - Ballast Cleaning and Plowing |
| 157 - Tools, Supplies | |
| | 056 - Small Tools (part) |
| | 057 - Roadway and Track Supplies (part) |
| 158 - Work Equipment | |
| | 058 - Repair Roadway Machines (part) |
| | 059 - Work Equipment Lease or Rentals (part) |
| | 087 - Repair Trucks and Autos (part) |

(It should be noted that roadway machines, tools and supplies, and work equipment have been included under track structure renewal costs because these items are contained in program production unit costs used later to determine measures of total economic consumption of the track structure. These costs could have been excluded and merely allocated on some other appropriate basis.)

As described in Section VI, procedures for determining and allocating variable track structure costs are based on engineering production functions developed to describe the varying behavior of the track structure as a function of varying physical and traffic conditions. These procedures require the synthesized application of existing relevant empirical research data, along with several as yet empirically unvalidated engineering hypotheses, to the various track-traffic environments existing across any given railroad's linehaul system. The procedures consist of the primary steps or tasks described below.

Task 1. Determination of factors, both track-related and traffic-related which significantly affect the physical and economic behavior of the track structure

Task 2. Inventory and categorize the linehaul trackage under study in terms of the cost-causal characteristics listed in (1) above

Task 3. Develop relationships which adequately describe the physical and economic behavior of the track structure as determined by the specific nature of the track/traffic environment

Task 4. Develop techniques for determining and allocating the track structure costs associated with the varying physical behavior of any type of track under any traffic conditions

These tasks are described in detail to complete the treatment of Linehaul Track Structure Costs.

### Task 1. Determination of Factors, both Track-Related and Traffic-Related Which Significantly Affect the Physical and Economic Behavior of the Track Structure

Track-related factors which have a significant effect upon track structure costs were described in Section IV. The proper measures or ranges of values for these factors (characteristics of the track structure) must be specified in order to relate the analysis to relevant conditions prevailing on a given railroad. The specification of certain parameter classes used in this study reflect to some extent conditions germane to the Southern Pacific Trackage selected for study. In addition, application and test of the costing procedures as conducted here does not necessarily provide data for all parameter classes. The track-related parameters and associated classes used are as follows:

Track-Related (Physical) Factors

| Parameter | Parameter Classes |
| --- | --- |
| o Weight of Rail (lbs./yd.) | $>$ 136 lbs./yd. |
| | 136 lbs./yd. |
| | 125-135 lbs./yd. |
| | 111-124 lbs./yd. |
| | 90-110 lbs./yd. |
| | 80-89 lbs./yd. |
| | $<$ 80 lbs./yd. |

| Parameter | Parameter Classes |
|---|---|

Rail weight affects section modulus and stiffness of the rail, which affects in turn the deflection of the rail and the life and stability of track. Larger rails also have a longer abrasive wear life. Since an attempt to identify and analyze each weight of rail would lead to an unmanageable number of different weights, the rail weight groups shown above are proposed. These groupings reflect the rail steel chemistry groupings in the specifications of the AREA. They also generally correspond to breaks in the section modulus groupings (stiffness measure) of the several available sections. Individual railroads may choose to consider finer groupings where internal data has been developed to reflect distinctions between rail weights and sections grouped together above.

| | |
|---|---|
| o Type of Rail | Continuous Welded Rail<br>78' Welded Rail<br>39' Jointed Rail |

Rails should be identified as to type, i.e., jointed or continuous welded (CWR). Jointed rail is subject to rail-end batter, bolt hole breaks, and joint bar renewal; also to bonding in track circuit territory. Continuous welded rail eliminates all, or a major portion of, rail joint costs, but poses special problems in transport, laying and maintaining.

| | |
|---|---|
| o Rail Metallurgy | Plain, Uncontrolled Cooled<br>Control Cooled<br>Special Metallurgy |

Metallurgy of rail may be a significant cost factor. Included in the category of special metallurgy are the following:

Flame hardened rail
Electric induction hardened rail
Heat treated rail
High silicon rail
End hardened rail
Vacuum degassed rail
All other metallurgies

| | |
|---|---|
| o Condition of Rail When Laid | New<br>Secondhand |

Condition laid will have an obvious bearing on remaining effective service life of rail and hence upon rail costs for any given track segment.

Track-Related (Physical) Factors (Cont.)

| Parameter | Parameter Classes |
| --- | --- |
| o Type of Tie (material) | Wood<br>Concrete<br>Steel |
| o Tie Treatment | Treated<br>Untreated |
| o Condition of Tie Installed | New<br>Secondhand |
| o Tie Spacing | 19.5 in.<br>22.5 in.<br>25.62 in. |

The four parameters listed above represent those signficant tie cost factors which are feasible for inclusion in the analysis.

| | |
| --- | --- |
| o Turnouts and Crossings | Main Track Turnouts<br>Yard and Side Track Turnouts<br>Track Crossings |

Main track turnouts occur with variable frequency. Turnouts can be grouped roughly by diversion number (the ratio between unit spread and distance to the frog point from which unit spread is measured):

| | |
| --- | --- |
| No. 8 and lower | - for slow-speed main line (branches), yard and spur tracks |
| No. 9 - No. 12 | - for main line turnouts to sidings and spur tracks |
| No. 15 - No. 20 | - for high-speed main line movements, crossovers, and diversions |

The turnout number will, however, have less effect on costs than merely grouping these as main track turnouts and yard and side track turnouts. Number and type of track crossings will also be a significant factor in linehaul track structure cost analysis.

o Other Linehaul Track Structure Material
Classification Based on Weight of Rail and Curvature

For the linehaul track structure, these items typically cover rail fastening - joint bars, track bolts, tie plates, tie plugs, spikes, rail anchors, gauge rods, and derails.

Track-Related (Physical) Factors (Cont.)

| Parameter | Parameter Classes |
|---|---|
| o Effective Ballast Type | Crushed Rock<br>Crushed Slag<br>Prepared Gravels<br>Chat<br>Cinders<br>Other |
| o Ballast Depth | Inches |

A depth of ballast equal approximately to the center-to-center spacing of ties (± 19½ - 22 inches) is generally considered necessary to assure the uniform distribution of tie load pressures. This depth need not be entirely of high-grade material. A sub-ballast section composed of lower grade materials may be used for 30 to 50 percent of the required ballast depth. It should be emphasized, however, that the ballast/sub-ballast combination must be sufficient to reduce the load distribution to a level commensurate with the bearing capacity of the subgrade.

| Parameter | Parameter Classes |
|---|---|
| o Subgrade Stability | Stable (no excess maintenance required)<br>Fairly Stable (excess maintenance required, routine force assignment)<br>Unstable (excess maintenance required, special force assignment) |

The great variations in soil types and conditions render a detailed identification of soil conditions impracticable. It will be sufficient to identify subgrades as stable (no excess maintenance required), fairly stable (some excess maintenance required, but no slow orders), and unstable (considerable excess maintenance and/or slow orders and operating problems).

Subgrade and ballast sections are interdependent. A strong subgrade needs a minimum amount of ballast to bear and distribute traffic loadings. If the subgrade is weak, a greater depth of ballast is required. For these reasons, the subgrade and ballast section may be stated together as stable, fairly stable, or unstable.

Track-Related (Physical) Factors (Cont.)

| Parameter | Parameter Classes |
|---|---|
| o Degree of Curvature | Tangent to < 0°30'<br>0°30' - 1°30'<br>1°30' - 2°30'<br>2°30' - 3°30'<br>3°30' - 4°30'<br>4°30' - 5°30'<br>5°30' - 6°30'<br>6°30' - 7°30'<br>7°30' - 8°30'<br>8°30' - 9°30'<br>> 9°30' |

Curvature is a signifcant characteristic of the track structure environment. Rail wear varies almost directly with the degree of curve. Ties, OTM and ballast life are affected although to a lesser degree. Track laying and surfacing costs are also affected.

| | |
|---|---|
| o Gradient | Level to < .5%<br>.5% - 1.0%<br>1.0% - 1.5%<br>1.5% - 2.0%<br>2.0% - 2.5%<br>> 2.5% |

Gradient, like curvature, is an environmental factor. It has a signficant effect on rail life and costs and a lesser effect on ties, ballast and OTM life and costs; also on man hours and machine hours for track laying and surfacing.

| | |
|---|---|
| o Precipitation | Annual rainfall<br>Annual snowfall |

The impact of rainfall upon roadway costs varies widely as previously descirbed. Primary effects are upon roadbed drainage and stability and vegetation control. Annual rainfall is seen as proposed indication of rainfall effects upon routine roadway maintenance. The severity of snow removal problems and attendant costs are functions not only of the amount of fall, but of wind, cut and drifting conditions.

| | |
|---|---|
| o Temperature | Maximum<br>Minimum |

Temperature extremes have an effect on labor productivity, work equipment utilization and the track structure itself.

Track-Related (Physical) Factors (Cont.)

| Parameter | Parameter Classes |
| --- | --- |
| o Icing/Frost Heaving Damage Exposure | None<br>Light<br>Heavy |

Icing conditions, particularly those associated with ice storms, may have significant impact on local roadway costs, including impending roadway maintenance work and damaging individual components of the roadway system, such as pole lines for signal, power and communications transmission. Yet another costly effected related to low temperatures is frost heaving.

| | |
| --- | --- |
| o Storm/Flood Damage Exposure | None<br>Yearly<br>1 to 10 years<br>10 to 25 years<br>25 to 50 years<br>> 50 years |

o Areal Nature of Roadway Segment

- Urban
- Suburban
- Rural

The nature and activities of areal governmental operations may influence specific roadway costs, particularly with respect to sanitary and drainage requirements, grade crossing protection, sidewalks, lighting, fences, etc. Additional cost effects of this "parameter" may be found in the degree of access to work areas and in interference with roadway work by the day-to-day activities associated with these areas.

o Condition or "Age" of the Track Structure

While no finite "classes" for this variable have been developed, there can be little doubt as to its signficance in predicting specific line segment costs. Experience has shown that as track deteriorates, many maintenance-of-way work functions (spot tamping, joint maintenance, repair of failed rails, etc.) must be performed more frequently and/or intensively, thus introducing an important "time" variable into any roadway maintenance cost function.

It will be shown that ballast condition plays an important role in the quality of track support and will affect the eventual classifications of track support conditions used to analyze the effects of traffic on the track structure.

Track-Related (Physical) Factors (Cont.)

| Parameter | Parameter Classes |
| --- | --- |

o Maintenance of Way Work Methods and Efficiency

This factor exists as both a physical and traffic-related parameter (see pp. 12-13) incident to the development of specific roadway costs. As a physical factor, work methods employed (force sizes, equipment types, procedures, etc.) will have a marked effect upon variations in unit "production" costs from railroad to railroad, or within different maintenance jurisdictions of a single railroad.

The parameters described above represent the environment of physical characteristics or factors which influence track structure costs. If the individual effects of each of these factors are ever to be isolated (or if the aggregate effect of any or all of these factors acting in combination is to be predicted) with reasonable accuracy, these parameters should be analyzed on a basis similar to that described, i.e., the physical parameters should be described in terms of reasonably detailed "classes" as shown. It will be seen that specific cost effects for several of these parameters, particularly those associated with climatic conditions have not been successfully determined in this study, but await the types and quantities of data which can be acquired through development of data bases recommended in the study.

## Traffic-Related Factors

Traffic-related characteristics (parameters) and relevant parameter classes are described below. These characteristics represent the significant cost-causal factors affecting the physical and economic behavior of railroad track structure. The parameter classes indicated are felt to adequately describe the basic variations in these factors necessary to differentiate between and evaluate the various effects of these factors. It will be seen that "consumption" of the track structure under varying service conditions is more nearly represented by continuous functional relationships derived from an analysis of the behavior of track structure, the traffic environment of which has been described in terms of these or similar parameter classes.

Traffic-Related Factors (Cont.)

| Parameter | Parameter Classes |
|---|---|
| o Annual Tonnage Density (Millions of gross tons) | 0-5 MGT (in one MGT increments, i.e., 1,2,3,4, & 5 MGT)<br>5-75 MGT (in five MGT increments) |

The amount of traffic is intuitively recognized as a prime cost factor. It should be measured by millions of gross tons carried, since it is the weight of traffic that has the wearing effect. Track material life should be measured in terms of the annual gross tonnage carried. Gross tonnage includes the effects of car weight (including empty movements) as well as contents and should also include locomotive and caboose weight.

Levels of maintenance tend to vary more at low tonnage than at higher rates, i.e., the same level of maintenance for 20 MGT may not differ much from that for 30 MGT, but there can be considerable difference between that for one MGT and five MGT. Therefore, the annual gross tonnage classes shown above are proposed.

| | |
|---|---|
| o Train Speed - MPH (by direction and service-type) | 80 - 110 mph and over<br>60 - 80 mph<br>40 - 60 mph<br>25 - 40 mph<br>10 - 25 mph<br>0 - 10 mph |

Speed effects are found in the increasing severity of dynamic impacts given to the track as speed increases. Higher levels of maintenance are required (for the same annual tonnage) to assure smooth and safe passage of trains as speed increases.

Slow speeds are cost-suspect as well as high. Speeds of 15 to 20 mph have been observed to cause severe rock and roll and derailing tendencies, while the impact effects of flat spots on wheels and low spots in the track are a maximum at speeds of 8 to 12 mph±.

Speed ranges for the classification of trackage should be based on maximum authorized speeds as set forth in the operating timetables because that is the speed for which maintenance levels are supposedly established. Actual maximum and actual average train speeds, by service-type, by direction will be important in determining and allocating service-specific costs, particularly where there are large speed differences between the slowest and fastest trains on a given line segment. If a significant portion of a track segment is covered by a slow order, the state of maintenance in the portion of track so

| Parameter | Parameter Classes |
| --- | --- |

covered is thereby reflected. Because it will have an extended use and be universally known, however, the speed ranges for the FRA's track classification are recommended for use in helping to categorize different linehaul track segments as to relative track structure cost.

| | |
| --- | --- |
| o Wheel Loads (lbs./wheel) | <15,000 lbs. |
| | 15,000-26,000 lbs. |
| | 26,000-30,000 lbs. |
| | 30,000-33,000 lbs. |
| | 33,000-35,000 lbs. |
| | 35,000-37,000 lbs. |
| | >37,500 lbs. |

The total weight a wheel places on a rail (related by a factor of two to the axle load) has a critical but not clearly defined effect on all aspects of the track structure. A prime effect is on rail life. Excessive wheel loads are recognized as contributory to the formation of plastic flow that leads in turn to battered rail ends, corrugations, shelly defects, headchecks, and to the growth of transverse fissures, detail fractures, horizontal fissures, vertical split heads and other defects related to the contact stresses developed immediately beneath the point of wheel load application.

Railroad engineers have generally accepted that wheel loads of 26,000 lbs. or less on 33-inch (nominal diameter) wheels create shearing stresses in the rail head low enough to permit an indefinitely long rail life, considering only contact pressure. Loads over 26,000 lbs. increase shearing stresses to a point that the life of rail (in terms of cycles of load application before failure) is definitely reduced. Some (relatively minor) amelioration of the effect occurs with the use of 36- and 38-inch wheels. Above 34,000 lbs. excessive stressing occurs, accompanied by rail head mashing and other aspects of plastic flow. It represents a type of rail "abuse" but is not an uncommon loading. Its significance is a function of the numbers of cars so operated.

The parameter classes listed contain more distinctions between wheel loads than the three described above. This is to allow the eventual comparison and use of predictive data for a number of different car sizes and types. Although some data of this type currently exists, much more will be forthcoming from research into this aspect of the track/train environment and from the data being accumulated on individual railroads.

| Parameter | Parameter Classes |
|---|---|
| o Train Service Type | Mixed consist trains<br>Unit trains<br>Intercity passenger trains<br>Commuter trains |

The cost effects of various types of service is an item for significant debate. An initial grouping might be that of freight and passenger service based on the lighter axle loads, higher speeds, and need for safety peculiar to passenger service. However, wheel loads have been accounted for as a separate factor, and many freight trains equal or exceed passenger train speeds. Nevertheless, the presence of even one passenger train introduces the need for a higher standard of maintenance (for the same speed) than would be required for freight only. This is dictated by consideration of safety and ride quality.

Train length is of some importance, especially with unit trains. Unit trains are of uniform consist and usually equipped with roller bearings. Each car in the train follows a repetitive pattern with respect to track geometry. Each track irregularity will be impacted by each car in a train of uniform consist in exactly the same way. This may account for the formation and growth of some corrugations, shells and detail fractures. The effect is further intensified by the use of roller bearings which are "stiff," not having the lateral play found in friction bearings. Any lateral movement of the trucks or car body is delivered to the rails with the full force of the entire truck-car body system.

Another effect of unit trains about which little is known is a "deterioration" in the resilient return of the track to its unloaded condition between the passage of the trucks at each end of the car as the final 1/3+ of the train passes. The track is in effect "beaten down" by the repetitive application of wheel loads. The effect is most pronounced in trains of over 80 cars and is probably less pronounced in trains of mixed consist where there is nonuniformity in load application.

The Association of American Railroads is presently engaged in a Track/Train Dynamics Research Program that should eventually shed more light on the effects of service types. Until more definitive data is available, use of the categories of service types shown is proposed.

o Maintenance of Way Work Methods and Efficiency

To the extent that traffic may interfere with planned maintenance activities, the resulting higher unit "production" costs associated with such work activities may be said to be a function of the amount and type of traffic. While daily train volume may be an indication of potential interference with roadway maintenance work (decreased work efficiency), only the analysis of specific schedules and/or actual movements will determine the extent of such interference.

The track and traffic characteristics (parameters) described above together with their associated parameter classes, are considered adequate, considering the current body of knowledge relevant to the behavior of the railroad track structure, to facilitate an analysis of the track structure to determine significant causal relationships and to adequately determine and allocate resulting track costs.

Task 2. Inventory and Categorize the Linehaul Trackage Under Study in Terms of the Cost-Causal Characteristics Listed in (1) Above

The true cost of owning and operating the roadway track structure associated with specific rail service can never be accurately developed and assigned unless the actual characteristics of such service are known. An inventory to "define" a specific roadway track system in terms of the parameters listed under (1) must be conducted to eventually determine and assign the actual cost influences of these parameters for a given roadway segment. The track and traffic inventory system presented here was developed and implemented on 5,000 miles of Southern Pacific mainline trackage. The specific purposes of the inventories are to:

a). Define the track and traffic characteristics of any segment of roadway trackage.

b). Serve as an information base for investigation of the effects of various types and volumes of rail traffic on various types of track structure.

c). Provide the basis for classification of roadway trackage into segments with homogeneous characteristics for use in calculating and assigning variable track structure costs.

d). Create a system of track/traffic information which can readily reflect periodic changes in either the nature of the track system or in the service demands being placed on it.

e). Provide the data base necessary for determining roadway costs on a route, train service or product line basis to facilitate profitability analyses.

The basic concepts, methods and data sources used in conducting the track and traffic inventories are described below.

## Track Characteristics Inventory

The track inventory effort conducted here sought to record the physical characteristics of the actual track structure under study. Provisions were developed for recording information on each of the physical parameters in (1) above, although certain of this information was found either impractical to obtain from conventional railroad engineering source documents or was not used directly in the analysis. Additional information was sometimes recorded to demonstrate the usefulness of the track inventory system as an automated engineering track data base. Information recorded, source documents used, and file format references are described below. Track inventory input file formats are included in Appendix A. All input files contain line segment, milepost, and track designation locater data.

| Rail Data | Information Source | File Format Reference |
|---|---|---|
| Rail Weight | Standard Engineering Track Charts | Rail Input File - Figure A-1 |
| Rail Metallurgy | Same | Same |
| Rail Type | Same | Same |
| Condition Laid | Same | Same |
| Track Designation (multiple track territory) | Same | Same |
| Manufacturer | Same | Same |
| Year Rolled | Same | Same |
| Year Laid | Same | Same |
| Year Transposed | Same | Same |
| Current Annual Tonnage | Railroad Gross Tonnage Statistics | Same |
| Cumulative Tonnage Since Rail Laid | Same | Same |

| Tie Data | Information Source | File Format Reference |
|---|---|---|
| Track Designation | No information source available. Input File Format developed to provide the basis for including tie data in a track inventory system where accumulated. | Tie Input File - Figure A-2 |
| Tie Material | Same | Same |
| Tie Spacing | Same | Same |
| Tie Treatment | Same | Same |

| | | |
|---|---|---|
| Type (cross, bridge, switch) | Same | Same |
| Tie Size | Same | Same |
| Last Program Renewal | Same | Same |
| No. Ties Renewed | Same | Same |

| Curvature Data | Information Source | File Format Reference |
|---|---|---|
| Curve Number (unique identification) | Field-maintained curve characteristic data | Curvature Input File - Figure A-3 |
| Compound Curve Designation | Same | Same |
| Degree of Curvature | Same | Same |
| Curvature Class | Curve Parameter Classes | Same |
| Superelevation | Field-maintained curve characteristic data | Same |
| Spiral Length | Same | Same |
| Curve Length | Same | Same |
| Curve Rail Lubricator Indicator | Same | Same |

| Gradient Data | Information Source | File Format Reference |
|---|---|---|
| Direction Code | Detail Engineering Line Profile Drawings | Gradient Input File - Figure A-4 |
| Milepost From-To | Same | Same |
| Elevation at Milepost From-To | Same | Same |
| Percent Grade | Calculated from Elevation Data | Same |
| Gradient Class | Gradient Parameter Classes | Same |

| Track Support Data | Information Source | File Format Reference |
|---|---|---|
| Track Support Class | Combination of tie spacing, general tie condition, ballast type, ballast depth and ballast condition used to differentiate levels of track support quality. See pps. VII-33,34. | Track Support File - Figure A-5 |
| Track Support Modulus | Estimated from separate research data. See pp. VII-35. | Same |

| Turnout and Track Crossing Data | Information Source | File Format Reference |
|---|---|---|
| Turnout Number | Siding Charts | Miscellaneous Object File - Figure A-6 |
| Location | Siding Charts | Miscellaneous Object File - Figure A-6 |

| Climatic/Atmospheric Data | Information Source | File Format Reference |
|---|---|---|
| Temperature Ranges | Climatological Data - U.S. Department of Commerce, Environmental Data Service | Subdirectory File - Figure A-7 |
| Precipitation | Same | Same |
| Areal Nature | Engineering Department Assigned Estimates | Same |
| Atmospheric Corrosion Conditions | Same | Same |
| Icing Conditions | Same | Same |
| Storm/Flooding Conditions | Same | Same |

This file also serves as a master track designation and location file. Each record carries a "sequence number" unique to each line code to serve as reference to the particular track segment location, track designation (multiple track territory), Engineering Division (maintenance jurisdiction) and railroad ownership (joint trackage territory). These records also reflect any equated milepost conditions ("equations") resulting from track alignment changes.

Individual track characteristic files are merged and homogeneous track segments are identified (based on the track parameter classes described previously). The resulting file is a track master directory file (Figure 1) containing all trackage in the study segmented by the limits of characteristic (class) homogeneity, i.e., between the milepost limits for each track segment shown, all track characteristics (classes) remain constant. This results in each segment being identifiable as a unique class or type of track. Each class of track may exist in varying amounts in locations across the track network under study.

FIGURE 1
MASTER TRACK FILE

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| DV | LINE | S:Q | M.P. FR | M.P. TO | WGT | TYP | CD | MT | CURVE | GRADE | TS | OILER | TC | LNKE | LNKW |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 04 | B | 69 | 736.670 | 737.420 | 113 | CWR | SH | | | .0 | 1A | | 2 | | 1006 |
| 04 | B | 69 | 737.420 | 737.457 | 113 | CWR | SH | | 10000 | .0 | 1A | | 2 | | 1008 |
| 04 | B | 69 | 737.457 | 737.470 | 113 | CWR | SH | | | .0 | 1A | | 2 | | 1008 |
| 04 | B | 69 | 737.470 | 737.490 | 113 | JT | N | | | .0 | 1A | | 2 | | 1006 |
| 04 | B | 69 | 737.490 | 737.512 | 136 | JT | N | | | .0 | 1A | | 2 | | 1006 |
| 05 | B | 70 | 737.512 | 740.300 | 136 | CWR | N | | | .0 | 1B | | 0 | 1007 | 1008 |
| 05 | B | 70 | 740.300 | 740.320 | 132 | JT | N | | | .0 | 1B | | 0 | 1007 | 1008 |
| 05 | B | 70 | 740.320 | 741.000 | 136 | CWR | N | | | .0 | 1B | | 0 | 1007 | 1008 |
| 05 | B | 70 | 741.000 | 743.000 | 136 | CWR | N | | | .0 | 6C | | 0 | 1007 | 1008 |
| 05 | B | 70 | 743.000 | 743.230 | 136 | CWR | N | | | .0 | 1B | | 0 | 1007 | 1008 |
| 05 | B | 70 | 743.230 | 743.240 | 136 | CWR | N | | 10030 | .0 | 1B | | 0 | 1007 | 1008 |
| 05 | B | 70 | 743.240 | 743.260 | 132 | CWR | SH | | 10030 | .0 | 1B | | 0 | 1007 | 1008 |
| 05 | B | 70 | 743.260 | 743.700 | 132 | CWR | SH | | 10030 | .2 | 1B | | 0 | 1007 | 1008 |
| 05 | B | 70 | 743.700 | 743.758 | 132 | CWR | SH | | 10030 | .1 | 1B | | 0 | 1009 | 1010 |
| 05 | B | 70 | 743.758 | 743.780 | 132 | CWR | SH | | | .1 | 1B | | 0 | 1009 | 1010 |
| 05 | B | 70 | 743.780 | 744.500 | 136 | CWR | N | | | .1 | 1B | | 0 | 1009 | 1010 |
| 05 | B | 70 | 744.500 | 744.520 | 136 | CWR | N | | | .1 | 6C | | 0 | 1009 | 1010 |
| 05 | B | 70 | 744.520 | 744.560 | 136 | JT | N | | | .1 | 6C | | 0 | 1009 | 1010 |
| 05 | B | 70 | 744.560 | 744.810 | 136 | CWR | N | | | .1 | 6C | | 0 | 1009 | 1010 |
| 05 | B | 70 | 744.810 | 745.610 | 136 | CWR | N | | | -.4 | 6C | | 0 | 1009 | 1010 |
| 05 | B | 70 | 745.610 | 745.680 | 136 | CWR | N | | 14100 | -.4 | 6C | | 0 | 1009 | 1010 |
| 05 | B | 70 | 745.680 | 745.700 | 136 | CWR | N | | 14100 | -.3 | 6C | | 0 | 1009 | 1010 |
| 05 | B | 70 | 745.700 | 745.720 | 136 | CWR | N | | 14100 | -.3 | 1B | | 0 | 1009 | 1010 |
| 05 | B | 70 | 745.720 | 745.738 | 136 | CWR | N | | 14100 | -.5 | 1B | | 0 | 1009 | 1010 |
| 05 | B | 70 | 745.738 | 745.940 | 136 | CWR | N | | | -.5 | 1B | | 0 | 1009 | 1010 |
| 05 | B | 70 | 745.940 | 746.000 | 136 | CWR | N | | 13800 | -.5 | 1B | | 0 | 1009 | 1010 |
| 05 | B | 70 | 746.000 | 746.110 | 136 | CWR | N | | 12800 | -1.3 | 1B | | 0 | 1009 | 1010 |
| 05 | B | 70 | 746.110 | 746.191 | 136 | CWR | N | | 13100 | -.3 | 1B | | 0 | 1009 | 1010 |
| 05 | B | 70 | 746.191 | 746.600 | 136 | CWR | N | | | -.3 | 1B | | 0 | 1009 | 1010 |
| 05 | B | 70 | 746.600 | 746.730 | 136 | CWR | N | | | -.3 | 1B | | 0 | 1011 | 1012 |
| 05 | B | 70 | 746.730 | 747.170 | 136 | CWR | N | | | -.1 | 1B | | 0 | 1011 | 1012 |
| 05 | B | 70 | 747.170 | 747.210 | 136 | CWR | N | | 11500 | -.1 | 1B | | 0 | 1011 | 1012 |
| 05 | B | 70 | 747.210 | 747.810 | 136 | CWR | N | | 11500 | .1 | 1B | | 0 | 1011 | 1012 |
| 05 | B | 70 | 747.810 | 747.845 | 136 | CWR | N | | 11500 | .4 | 1B | | 0 | 1011 | 1012 |
| 05 | B | 70 | 747.845 | 748.270 | 136 | CWR | N | | | .4 | 1B | | 0 | 1011 | 1012 |
| 05 | B | 70 | 748.270 | 748.290 | 136 | JT | N | | | .4 | 1B | | 0 | 1011 | 1012 |
| 05 | B | 70 | 748.290 | 748.300 | 132 | CWR | SH | | | .4 | 1B | | 0 | 1011 | 1012 |
| 05 | B | 70 | 748.300 | 748.370 | 132 | CWR | SH | | 13600 | .4 | 1B | X | 0 | 1011 | 1012 |
| 05 | B | 70 | 748.370 | 748.430 | 132 | CWR | SH | | 13600 | .3 | 1B | X | 0 | 1011 | 1012 |
| 05 | B | 70 | 748.430 | 748.450 | 132 | CWR | SH | | 13600 | .1 | 1B | X | 0 | 1011 | 1012 |
| 05 | B | 70 | 748.450 | 748.491 | 132 | JT | N | | 13600 | .1 | 1B | X | 0 | 1011 | 1012 |
| 05 | B | 70 | 748.491 | 748.500 | 132 | JT | N | | | .1 | 1B | | 0 | 1011 | 1012 |
| 05 | B | 70 | 748.500 | 748.580 | 136 | CWR | N | | | .1 | 1B | | 0 | 1011 | 1012 |
| 05 | B | 70 | 748.580 | 748.620 | 136 | CWR | N | | 40000 | .1 | 1B | X | 0 | 1011 | 1012 |
| 05 | B | 70 | 748.620 | 748.770 | 136 | CWR | N | | 40000 | .0 | 1B | X | 0 | 1011 | 1012 |
| 05 | B | 70 | 748.770 | 748.821 | 136 | CWR | N | | 40000 | -.5 | 1B | X | 0 | 1011 | 1012 |
| 05 | B | 70 | 748.821 | 748.870 | 136 | CWR | N | | | -.5 | 1B | | 0 | 1011 | 1012 |
| 05 | B | 70 | 748.870 | 749.002 | 136 | CWR | N | | 20000 | -.5 | 1B | | 0 | 1011 | 1012 |
| 05 | B | 70 | 749.002 | 749.060 | 136 | CWR | N | | | -.5 | 1B | | 0 | 1011 | 1012 |
| 05 | B | 70 | 749.060 | 749.070 | 136 | WR | SH | HS | | -.5 | 1B | | 0 | 1011 | 1012 |
| 05 | B | 70 | 749.070 | 749.130 | 136 | WR | SH | HS | 60000 | -.5 | 1B | X | 0 | 1011 | 1012 |
| 05 | B | 70 | 749.130 | 749.170 | 136 | WR | SH | HS | 60000 | -.3 | 1B | X | 0 | 1011 | 1012 |
| 05 | B | 70 | 749.170 | 749.240 | 136 | WR | SH | HS | 60000 | -.6 | 1B | X | 0 | 1011 | 1012 |
| 05 | B | 70 | 749.240 | 749.245 | 136 | CWR | N | | 60000 | -.6 | 1B | X | 0 | 1011 | 1012 |
| 05 | B | 70 | 749.245 | 749.420 | 136 | CWR | N | | | -.6 | 1B | | 0 | 1011 | 1012 |
| 05 | B | 70 | 749.420 | 749.450 | 136 | CWR | N | | 20000 | -.6 | 1B | | 0 | 1011 | 1012 |

## Traffic Characteristics Inventory

The traffic inventory for this study was conducted using data from the Total Operations Processing System (TOPS) in use on the Southern Pacific. Similar data can be developed from other computer based railroad management information systems or by manual sampling and analysis of train sheets or conductors wheel reports. This information was developed to demonstrate how cost-causal traffic characteristics can be identified for any track segment under study to facilitate the analysis of the effects on specific track structures of various types and volumes of rail traffic and to serve as the basis for actual calculation and assignment of service-specific track structure variable costs. The inventory was constructed by matching all train and car movement records for four one-week sample periods to determine the characteristics of the freight traffic moving over all the linehaul trackage under study during the year 1974. The resulting data (See Figure 2 , Traffic Characteristics Inventory) indicates the percentage of the gross tonnage on the line segment in each wheel load, speed potential, equipment type and train service type "class." These are the traffic parameter classes described previously in this section. Data shown in Figure 6 is to be interpreted as follows:

### Basic Traffic Segment Data

| | |
|---|---|
| Segment ID | This is a unique numeric identifier for the line segment, track designation, milepost limits and directionality of the traffic "profile" shown in the report, i.e., there are two such reports (Seg.ID's) for single track territory with traffic in both directions. |
| Annual GTON | Annual Gross Tonnage on this traffic "link" |
| Annual TTON | Annual Trailing Tonnage (cars and contents) on the link |
| Annual GTM | Annual Gross Ton-Miles on the link |
| Annual Trains | Number of identified trains on the link |
| Annual Cars | Number of cars on the link |
| AVCARWT | Average Car Weight of all cars on the link (loads and empties) |

### Detailed Traffic Characteristic Data

| SEC-ID | LN CODE | SEQ FR | SEQ TO | MP FROM | MP TO | MILES | ANNUAL GTON | ANNUAL TTON | ANNUAL GTM | ANNUAL TRAINS | ANNUAL CARS | AVCARWT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 605 | 0 | 6 | 5 | 42.000 | 45.300 | 3.3 | 1253265 | 1046019 | 4??7931 | 793 | 23192 | 45 |

MIXED CONSIST TRAINS

** CARS **

| HP/ GTON | 150 | 260 | 2X 300 | MX 300 | 2X 330 | MX 330 | 2X 350 | MX 350 | 2X 375 | MX 375 | 2X GTR | MX GTR | CAR TOT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 4 | 2 | 4 | | | | | | | | | | 10 |
| 2 | 11 | 14 | 5 | | 4 | | | | | | 1 | | 37 |
| 3 | 12 | 3 | 2 | | 1 | | * | | | | 1 | | 19 |
| 4 | 2 | 1 | | | * | | | | | | | | 4 |
| 5 | 4 | 3 | * | | | | | | | | | | 7 |
| TOT | 34 | 22 | 13 | | 6 | | * | | | | 2 | | 77 |

** LOCOMOTIVES **

| HP/ GTON | 150 | 260 | 2X 300 | MX 300 | 2X 330 | MX 330 | 2X 350 | MX 350 | 2X 375 | MX 375 | 2X GTR | MX GTR | LOC TOT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | 1 | | | | * | | | | | 1 |
| 2 | | | | 1 | * | | | 3 | | | | | 4 |
| 3 | | | | 1 | * | | | 2 | | | | | 3 |
| 4 | | | | * | | | | 1 | | | | | 1 |
| 5 | | | | 3 | * | | | 3 | | | | | 7 |
| TOT | | | | 5 | 1 | | | 9 | | | | | 16 |

UNIT TRAINS

** CARS **

| HP/ GTON | 150 | 260 | 2X 300 | MX 300 | 2X 330 | MX 330 | 2X 350 | MX 350 | 2X 375 | MX 375 | 2X GTR | MX GTR | CAR TOT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | | | | | |
| 2 | 2 | | | | | | | | | | | | 2 |
| 3 | 4 | | | | | | | | | | | | 4 |
| 4 | | | | | | | | | | | | | |
| 5 | * | | | | | | | | | | | | * |
| TOT | 6 | | | | | | | | | | | | 6 |

** LOCOMOTIVES **

| HP/ GTON | 150 | 260 | 2X 300 | MX 300 | 2X 330 | MX 330 | 2X 350 | MX 350 | 2X 375 | MX 375 | 2X GTR | MX GTR | LOC TOT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | | | | | |
| 2 | | | | | | | | * | | | | | * |
| 3 | | | | | * | | | * | | | | | 1 |
| 4 | | | | | | | | | | | | | |
| 5 | | | | * | | | | | | | | | * |
| TOT | | | | * | * | | | 1 | | | | | 1 |

SUMMARY

** MIXED CONSIST TRAINS **

| HP/ GTON | 150 | 260 | 300 | 330 | 350 | 375 | GTR | TOT |
|---|---|---|---|---|---|---|---|---|
| 1 | 4 | 2 | 4 | | * | | | 11 |
| 2 | 11 | 14 | 9 | [illegible] | 2 | | 1 | 41 |
| 3 | 12 | 3 | 2 | 2 | 3 | | 1 | 23 |
| 4 | 2 | 1 | * | * | 1 | | | 5 |
| 5 | 4 | 3 | 3 | * | 3 | | | 14 |
| TOT | 34 | 22 | 19 | 7 | 10 | | 2 | 93 |

** UNIT TRAINS **

| HP/ GTON | 150 | 260 | 300 | 330 | 350 | 375 | GTR | TOT |
|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | |
| 2 | 2 | | | | * | | | 2 |
| 3 | 4 | | | * | * | | | 5 |
| 4 | | | | | | | | |
| 5 | * | | * | | | | | * |
| TOT | 6 | | * | * | 1 | | | 7 |

FIGURE 2

TRAFFIC CHARACTERISTICS INVENTORY REPORT-INITIAL

(WHEEL LOAD, TRAIN SERVICE TYPE, BY ASSIGNED HP/TON)

## Train Service-Type Data

All freight traffic is categorized as either mixed-consist train service or unit train service. Unit trains are not determined on the basis of a special identifier but rather on a car weight/car length criteria, i.e., if at least 80% of the cars in a train have a car weight within ±5% of the average car weight in the train and have a car length within ±5% of the average car length of the cars in the train, the train is considered a unit train. The percentage of total tonnage moving in each train service-type (mixed/unit) is then determined.

## Wheel Load Class

The percentage of total car and locomotive tonnage is shown segregated by wheel load class and equipment type within each train service-type. Class headings should be interpreted as follows:

'150' = Percent of tonnage moving in cars/locomotives with wheel loads less than 15,000 lbs.

'260' = Percent of tonnage moving in cars/locomotives with wheel loads between 15,000 and 26,000 lbs.

'2X' 300 = Percent of tonnage moving in cars/locomotives with wheel loads between 26,000 and 30,000 lbs. in equipment with three-axle trucks.

The same equipment-type designations apply to the rest of the wheel load classes, i.e.:

'330' = Percent of tonnage moving in cars/locomotives with wheel loads between 30,000 and 33,000 lbs.

'350' = Percent of tonnage moving in cars/locomotives with wheel loads between 33,000 and 35,000 lbs.

'375' = Percent of tonnage moving in cars/locomotives with wheel loads between 35,000 and 37,500 lbs.

'GTR' = Percent of tonnage moving in cars/ locomotives with wheel loads greater than 37,500 lbs.

Speed Potential Class

The percentage of car and locomotive tonnage moving in various train horsepower/gross ton classes is shown for each train service-type and wheel load class within train service-type. This results in the matrix format shown, where speed potential (HP/GTON) by wheel load class, by train service-type is displayed. Speed potential (HP/GTON) classes are:

HP/GTON

'1' = Percent of car and locomotive tonnage moving in trains with less than one horsepower assigned per gross ton.

'2' = Percent of car and locomotive tonnage moving in trains with between one and two horsepower assigned per gross ton.

'3' = Percent of car and locomotive tonnage moving in trains with between two and three horsepower assigned per gross ton.

'4' = Percent of car and locomotive tonnage moving in trains with between three and four horsepower assigned per gross ton.

'5' = Percent of car and locomotive tonnage moving in trains with more than four horsepower assigned per gross ton.

The Traffic Characteristics Inventory shown in Figure 2 is used to produce the Final Traffic Inventory Report shown in Figure 3. In this report, the traffic speed potential noted by the HP/GTON ranges in Figure 2 is converted to the actual speed classes shown in the final inventory report. This is done by first converting horsepower/ton ranges into specific hp/ton values. This is accomplished by analyzing both actual past and recommended power assignments on each traffic link under analysis. Where otherwise unavailable, mid-range

FIGURE 3

TRAFFIC CHARACTERISTICS INVENTORY REPORT-FINAL

(WHEEL LOAD, TRAIN SERVICE TYPE, BY TRAIN SPEED)

| SEG-ID | LN CODE | SEG FR | SEG TO | MP FROM | MP TO | MILES | ANNUAL CTON | ANNUAL TTON | ANNUAL GTM | ANNUAL TRAINS | ANNUAL CARS | AVCARWT | % LOC TONNAGE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 603 | 5 | 6 | 6 | 43.000 | 46.900 | 3.9 | 1253265 | 1046019 | 4587831 | 793 | 23192 | 45 | 17 |

MIXED CONSIST TRAINS — ** CARS ** WHEEL LOAD CLASS / ** LOCOMOTIVES ** WHEEL LOAD CLASS

| MPH | HP/ GTON | 150 | 200 | 2X 300 | MX 300 | 2X 330 | MX 330 | 2X 350 | MX 350 | 2X 375 | MX 375 | 2X GTR | MX GTR | CAR TOT | 150 | 260 | 2X 300 | MX 300 | 2X 330 | MX 330 | 2X 350 | MX 350 | 2X 375 | MX 375 | 2X GTR | MX GTR | LOC TOT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 27 | 1 | 4 | 2 | 4 | | | | | | | | | | 30 | | | | 1 | | | | * | | | | | 1 |
| [illegible] | 2 | 11 | 14 | 7 | | * | | | | | | 1 | | 37 | | | | 1 | * | | | 3 | | | | | 4 |
| 40 | 2 | 12 | 3 | 2 | | * | | * | | | | 1 | | 19 | | | | 1 | * | | | 2 | | | | | 3 |
| 41 | 4 | [illegible] | 1 | | | * | | | | | | | | 4 | | | | * | | | | 1 | | | | | 1 |
| 42 | [illegible] | [illegible] | 3 | * | | | | | | | | | | 7 | | | | 2 | * | | | 3 | | | | | 7 |
| TOT | | 24 | 22 | 13 | | 7 | | * | | | | 2 | | 77 | | | | 5 | 1 | | | 9 | | | | | 16 |

UNIT TRAINS — ** CARS ** WHEEL LOAD CLASS / ** LOCOMOTIVES ** WHEEL LOAD CLASS

| MPH | HP/ GTON | 150 | 200 | 2X 300 | MX 300 | 2X 330 | MX 330 | 2X 350 | MX 350 | 2X 375 | MX 375 | 2X GTR | MX GTR | CAR TOT | 150 | 260 | 2X 300 | MX 300 | 2X 330 | MX 330 | 2X 350 | MX 350 | 2X 375 | MX 375 | 2X GTR | MX GTR | LOC TOT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 27 | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| [illegible] | 2 | [illegible] | | | | | | | | | | | | 2 | | | | | | | | * | | | | | * |
| 40 | 3 | 4 | | | | | | | | | | | | 4 | | | | | * | | | * | | | | | 1 |
| 41 | 4 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 42 | [illegible] | * | | | | | | | | | | | | [illegible] | | | | * | | | | | | | | | * |
| | TOT | 6 | | | | | | | | | | | | 6 | | | | * | * | | | 1 | | | | | 1 |

SUMMARY

** MIXED CONSIST TRAINS ** WHEEL LOAD CLASS / ** UNIT TRAINS ** WHEEL LOAD CLASS

| MPH | HP/ GTON | 150 | 260 | 300 | 330 | 350 | 375 | GTR | TOT | HP/ GTON | 150 | 260 | 300 | 330 | 350 | 375 | GTR | TOT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 27 | 1 | 4 | 2 | 4 | | * | | | 11 | 1 | | | | | | | | |
| [illegible] | 2 | 11 | 14 | 9 | 5 | [illegible] | | 1 | 41 | 2 | 2 | | | | * | | | 2 |
| 40 | [illegible] | 12 | [illegible] | [illegible] | 2 | [illegible] | | 1 | 27 | 3 | 4 | | | * | * | | | 5 |
| 41 | [illegible] | [illegible] | 1 | * | * | 1 | | | [illegible] | 4 | | | | | | | | |
| 42 | [illegible] | [illegible] | [illegible] | [illegible] | * | [illegible] | | | 14 | 5 | * | | * | | | | | * |
| | TOT | 24 | 22 | 19 | 7 | 10 | | 2 | [illegible] | TOT | 6 | | * | * | 1 | | | 7 |

hp/ton values were used. These resulting horsepower assignments, together with estimates of other relevant train and track characteristics were then used with a train performance simulation model to predict actual average train speeds for each horesepower assignment, for each traffic link. The resulting inventory, then, is a traffic characterisitics profile (tonnages, speeds, wheel loads, train service-types) for each traffic link. It should be noted that traffic link identifiers (SEG ID) are also carried in the Master Track Directory File to establish all relevant track and traffic conditions on any track segment.

As stated, the Traffic Characteristics Inventory will serve both the analysis of the effect of different types and volumes of traffic on various types of track structure and also the calculation and assignment of resulting variable track structure costs.

Task 3. <u>Develop Relationships Which Adequately Describe the Physical and Economic Behavior of the Track Structure as Determined by the Specific Nature of the Track/Traffic Environment</u>

This task is, of course, crucial to the application of any predictive approach to track structure costing. The implications here are that enough data and information can be accumulated or that engineering opinion is sufficiently solidified to facilitate the accurate prediction of track structure performance as a function of various types and volumes of traffic. There is no question that the general lack of relevant and well-documented track research data treating a wide range of track/traffic conditions makes this presently the most difficult and tentative aspect of the analysis. There is also no doubt, however, that economic analyses of railroad track structure must seek to utilize the results of new and expanded research activities currently in progress or planned for the future, and that the methods and procedures employed in such analyses should be structured to take advantage of the more recent and better data forthcoming.

This task, then, has concentrated on developing the most adequate set of predictive 'tools' which can be formulated from existing data and drawing upon the judgement and experience of Southern Pacific engineering forces. There will, of course, be potential for wide differences of opinion between railroads as to the most appropriate measures of track structure performance to be expected under varying track/traffic conditions. While many of these differences may arise as a result of differing maintenance policies and practices, individual railroads may perhaps possess better internally-developed data for application to specific conditions. One of the most important aspects, then, of predictive procedures used to analyze the economic costs of the railroad track structure is that such procedures be capable of reflecting differing assumptions as to maintenance policies and practices, and of accepting variations in track structure performance data.

The approach to the effort embodied in this task has been to 1) develop a preliminary set of factors, equations, estimates, etc. for predicting track structure behavior substantially based on relevant existing research data or hypotheses 2) test these relationships both against specific sample track and traffic conditions on the study trackage and against the judgement and opinions of experienced track personnel and 3) modify the initial data where substantial justification results from the analysis of sample trackage and the judgement of engineering forces. These three processes and resulting data are described below.

## I. Development of Initial Predictions of Track Structure Behavior

Working with industry research data including that of the American Railway Engineering Association (AREA) and available information developed by several individual railroads, and also using several as yet untested hypotheses in areas where relevant data could be found, initial track structure performance estimates were developed. This data was superimposed on the basic track maintenance policies and practices applicable to the sample trackage under study. Treatment of each of the major elements of the track structure is described in the following sections. Underlying these analyses is the basic assumption that track structure behavior can be established for a set of "base" track/traffic conditions and that variations from these base conditions can be reflected by a process of factor analysis, i.e., that basic track structure performance can be "factored" to predict the relative effects of differing track/traffic environments.

o Rail Life

The analysis evaluates rail life as a function of these track and traffic characteristics:

- Annual tonnage density - MGT
- Composite of rail type, weight, metallurgy and condition
- Actual average train speeds, by train service-type, by traffic wheel load class
- Track gradient

- Curvature and use of curve oilers
- Wheel loads, by train service-type, by train speed class
- Train service-type, by wheel load class, by train speed class

Policy Assumptions

- o No rail cascading program is in effect, i.e., study trackage rail is not removed from track at some specified point short of its normal physical (1st position) life in order to meet requirements for branchline/yard track rail or to reduce the amout of jointed rail in main tracks.

- o All rail on curves greater than three degrees will be assumed as eligible for transposition. Transposed rail is assumed to have a life 33% greater than curve rail which is not transposed. Transposition is assumed at 50% of this new (greater) life.

- o Rail removal criteria is based on total service condition of the rail, i.e., when head wear, surface defects and incidence of internal defects noted by rail detector car inspections render the rail unusable or unsafe at present tonnage and speed conditions, its service life in main track is considered used up. This is felt to represent normal practice rather than establishing strict removal criteria based on any single wear or defect parameter.

The factors/formulas assembled for preliminary use in predicting rail life are as follows:

1) As a function of annual tonnage density

$$T = KWD^{.565} \qquad (1)$$

where: T = life of rail in main track (MGT)
K = composite constant reflecting level of track maintenance and type/condition of track structure
W = weight of rail (lbs./yd.)
D = annual tonnage density (MGT)

The basic equation currently accepted by the AREA is used here. The equation was developed from surveys of industry experience and was felt to generally represent a predictive measure of rail life in tangent, level, jointed track under mainline speed conditions (here assumed to be 50 mph).

2) As a function of the composite of rail type, weight, metallurgy and condition as laid (new or secondhand)

The following "K" factors (for use in equation 1) were considered initially applicable to rail of the types found in the study trackage.

| Rail type, Metallurgy, Condition | Rail Weight (Lbs./Yd.) | | |
|---|---|---|---|
| | <111 | 111-123 | >123 |
| Jointed, Plain (Control-cooled), New | .545 | .545 | .545 |
| Jointed, Plain (Control-cooled), SH | .545 | .545 | .545 |
| CWR, Plain (Control-cooled), New | N/A | .774 | .964 |
| CWR, Plain (Control-cooled), SH | N/A | .774 | .964 |
| 78', Plain (Control-cooled), New | .545 | .545 | .545 |
| 78', Plain (Control-cooled), SH | .545 | .545 | .545 |
| 78', Flame-Hardened, New | N/A | .545 | .545 |
| 72', Flame-Hardened, SH | N/A | .545 | .545 |
| 78', High Silicon, New | N/A | .812 | .567 |

These preliminary values were developed based on AREA recommendation and upon rail research conducted at the University of Illinois.[1]

3) As a function of actual train speed

The early work of Professor Talbot conducted under the auspices of the AREA, American Society of Civil Engineers (ASCE) and the American Railway Association (now AAR) has served as the basis for constructing estimates of the relative dynamic effects of train speed on the track structure. This work resulted in predicting increases in dynamic impact on the track structure of 1% per mile-per-hour increase in train speed for speeds in excess of five mph. This resulted in the use of the following relative K factors (for use in equation (1)) for initial estimation of

1. Evaluation of Rail Section, Civil Engineering Studies Transportation Series No. 9, University of Illinois Project No. 44-22-20-332, Urbana, Illinois, May 1973.

the life of rail under varying speed conditions.

| Actual Speed Range | Assumed Speed | K Factor |
|---|---|---|
| 67.5 - 72.5 | 70 | .80 |
| 62.5 - 67.5 | 65 | .85 |
| 57.5 - 62.5 | 60 | .90 |
| 52.5 - 57.5 | 55 | .95 |
| 47.5 - 52.5 | 50 | 1.00 |
| 42.5 - 47.5 | 45 | 1.05 |
| 37.5 - 42.5 | 40 | 1.10 |
| 32.5 - 37.5 | 35 | 1.15 |
| 27.5 - 32.5 | 30 | 1.20 |
| 22.5 - 27.5 | 25 | 1.25 |
| 17.5 - 22.5 | 20 | 1.30 |
| 12.5 - 17.5 | 15 | 1.35 |
| 7.5 - 12.5 | 10 | 1.40 |

4) As a function of track gradient

While no research data was found to substantiate initial estimates of the effects of track gradient, preliminary factors were developed based upon a limited review of Southern Pacific experience with rail relay in relatively steep gradient, tangent track territory. The relative loss in rail life estimated to occur in such territory (resulting 'K' factor, again applied to equation (1) above) is:

| Gradient Class | K Factor |
|---|---|
| 0 - 5% grades | 1.0 |
| .5 - 1% grades | 1.0 |
| 1.0 - 1.5% grades | .9 |
| 1.5 - 2.0% grades | .8 |
| >2% grades | .7 |

5) As a function of curvature and use of curve oilers

The following factors, based on data from the AREA,[1] were initially assigned.

1. Area Bulletin 615, Volume 10, September-October 1968.

| Curve Class | K | K-Oilers |
|---|---|---|
| 0 - .5 | 1.0 | 1.00 |
| .5 - 1.5 | .87 | 1.00 |
| 1.5 - 2.5 | .74 | .88 |
| 2.5 - 3.5 | .61 | .79 |
| 3.5 - 4.5 | .49 | .70 |
| 4.5 - 5.5 | .38 | .62 |
| 5.5 - 6.5 | .30 | .55 |
| 6.5 - 7.5 | .22 | .48 |
| 7.5 - 8.5 | .16 | .44 |
| 8.5 - 9.5 | .12 | .40 |
| 9.5 | .10 | .37 |

6) <u>As a function of wheel loads</u>

The initial estimations of wheel load effects on rail life draw upon the recent work by Robert E. Ahlf of the Illinois Central Gulf Railroad as reported in AREA Proceedings.[1] This work related rail life and rail life-related maintenance costs to relative variations in contact pressure associated with varying wheel loads (car capacities). The relative factors for initial estimates of wheel load effects were derived from Figure 4, using average tare weights for the car sizes shown.

1. "Heavy Four-Axle Cars and Their Maintenance of Way Costs," AREA Bulletin No. 653, Proceedings Volume 76, June-July 1975.

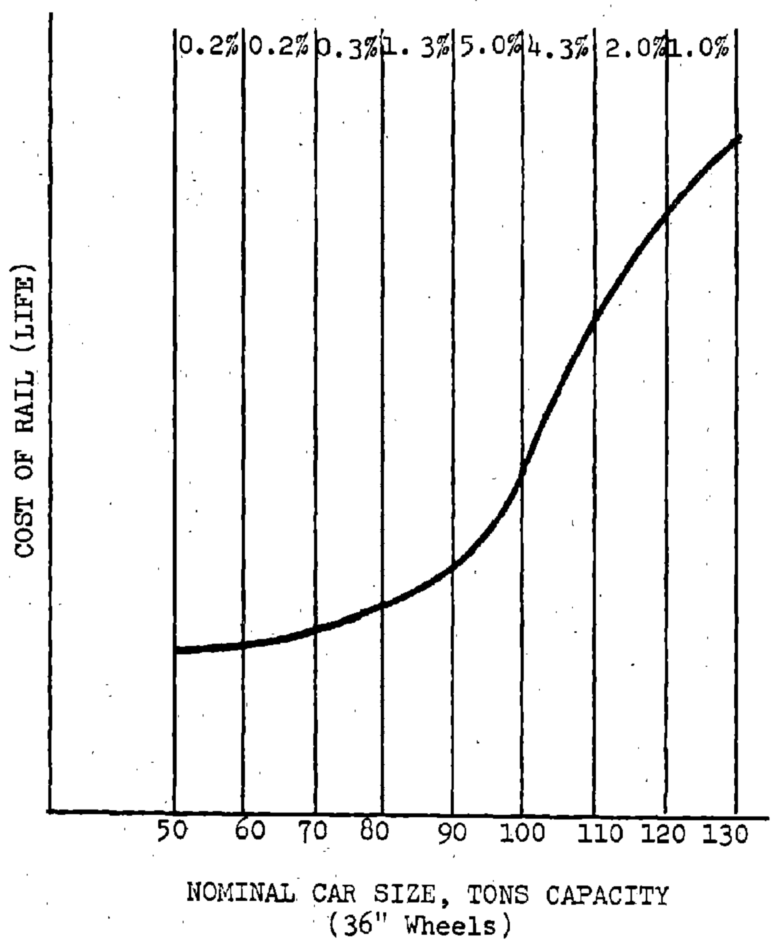


Figure 4. Percent Increase in Rail Life Cost Per One Percent Increase in Car Capacity

Rail Life Factors

| Wheel Load Range | Factor |
|---|---|
| ≤15,000 lbs. | 1.1534 |
| >15,000 lbs. ≤26,000 lbs. | .8617 |
| >26,000 lbs. ≤30,000 lbs. | .8409 |
| >30,000 lbs. ≤33,000 lbs. | .5454 |
| >33,000 lbs. ≤35,000 lbs. | .4390 |
| >35,000 lbs. ≤37,500 lbs. | .3808 |
| >37,500 lbs. | .3254 |

7) As a function of train service-type

a) Unit Trains

No initial estimates were available to adequately predict rail life effects possibly resulting from the operation of uniform consist trains.

b) Passenger Trains

Unless specific instances of unbalanced superelevation are identified, there are felt to be no unique effects on rail life due to the presence of passenger train operation. Passenger train tonnage and speed would, of course, be treated as contributory factors in the loss of rail life as described previously.

Tie Life

The analysis evaluates tie life as a function of the following track and traffic characteristics:

- Annual tonnage density
- Track curvature
- Rail weight (tie plate size)
- Type of rail
- Track gradient
- Wheel load and track support
- Train speed
- Train service-type

Policy/Maintenance Practice Assumptions

1. Cross ties in the trackage under study are main track standard (7" X 9" X 9') creosoted wooden ties on 19½-inch centers.

2. Tie conditions at least meet FRA minimum standards for adequate track support in each FRA track class.

The factors/formulas/estimates intended for initial use in predicting cross tie life are as follows:

1) As a function of annual tonnage density and curvature

Main track tie lives reflected in AREA data[1] can be predicted with good accuracy with the following equation:

$$\text{Life(MGT)} = e^{\left[4.0925 - .06077(\alpha)\right]} D^{.816872} \quad (2)$$

where: D = Annual Gross Tonnage (MGT)
$\alpha$ = Degree of curvature

This equation will be adjusted for specific variations in the remaining track and traffic characteristics by the factors developed in items (2) through (7) below. The equation, while probably also representative of track conditions other than those described as "base" conditions (level, jointed rail, main track territory, subject to average speeds approximating 50 mph) was felt to provide the most reasonable basis for preliminary tie life prediction.

2) <u>As a function of rail weight (tie plate size)</u>

Using 18" tie plates as the "standard" or "base" condition, relative factors were developed to reflect the effects of tie plate cutting by using the ratio of other tie plate areas to the standard. For the study trackage, these are:

| Rail Weight Class | K |
|---|---|
| >132 lb. | 1.0 |
| <132 lb. | .925 |

3) <u>As a function of type of rail</u>

Initial relative tie life factors for ties in continuous welded rail (CWR) or 78' welded rail (WR) territory are:

| Rail Type | K |
|---|---|
| Jointed | 1.00 |
| CWR | $1.03 = \left(1 + \frac{\text{JTS/mi(CWR)}}{\text{JTS/mi(JT)}}\right)$ |

1. AREA Bulletin No. 615, Proceedings Volume 70, September-October 1968.

| | | |
|---|---|---|
| WR | 1.015 = | Elimination of half as many Joints as for Jointed vs. CWR |

4) <u>As a function of gradient</u>

No factors or tie data initially available.

5) <u>As a function of wheel load and track support</u>

Preliminary factors for tie life are based upon Talbot's rail deflection equation (3) and the previously cited work of Robert E. Ahlf.

$$Y_o = -\frac{P}{\sqrt[4]{64EIu^3}} = -0.5\,\frac{P}{u}\sqrt[4]{\frac{u}{4EI}} \qquad (3)$$

where:

Y = rail deflection (inches)

P = dynamic wheel load (pounds)

u = modulus of elasticity of rail support(lbs./in.$^2$)

E = modulus of elasticity of rail steel($30\times10^6$ lbs./in.$^2$)

I = moment of inertia of rail section

This work assumes that tie cost/life is directly proportional to deflection. Holding this to be true, relative life factors were determined based upon relative deflection. The base case used was:

1. Wheel load = 19,385 lbs.
2. Track support modulus = 3500
3. Rail weight = 132 lb./yd.

Relative factors for wheel load were determined from the relative deflections holding u, I constant (equation 4).

$$\frac{Y_o}{Y'} = \frac{0.5\,\frac{P_o}{u}\sqrt[4]{\frac{u}{4EI}}}{0.5\,\frac{P'}{u}\sqrt[4]{\frac{u}{4EI}}} = \frac{P_o}{P'} \qquad (4)$$

Resulting initial relative wheel load factors for application to equation (2) and the specific wheel loading used in the factor calculator for each wheel load class are shown below. Specific wheel loadings are based on an analysis of car capacities and respective tare weights of Southern Pacific system freight cars.

| Wheel Load Class | | Wheel Load (lbs.) Wheel Load Used in Calculation | Factor |
|---|---|---|---|
| ≤15,000 | | (7,900) | 2.4541 |
| >15,000 | ≤26,000 | (25,400) | 0.7632 |
| >26,000 | ≤30,000 | (27,500) | 0.7049 |
| >30,000 | ≤33,000 | (32,700) | 0.5928 |
| >33,000 | ≤35,000 | (34,500) | 0.5619 |
| >35,000 | ≤37,000 | (36,000) | 0.5385 |
| >37,500 | | (40,000) | 0.4846 |

Initial relative factors for predicting the effects of track support quality on tie life were determined from relative deflections holding P, I constant (equation 5).

$$\frac{Y_o}{Y'} = \frac{0.5 \frac{P}{u_o} \sqrt[4]{\frac{u_o}{4EI}}}{0.5 \frac{P}{u'} \sqrt[4]{\frac{u'}{4EI}}} = \frac{u' \sqrt[4]{u_o}}{u_o \sqrt[4]{u'}} \qquad (5)$$

For this work, it was necessary to develop and describe the various "classes" of track support quality (and to estimate associated values of track support modulus, u,) existing on the trackage under study. Classes were constructed based on type, condition, and depth of ballast, adequacy of drainage and general stability of subgrade. These are shown below.

Track Support Class Descriptions

1. Good ballast, good drainage, stable subgrade
2. Good ballast, good drainage, unstable subgrade
3. Good ballast, poor drainage, stable subgrade

4. Foul ballast, poor drainage, fair subgrade
5. Foul ballast, poor drainage, poor or unstable subgrade
6. Foul ballast (due to sand), good drainage, stable subgrade

Ballast Depth

A. Eight inches or more
B. Six to eight inches
C. Less than six inches

These ballast sections refer to depth of primary ballast and do not include depth of sub-ballast, generally taken to be 8"-12" on the study trackage. Track support class is defined by one of each of the above factors, for example:

1-B: Six to eight inches of good ballast with good drainage and a stable subgrade.

These track support descriptions are necessarily general, although the following guidelines have been applied in order to consistently treat the trackage under study:

- "Good" ballast is taken to be clean, dry ballast material with high shearing strength, good internal friction, lateral stability, with high resistance to abrasion and weathering.

- "Good" drainage is taken to be territory with adequate runoff, with little or no accumulation of standing water.

- "Stable" subgrade is taken to be territory which has either been permanently stabilized or where no such work is contemplated or required. Occasional or infrequent minor stabilization by section forces would not categorize track as "unstable."

- "Foul" ballast (classes four and five) is mud or oil contaminated ballast section.

Estimated values for associated track support moduli were also based primarily on the previously cited work, although general modifications resulted from reviewing relative track support quality with Southern Pacific track maintenance personnel.

Resulting initial tie life factors and associated track support moduli for the track support classes described above are as follows:

Factors for Track Support Class

| Track Support Class | Ballast Depth Class A | B | C |
|---|---|---|---|
| 1,6 | 1.1056 | 1.0000 | 0.8910 |
| 2 | 0.8910 | 0.7771 | 0.6572 |
| 3 | 0.7771 | 0.6572 | 0.5946 |
| 4 | 0.6572 | 0.5946 | 0.5295 |
| 5 | 0.5295 | 0.4620 | 0.3907 |

U Value by Track Class

| Track Support Class | A | B | C |
|---|---|---|---|
| 5 | 1,500 | 1,250 | 1,000 |
| 4 | 2,000 | 1,750 | 1,500 |
| 3 | 2,500 | 2,000 | 1,750 |
| 2 | 3,000 | 2,500 | 2,000 |
| 1,6 | 4,000 | 3,500 | 3,000 |

6) As a function of train speed

Preliminary relative factors developed for dynamic impact effects on rail life are also applied to tie life.

7) As a function of train service-type

a) Presence of passenger trains -- no effect

b) Unit trains - no factors or data initially available.

Surfacing Cycle Requirements

The analysis treats surfacing requirements (considered here to be the periodic program or out-of-face restoration of track line and surface with a major ballast raise and track lining) as a function of the following parameters:

- Annual tonnage (MGT)
- Train speed
- Wheel loads and track support quality

- Train service-type
- Gradient
- Type of rail
- Weight of rail

The factors/formulas/estimates developed for initial use in predicting surfacing requirements are as follows:

1) <u>As a function of Annual Gross Tonnage (MGT)</u>

   Initial predictions of major cycle length will be estimated by the equation developed from review of AREA surveys of industry practice.

$$\text{Cycle length (years)} = 10^{\left(\frac{T - A}{B}\right)} \qquad (6)$$

   where: T = annual tonnage density(MGT)
   A = a constant = 121.31
   B = a constant =-149.5

2) <u>As a function of train speed</u>

   Preliminary relative factors developed for dynamic impact effects on rail and tie life are also applied to surfacing cycle length.

3) <u>As a function of wheel loads and track support quality</u>

   Preliminary relative factors based on track deflection developed for wheel load and track support effects on tie life are also applied to surfacing cycle length.

4) <u>As a function of train service-type</u>

   a) Passenger trains -- Preliminary cycle lengths are initially decreased by 20% in passenger train territory, solely related to the need to maintain ride quality superior to that generally required for freight traffic. This factor is based on methodology developed from Chessie System experience[1] and found generally applicable by Southern Pacific track maintenance personnel.

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1. "Maintenance Costs of Jointly Operated Tracks," Chessie System Monograph, March 1974.

b) Unit trains -- no factors or specific data initially available.

5) As a function of gradient

No factors or surfacing data initially available.

6) As a function of type of rail

Based on limited data accumulated by the University of Illinois and preliminary findings on Southern Pacific, preliminary surfacing cycles are extended by one year in continuous welded rail (CWR) territory.

7) As a function of weight of rail

Initial relative factors for predicting effects of various rail weights on surfacing cycle requirements were determined by comparing relative deflections as computed from equation (4) holding P (dynamic wheel load) and (track support modulus) constant. The resulting equation becomes:

$$\frac{Y_o}{Y'} = \frac{0.5\,\frac{P}{u}\,\sqrt[4]{\frac{u}{4EI_o}}}{0.5\,\frac{P}{u}\,\sqrt[4]{\frac{u}{4EI'}}} = \sqrt[4]{\frac{I'}{I_o}} \qquad (7)$$

Relative factors determined from this equation are as follows:

| Rail Weight | K |
|---|---|
| 136 | 1.01 |
| 132 | 1.00 |
| 119 | 0.96 |
| 113 | 0.95 |
| 90 | 0.88 |

OTM (Other Track Material) Life

Life of other track material was initially related to and stated as a percentage of resulting rail life (L), based on review of existing AREA data and limited data available at the University of Illinois and on the Southern Pacific. Resulting initial relative OTM lives are shown below.

| Open Track OTM | | |
|---|---|---|
| Joint Bar Life | = | .5L |
| Track Bolts | = | .25L |
| Tie Plates | = | L |
| Spikes | = | .25L |
| Tie Plugs | = | .25L |
| Rail Anchors | = | L |
| Nut Locks | = | .25L |

| Turnouts/Track Crossings | | |
|---|---|---|
| Frogs | = | ½ life of rail in each location |
| Switch points | = | ½ life of rail in each location |
| Guard rails | = | .5L |
| Stock rails | = | ½ life of rail in each location |
| Turnout OTM except | = | same life cycles as for open track |
| Switch Plates | = | ½ life of rail in each location |
| Rail (closure) | = | Based on turnout curvature and annual gross tonnage (as for rail in open track) |

The initial factors and relationships described above for predicting track structure performance must all be combined in an analysis which estimates track structure component life under varying track and traffic conditions. Methodology for analyzing any specific track/traffic environment given data of the type previously described is presented in the following section. The example is carried out for the development of resultant rail life and the allocation of specific loss in rail life to traffic on a causal basis. Similar component life equations are developed for tie life and surfacing cycle determinations.

Rail Life Determination

As stated previously, physical conditions which affect rail life include the weight, type and metallurgy of the rail, as well as curvature and gradient. Traffic characteristics that affect rail life include annual tonnage, wheel loadings, train speed and train service type. Assuming the effects of these traffic and physical characteristics to be independent, the pertinent variables may be defined as follows:

$T$ = Total mainline track rail life in million gross tons

$D$ = Total annual tonnage in million gross tons (includes locomotive tonnage)

$W$ = Weight of rail in pounds per yard

$K$ = Factor which reflects the physical conditions associated with the roadbed. For level tangent track maintained at an adequate level, it is assumed to be 0.545. This can be modified to reflect other physical conditions such as curvature, gradient, rail metallurgy and/or continuous welded rail, as previously described.

$F_{ijk}$ = Multiplier which relates the effect upon rail life of type i wheel loads carried at class j speeds in train service-type k. This multiplier is the resultant product of rail life factors for type i wheel loads, class j speeds and train service-type k.

$D_{ijk}$ = Annual tonnage carried in type i wheel loads, at class j speeds, in train service-type k.

Using the initial basic relationship for rail life in main track shown in equation (1) of the previous section: $T=KWD^{.565}$, and assuming for this example the multiplier ($F_{ijk}$) for the traffic characteristics during the periods for which the equation was developed has a value of 1.0, consider the case where all traffic over a given roadway segment is carried in type a wheel loads at class b speeds in train service-type c. For the purpose of an example, assume that $F_{abc}$ = 1.0. Under these conditions the estimated rail life would be given by (1.0) ($KWD^{.565}$). Now consider the case where all traffic over the same roadway segment is carried in type x wheel loads at class y speeds in train service-type z, and $F_{xyz}$ = 0.5. Under these conditions the estimated rail life would be given by (0.5) ($KWD^{.565}$).

If the life of a rail under xyz traffic conditions is one half the life of rail under abc traffic conditions, then each ton of xyz traffic wears (or uses up) twice as much rail as each ton of type abc traffic. With this concept it is possible to estimate rail life for the situation where one half the annual tonnage over a given segment has type abc characteristics and the other half has type xyz characteristics.

For each ton of abc traffic moved over the segment, there is a ton of xyz traffic. However, each ton of xyz traffic wears twice as much rail as each ton of abc traffic. Therefore, over the life of the rail, one third of the rail will be worn by type abc traffic and two thirds by xyz traffic. This indicates that the tonnage of type abc traffic moved during the life of the rail would be (0.333) ($KWD^{.565}$). The total tonnage (type abc and xyz) which would move over the segment during the life of the rail would be (2) (.33) ($KWD^{.565}$). This is the estimated rail life in terms of the actual tonnage which moves over the rail.

Rail life may be determined for the general case where several different types of traffic move over the same segment of roadway. If $D_{abc}$ is the annual tonnage with type abc characteristics, then the proportion of the rail worn out by this traffic is given by:

$$\frac{\dfrac{D_{abc}}{F_{abc}}}{\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{r}\left[\dfrac{D_{ijk}}{F_{ijk}}\right]} \qquad (8)$$

The total tonnage this proportion represents is determined by equation (9).

$$\frac{\dfrac{D_{abc}}{F_{abc}}}{\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{r}\left[\dfrac{D_{ijk}}{F_{ijk}}\right]} \left[KWD^{.565}\right] \left[F_{abc}\right] \qquad (9)$$

The product of the first two terms represents the tonnage with a traffic multiplier ($F_{ijk}$) of 1.0 which would use the given proportion of the rail. Multiplying this product by the traffic converts this into tons of type abc traffic. This tonnage is a specified proportion ($D_{abc} \div D$) of the total. Therefore the total tonnage can be determined by equation (10).

$$T = \left[\frac{\dfrac{D_{abc}}{F_{abc}}}{\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{r}\left[\dfrac{D_{ijk}}{F_{ijk}}\right]}\right] \left[KWD^{.565}\right] \left[F_{abc}\right] \left[\frac{D}{D_{abc}}\right] \qquad (10)$$

This simplifies to:

$$T = \frac{KWD^{1.565}}{\sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{r} \left[\frac{D_{ijk}}{F_{ijk}}\right]} \qquad (11)$$

It can easily be shown that this equation yields the estimated rail life expected in the special cases discussed previously (page 41).

Case 1: All the traffic has a multiplier of 1.0.

$$T = \frac{KWD^{1.565}}{\frac{D}{1}} = KWD^{.565}$$

Case 2: All the traffic has a multiplier of 0.5.

$$T = \frac{KWD^{1.565}}{\frac{D}{0.5}} = 0.5\ KWD^{.565}$$

Case 3: One half of the traffic has a multiplier of 1.0.

$$T = \frac{KWD^{1.565}}{\frac{0.5D}{0.5} + \frac{0.5D}{1.0}} = \frac{KWD^{1.565}}{\frac{1.5D}{1.0}} = .667\ KWD^{.565}$$

The three basic track structure component life equations then, based on the preliminary relationships provided earlier, can be stated as follows:

Component Life Equations

Rail:

$$T = \frac{KWD^{1.565}}{\sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{r} \left[\frac{D_{ijk}}{F_{ijk}}\right]} \qquad (12)$$

where:

T = Total mainline track rail life in million gross tons

D = Total annual tonnage in million gross tons

$W$ = Weight of rail in pounds per yard

$K$ = Relative life factor which reflects the physical conditions associated with the track structure. For level, tangent, jointed track maintained at an adequate level, K is initially assumed to be 0.545. This is modified by the factors for curvature, gradient, rail metallurgy and/or continuous welded rail to reflect other physical conditions.

$F_{ijk}$ = Multiplier which relates the effect upon rail life of type i wheel loads carried at class j speeds, in train service-type k. $F_{ijk} = (F_i)(F_j)(F_k)$.

$D_{ijk}$ = Annual tonnage carried in type i wheel loads, at class j speeds, in train service-type k.

Ties:

$$H = \frac{LDe^{[4.0925 - .06077(\alpha)]}}{\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{r}\left[\frac{D_{ijk}}{F_{ijk}}\right]} \qquad (13)$$

where:

$H$ = Tie life in years

$L$ = Relative life factor which relates the effects of tie plate size, rail type (CWR, jointed) and gradient, and track support quality on tie life.

$\alpha$ = Track curvature in degrees

$F_{ijk}$ = Multiplier which relates the effect upon tie life of type i wheel loads carried at class j speeds, in train service-type k.

$D$ and $D_{ijk}$ = Defined the same as for the rail life equation.

Surfacing:

$$J = \frac{MD \quad 10^{\left(\frac{D-A}{B}\right)}}{\sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{r} \frac{D_{ijk}}{F_{ijk}}} \qquad (14)$$

where:

$J$ = Surfacing cycle length in years

$M$ = Relative cycle length factor which relates the effects of gradient, track support quality, rail weight and rail type (CWR, jointed) on surfacing cycle length.

$A$ = 121.31

$B$ = -149.5

$F_{ijk}$ = Multiplier which relates the effect upon surfacing cycle length of type i wheel loads, carried at class j speeds in train service type k.

$D$ and $D_{ijk}$ = Defined the same as for the rail life equation.

The preceding equations, together with the preliminary track and traffic factors previously described, were used to develop initial predicted track structure component lives/cycles for the study trackage and associated traffic conditions as determined by the track and traffic characteristics inventories.

## II. Test of Initial Relationships

In order to complete the next phase in the eventual development of relationships which adequately describe the physical and economic behavior of the track structure, the initial factors, equations, estimates and resulting track component service lives were tested both against sample track/traffic environments from the study trackage and the judgements and opinions of experienced track maintenance personnel.

In order to accomplish this effort, all trackage in the Master Track Directory (see Figure 1 ) was "classified" to develop homogeneous groups or classes of track, i.e., all track segments with identical track and traffic characteristics were grouped together so that sample trackage could be selected for a broad range of track "classes." An example of resulting track "classes" is shown in Figure 5.

| WGT | TYP | CD | MT | CV | O | GR | TS | TC | MILES |
|---|---|---|---|---|---|---|---|---|---|
| 136 | CWR | N | | 1 | | .3 | 3A | 0 | 1.260 |

*

## FIGURE 5

### TRACK CLASSIFICATION REPORT

********

| WESTERN DIVISION | | | | | | SACRAMENTO DIVISION | | | | | | SAN JOAQUIN DIVISION | | | | | | LOS ANGELES DIVISION | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MILES | <.5 | .5-1 | 1-2 | >2 | TOTAL | MILES | <.5 | .5-1 | 1-2 | >2 | TOTAL | MILES | <.5 | .5-1 | 1-2 | >2 | TOTAL | MILES | <.5 | .5-1 | 1-2 | >2 | TOTAL |
| | | | | | | | | | | | | | | | | | | 1.2 | 3 | 1 | | | 4 |

| TUCSON DIVISION | | | | | | SAN ANTONIO DIVISION | | | | | | OREGON DIVISION | | | | | | NWP DIVISION | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MILES | <.5 | .5-1 | 1-2 | >2 | TOTAL | MILES | <.5 | .5-1 | 1-2 | >2 | TOTAL | MILES | <.5 | .5-1 | 1-2 | >2 | TOTAL | MILES | <.5 | .5-1 | 1-2 | >2 | TOTAL |

********

| LINE | SEQ | MILEPOST FROM | MILEPOST TO | LENGTH | DV | LINK EAST | LINK WEST | TONNAGE | FREIGHT EB | FREIGHT WB | PASS EB | PASS WB |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B | 53 | 518.040 | 518.990 | .950 | 04 | 0979 | 0980 | 51.858 | 60 | 60 | 65 | 65 |
| B | 53 | 519.030 | 519.220 | .190 | 04 | 0979 | 0980 | 51.858 | 60 | 60 | 65 | 65 |
| B | 53 | 527.250 | 527.340 | .090 | 04 | 0979 | 0980 | 51.858 | 60 | 60 | 70 | 70 |
| B | 53 | 527.360 | 527.390 | .030 | 04 | 0979 | 0980 | 51.958 | 60 | 60 | 70 | 70 |

* Key

WGT = Weight of rail (lbs./yd.)
TYP = Type of rail (jt., CWR, WR)
CD = Condition of rail when laid (new or SH)
MT = Rail metallurgy (blank = plain, control-cooled)
CV = Curve class (1 = .5° - 1.5°)
O = Curve oiler indicator (blank = none)
GR = Percent grade
TS = Track code (0 = single track)
Miles = Miles of this "class" of track.

It should be noted that, when all relevant track and traffic characteristics are considered, the number of possible permutations or different track classes can be quite large (several hundred classes resulted soley from consideration of the physical track characteristics existing on the study trackage). Hence the total track miles existing in any one class may be relatively few. For purposes of this study, trackage in over forty separate "classes" was selected for analysis, based primarily on total frequency of occurance (by mileage).

Engineering estimates of track structure component performance were prepared for each of the sample track segments selected from each of the track classes. These estimates were prepared by the track maintenance (Roadmaster) personnel responsible for maintaining each specific sample track segment. In addition, comparative estimates of the relative effects of varying track and traffic conditions were obtained from these personnel, division-level engineering officers and headquarters engineering staff. All of this information was accumulated through an Engineering Field Survey Questionnaire developed for this study. The questionnaire, together with the mean value responses of engineering forces is contained in Appendix B. These surveys were completed after thorough briefing sessions with personnel involved to help insure consistent interpretations.

Subsequent analysis of the field survey data was conducted with the following objectives:

1. Test the aggregate predictive utility of preliminary relationships, factors, and methodology.

2. For as many track and traffic conditions as were feasible to isolate within the scope of the study, test the individual factors and assumptions previously developed against actual specific requirements as specified by track maintenance forces.

3. Use the resulting data to modify any or all previously developed information to develop the best attainable predictive "tools" for application to the study trackage and economic cost determination.

There are, of course, several significant aspects of such a procedure which weigh heavily on the utility of final results.

1. Neither statistical significance nor scientific accuracy is implied. Where collective estimates and opinions of engineering forces differed substantially from preliminary relationships and provided results more closely related to observed (but not empirically measured) conditions,

these estimates and opinions were used to modify the predictive measures finally used in the analysis. Resulting relationships thus essentially meet only a test of reasonability at this point, pending indepth research into these areas of track/traffic environment.

2. Single-railroad bias may have been introduced to too great an extent. Where utilized, resultant data reflect the training, experience and competence of the track maintenance forces participating in this study. The point has been previously made, however, that the procedures employed in this analysis retain the capability to utilize newer, better, or simply "other" data.

With these aspects of the TOPS field survey in context, the following section contains the resultant data/relationships used in the costing phase of linehaul track structure analysis.

## III. Final Predictions of Track Structure Behavior

Equations for predicting track structure component lives as well as unit and annual costs are described in detail in Appendix E. However, the general forms of the life equations are noted in this section.

- Rail Life

The factors/formulas for predicting rail life which resulted from the field survey are as follows:

1) As a function of annual tonnage density

$$T = KWD^{.565} \qquad (1)$$

No change was made in this basic equation. For the ranges of traffic densities and specific rail weights/sections investigated, a curvilinear relationship very similar to that resulting from the use of the basic AREA equation was found. As will be shown, however, substantial variations in values for the factor "K" (as compared with the value of 0.545 typically used with the AREA equation) were determined from the survey.

2) As a function of the composite of rail type, weight, metallurgy and condition as laid (new or secondhand)

The following factors resulted from the survey to determine the first-position life in million gross tons which should be expected from the types and condition of rails noted. These factors represent the constant "K" to be used with equation 1) above for predicting the service life of rail under conditions of tangent, level track with track support quality reflecting good ballast and drainage and stable subgrades. The traffic conditions attendant to these "K" factors reflect average train speeds of 50 mph, with average wheel loads of 20,000 lbs. It must be emphasized that these resultant factors also reflect the policies and practices of Southern Pacific track maintenance forces and may not agree with the data or judgments of other railroads.

| Rail Type, Metallurgy, Condition | Rail Weight (Lbs./Yd.) "K" Factor | | |
|---|---|---|---|
| | <111 | 111-123 | >123 |
| Jointed, Plain (Control-cooled), New | 1.2808 | .9810 | .9538 |
| Jointed, Plain (Control-cooled), SH | 1.2808 | .9810 | .9538 |
| CWR, Plain (Control-cooled), New | N/A | 1.3930 | 1.3544 |
| CWR, Plain (Control-cooled), SH | N/A | 1.3930 | 1.3544 |
| 78', Plain (Control-cooled), New | 1.2808 | .9810 | .9538 |
| 78', Plain (Control-cooled), SH | 1.2808 | .9810 | .9538 |
| 78', Flame-Hardened, New | N/A | .9810 | .9538 |
| 72', Flame-Hardened, SH | N/A | .9810 | .9538 |
| 78', High Silicon, New | N/A | 1.4616 | 1.4210 |

3) As a function of train speed

| Actual Speed Range | Assumed Speed | K Factor |
|---|---|---|
| 67.5 - 72.5 | 70 | .80 |
| 62.5 - 67.5 | 65 | .85 |
| 57.5 - 62.5 | 60 | .90 |
| 52.5 - 57.5 | 55 | .95 |
| 47.5 - 52.5 | 50 | 1.00 |
| 42.5 - 47.5 | 45 | 1.05 |
| 37.5 - 42.5 | 40 | 1.10 |
| 32.5 - 37.5 | 35 | 1.15 |
| 27.5 - 32.5 | 30 | 1.20 |
| 22.5 - 27.5 | 25 | 1.25 |
| 17.5 - 22.5 | 20 | 1.30 |
| 12.5 - 17.5 | 15 | 1.35 |
| 7.5 - 12.5 | 10 | 1.40 |

No changes were made to these initial factors. When judgmental responses of track forces were related to specific experience with train speed effects on main line trackage (excluding branch lines, yard, and miscellaneous tracks), reasonably close agreement with the dynamic impact factors developed by A. N. Talbot was obtained.

4) As a function of track gradient

| Gradient Class | K Factor |
|---|---|
| 0 - .5% | 1.0 |
| .5 - 1.0% | .9655 |
| 1.0 - 1.5% | .9029 |
| 1.5 - 2.0% | .8010 |
| 2.0 - 2.5% | .7326 |
| > 2.5% | .6821 |

5) As a function of curvature and use of oilers

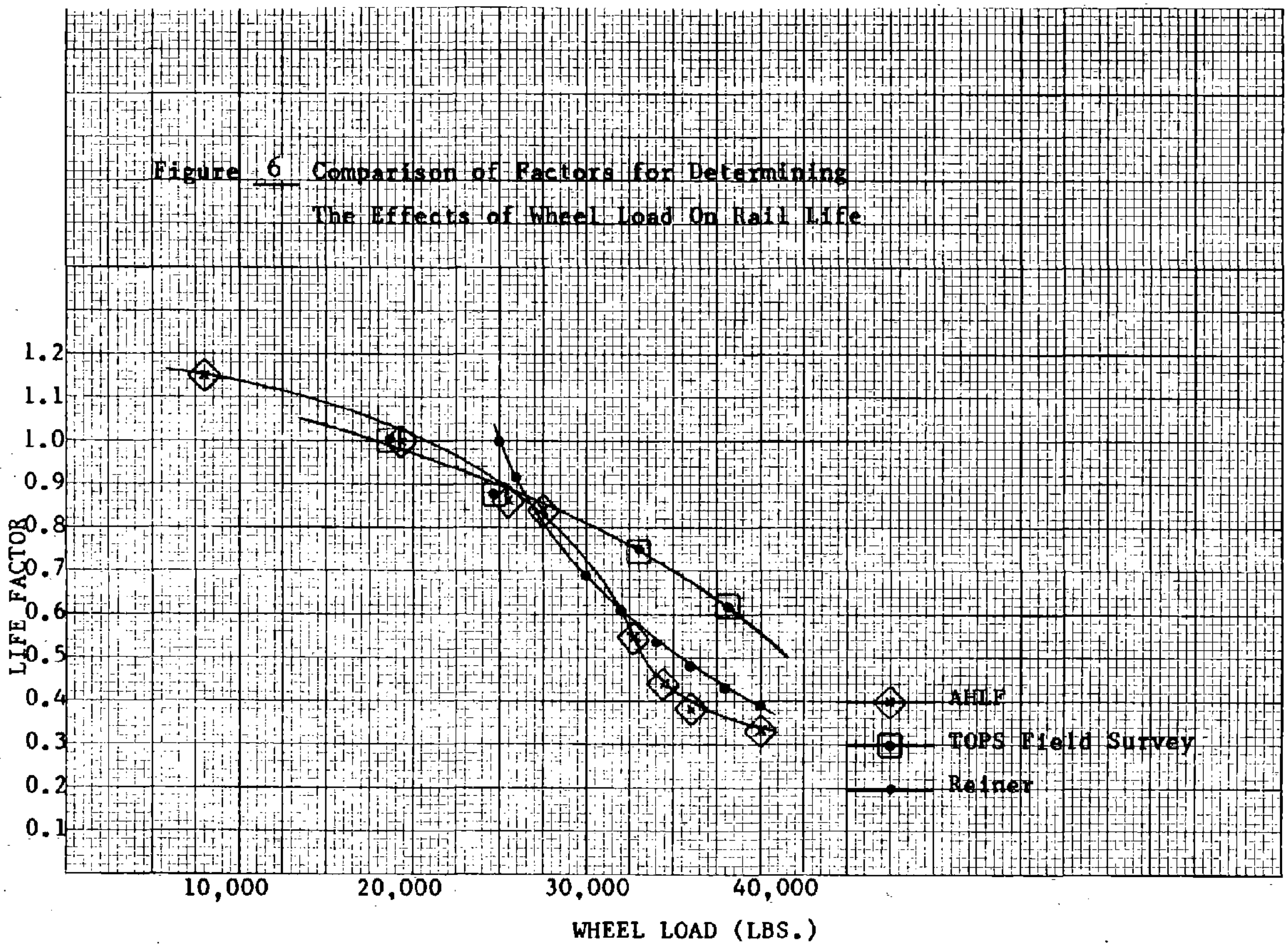
| Curve Class | K | K-Oilers |
|---|---|---|
| 0 - .5 | 1.0 | 1.00 |
| .5 - 1.5 | .87 | 1.00 |
| 1.5 - 2.5 | .74 | .88 |
| 2.5 - 3.5 | .61 | .79 |
| 3.5 - 4.5 | .49 | .70 |
| 4.5 - 5.5 | .38 | .62 |
| 5.5 - 6.5 | .30 | .55 |
| 6.5 - 7.5 | .22 | .48 |
| 7.5 - 8.5 | .16 | .44 |
| 8.5 - 9.5 | .12 | .40 |
| 9.5 | .10 | .37 |

6) As a function of wheel loads

| Wheel Load Range | Factor |
|---|---|
| <15,000 | 1.1534 |
| >15,000 ≤ 26,000 | .8617 |
| >26,000 ≤ 30,000 | .8409 |
| >30,000 ≤ 33,000 | .5454 |
| >33,000 ≤ 35,000 | .4390 |
| >35,000 ≤ 37,500 | .3808 |
| > 37,500 | .3254 |

A comparison of wheel load factors based on the previously cited work of Robert E. Ahlf (Illinois Central Gulf), Imre Reiner (Chessie System), and the TOPS Field Survey is shown in Figure 6. There is little doubt that wheel load effects remain an area of considerable subjectivity, pending additional research.

Figure 6 Comparison of Factors for Determining The Effects of Wheel Load On Rail Life



7) As a function of train service type

a) Unit Trains - K = .91

b) Passenger Trains

The field survey confirmed the initial indication that unless specific instances of unbalanced superelevation are identified, there are no unique effects on rail life due to the presence of passenger train operation.

Summary - Rail Life Predictions

Individual track/traffic effects on rail life are predicted utilizing factor analysis incorporating the resultant factors or values given above. Several specific cases were evaluated by Thomas K. Dyer, Inc., Engineering Consultants, and comparisons were made between resultant TOPS data and the data/formulas resulting from the investigations made by Dyer Inc. Generally close agreement was obtained for the prediction of first-position rail life, with Dyer data tending to show slightly longer life for tangent track and slightly shorter life for curved track. In addition, estimated effects of track support quality on rail life are expressly treated by the Dyer data where no individual treatment of this factor was developed in this study.

o Tie Life

The factors/formulas for predicting tie life which resulted from the field survey are as follows:

1) As a function of annual tonnage density (D) and degree of curvature ($\alpha$)

$$\text{Life (MGT)} = \left(e^{[4.5881 - 0.06077(\alpha)]}\right)(1.181)(D^{0.60825}) \qquad (15)$$

2) As a function of rail weight (tie plate size)

| Rail Weight Class | K |
|---|---|
| >132 lb. | 1.0 |
| <132 lb. | .925 |

No changes were made to these initial factors.

3) As a function of type of rail

| Rail Type | K |
|---|---|
| Jointed | 1.0 |
| CWR | 1.03 |
| WR | 1.015 |

No changes were made to these initial factors.

4) As a function of gradient

| Gradient Class | Factor |
|---|---|
| 0 - .5% | 1.0 |
| .5 - 1.0% | .9655 |
| 1.0 - 1.5% | .9029 |
| 1.5 - 2.0% | .8010 |
| 2.0 - 2.5% | .7326 |
| 2.5% | .6821 |

5) As a function of wheel load and track support

| Wheel Load Class | Factor |
|---|---|
| ≤15,000 | 1.0 |
| >15,000≤26,000 | 0.89 |
| >26,000≤30,000 | 0.85 |
| >30,000≤33,000 | 0.76 |
| >33,000≤35,000 | 0.73 |
| >35,000≤37,500 | 0.70 |
| >37,500 | 0.63 |

Factors for Track Support Class

| Track Support Class | Ballast Depth Class | | |
|---|---|---|---|
| | A | B | C |
| 1 | 1.1056 | 1.0000 | .8910 |
| 2 | .8910 | .8228 | .7533 |
| 3 | .8228 | .7533 | .6572 |
| 4 | .7533 | .5946 | .5295 |
| 5 | .5295 | .4620 | .3907 |
| 6 | .8910 | .8228 | .7533 |

6) As a function of train speed

| Actual Speed Range | Assumed Speed | Factor |
|---|---|---|
| 67.5 - 72.5 | 70 | .80 |
| 62.5 - 67.5 | 65 | .85 |
| 57.5 - 62.5 | 60 | .90 |
| 52.5 - 57.5 | 55 | .95 |
| 47.5 - 52.5 | 50 | 1.00 |
| 42.5 - 47.5 | 45 | 1.05 |
| 37.5 - 42.5 | 40 | 1.10 |
| 32.5 - 37.5 | 35 | 1.15 |
| 27.5 - 32.5 | 30 | 1.20 |
| 22.5 - 27.5 | 25 | 1.25 |
| 17.5 - 22.5 | 20 | 1.30 |
| 12.5 - 17.5 | 15 | 1.35 |
| 7.5 - 12.5 | 10 | 1.40 |

7) <u>As a function of train service type</u>

a) Presence of passenger trains - no effect

b) Unit trains - no effect

<u>Summary - Tie Life Predictions</u>

Tie lives are predicted using the basic equation (15), again taken to represent conditions of tangent, level track; good track support, average train speeds of 50 mph, and average wheel loads of 20,000 lbs. Equation (15) is factored to reflect specific variant conditions using the factors shown in items 2 through 7 above.

Representative resultant tie lives and the imputed effects of the various track and traffic conditions were reviewed and evaluated by Thomas K. Dyer, Inc. Tie life data as developed and utilized by the Dyer firm reflected their use of published information, interviews with maintenance departments on several railroads, inspections of many miles of track throughout the country, and actual tie life information from ten tie renewal projects of three railroads.

Basic tie life formulas of TOPS and Dyer were somewhat similar, including the effects of curvature, gradient, and type of rail. Dyer data indicated more of an effect of annual tonnage density in higher tonnage ranges (above 21 MGT). A much greater impact of track support quality on tie life is evident in the TOPS data. Dyer data also indicated a separate weight-of-rail effect in addition to effects ascribed to tie plate size. No such separate effect was noted or developed in the TOPS survey. A portion of the Dyer data (two tie renewal projects) indicated predominance of the number of wheel load cycles over annual tonnage density as contributory to tie life degradation.

Additional documented and controlled tie data is required to isolate and substantiate the effect of various track/traffic environments on cross tie life.

o <u>Surfacing Cycle Requirements</u>

The factors/formulas for predicting surfacing cycle requirements which resulted from the field survey are as follows:

1) <u>As a function of annual tonnage density (D)</u>

$$\text{Cycle Length (years)} = (D^{-0.36302})(e^{3.2451}) \qquad (16)$$

2) <u>As a function of train speed</u>

| Actual Speed Range | Assumed Speed | K Factor |
|---|---|---|
| 67.5 - 72.5 | 70 | .80 |
| 62.5 - 67.5 | 65 | .85 |
| 57.5 - 62.5 | 60 | .90 |
| 52.5 - 57.5 | 55 | .95 |
| 47.5 - 52.5 | 50 | 1.00 |
| 42.5 - 47.5 | 45 | 1.05 |
| 37.5 - 42.5 | 40 | 1.10 |
| 32.5 - 37.5 | 35 | 1.15 |
| 27.5 - 32.5 | 30 | 1.20 |
| 22.5 - 27.5 | 25 | 1.25 |
| 17.5 - 22.5 | 20 | 1.30 |
| 12.5 - 17.5 | 15 | 1.35 |
| 7.5 - 12.5 | 10 | 1.40 |

No changes were made to these initial factors.

3) <u>As a function of wheel loads and track support quality</u>

| Wheel Load Class (lbs.) | | Factor |
|---|---|---|
| ≤15,000 | | 1.00 |
| >15,000 | ≤26,000 | .89 |
| >26,000 | ≤30,000 | .85 |
| >30,000 | ≤33,000 | .76 |
| >33,000 | ≤35,000 | .73 |
| >35,000 | ≤37,500 | .70 |
| >37,500 | | .63 |

**Factors for Track Support Class**

| | Ballast Depth Class | | |
|---|---|---|---|
| Track Support Class | A | B | C |
| 1 | 1.1056 | 1.0000 | .8910 |
| 2 | .8910 | .8228 | .7533 |
| 3 | .8228 | .7533 | .6572 |
| 4 | .7533 | .5946 | .5295 |
| 5 | .5295 | .4620 | .3907 |
| 6 | .8910 | .8228 | .7533 |

4) <u>As a function of train service-type</u>

   a) Passenger trains - Cycle lengths are decreased by 20% in passenger train territory, solely related to the need to maintain ride quality superior to that generally required for freight traffic.

   b) Unit trains - Factor = 0.90

5) <u>As a function of gradient</u>

| Gradient Class | Factor |
|---|---|
| 0 - .5% | 1.00 |
| .5 - 1.0% | .9655 |
| 1.0 - 1.5% | .9029 |
| 1.5 - 2.0% | .8010 |
| 2.0 - 2.5% | .7326 |
| >2.5% | .6821 |

6) <u>As a function of type of rail</u>

| Type of Rail | Factor |
|---|---|
| Jointed | 1.0 |
| WR | 1.0 |
| CWR | 1.2 |

7) <u>As a function of weight of rail</u>

| Rail Weight Class | Factor |
|---|---|
| >132 | 1.01 |
| >119 ≤132 | 1.00 |
| >115 ≤119 | .96 |
| >110 ≤115 | .95 |
| ≤110 | .88 |

<u>Summary - Surfacing Cycle Predictions</u>

The basic surfacing cycle equation (16) was developed to reflect the same track/traffic conditions attendant to the basic equations previously cited for rail and ties. Additionally, this basic equation specifically relates to requirements for a major (3 inch) ballast lift, accompanied by two smoothing operations (each including a minor 1 inch lift) within the duration of the basic cycle. As with the basic rail and tie life equations, specific variants as to track/traffic conditions are evaluated with the factors given in items 2 through 7, above. Surfacing cycles developed in this manner, based in part on track deflection considerations, were compared with cycles which would be associated with carrying out normal tie renewals (20-25% tie renewal on a program basis) given previously calculated tie lives. Resulting cycles were generally close to those resulting from application of the basic surfacing cycle equaltion with adjustments for specific track/traffic conditions.

- OTM (Other Track Material) Life

  Results of the field survey provided the following estimates of other track material life relative to rail life (L).

  Open Track OTM

| | | |
|---|---|---|
| Joint Bar Life | = | 1.07L |
| Track Bolts | = | .70L |
| Tie Plates | = | 1.73L |
| Spikes | = | .88L |
| Tie Plugs | = | .90L |
| Rail Anchors | = | 1.17L |
| Nut Locks | = | 1.09L |

  Turnouts/Track Crossings

| | | |
|---|---|---|
| Frogs | = | .71L |
| Switch Points | = | .76L |
| Guard Rails | = | 1.20L |
| Stock Rails | = | .70L |
| Closure Rail | = | 1.11L |
| Turnout OTM | = | 1.43L |
| Switch Plates | = | 1.35L |

  Results of the TOPS field survey indicated substantial variance or scatter in terms of perceived rail-OTM life relationships. Sufficient justification for deviating from initially developed estimates of relative OTM component lives was not found, particularly for those components whose life would normally correspond exactly to the life of rail for economic reasons rather than exhibiting the same service life given wear or defect considerations.

Track Component Economic Service Life

TOPS predicted economic service lives for rail, ties and surfacing cycle under various track conditions are shown in Figures 7 - 16. The estimation of these lives is based upon 1) the average speed on the track segment being 50 mph, 2) average wheel load being 20,000 lbs. and 3) track support quality being described by good ballast, good drainage, and a stable subgrade. It should be noted that little data has been accumulated for tonnage densities greater than 50 MGT/year and thus less accuracy can perhaps be expected for trackage in this density range.

Rail life as a function of annual tonnage, rail weight, rail type, curvature and gradient is shown in Figures 7 - 12. Cross tie life as a function of annual tonnage and curvature is shown in Figures 13 - 14. Major surfacing cycle length as a function of gradient and annual tonnage is shown in Figures 15 - 16.

It must again be emphasized that to the extent that resulting factors/formulas have been developed based on results of the TOPS field survey, they reflect the practices, experience, and judgment of Southern Pacific track maintenance personnel.

Figures 17 through 22 compare initial vs. final predictions of rail and tie lives and major surfacing cycles for various selected track conditions. These graphs show the extent to which initial assumptions/formulas were modified to reflect the results of the TOPS field survey and subsequent analyses.

A single portion of resulting track component data for specific track segments in the Master Track File is reproduced as Appendix C.

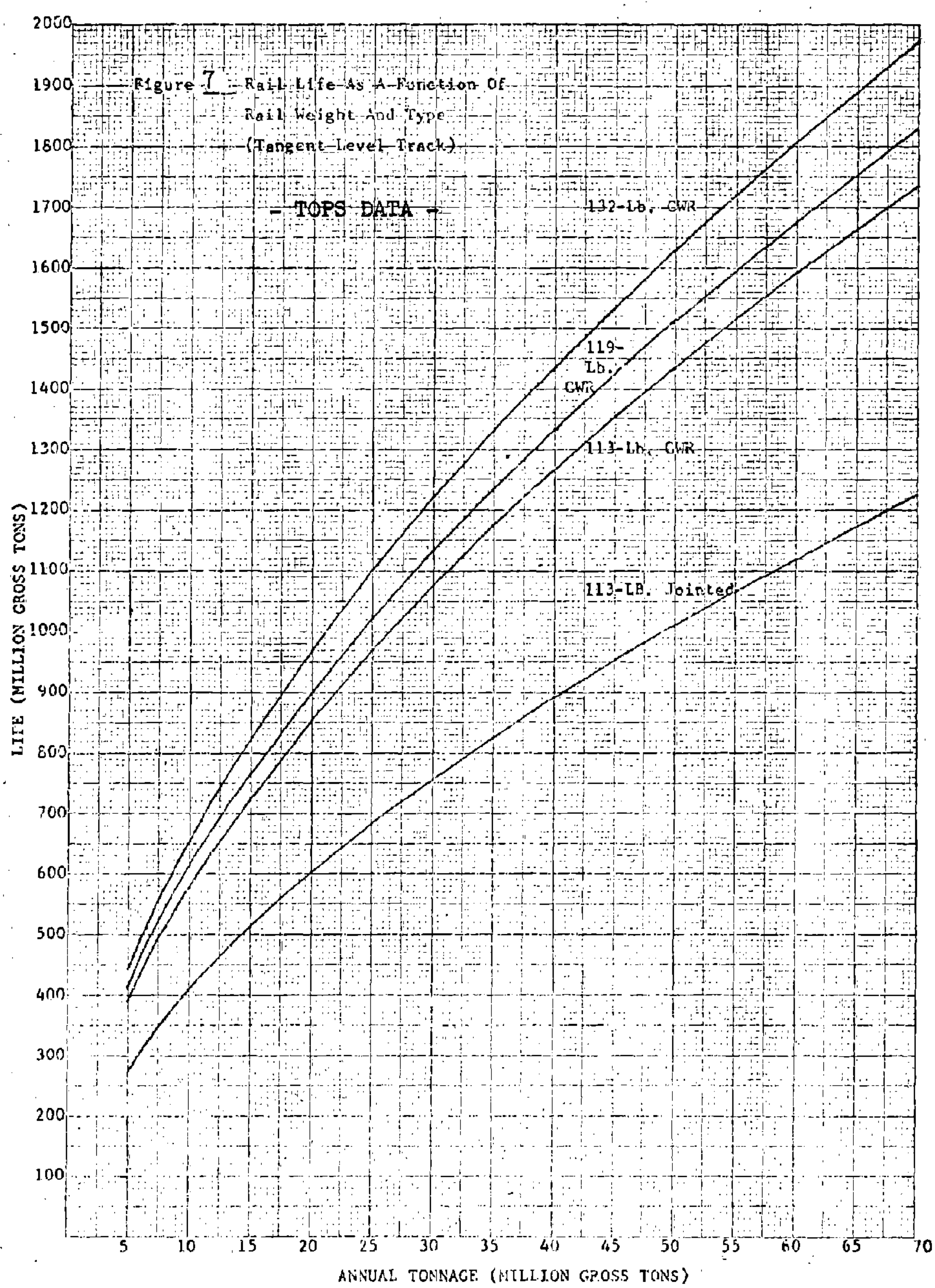


Figure 7 Rail Life As A Function Of
Rail Weight And Type
(Tangent Level Track)
- TOPS DATA -
132-Lb. CWR
119-Lb. CWR
113-Lb. CWR
113-LB. Jointed
LIFE (MILLION GROSS TONS)
ANNUAL TONNAGE (MILLION GROSS TONS)

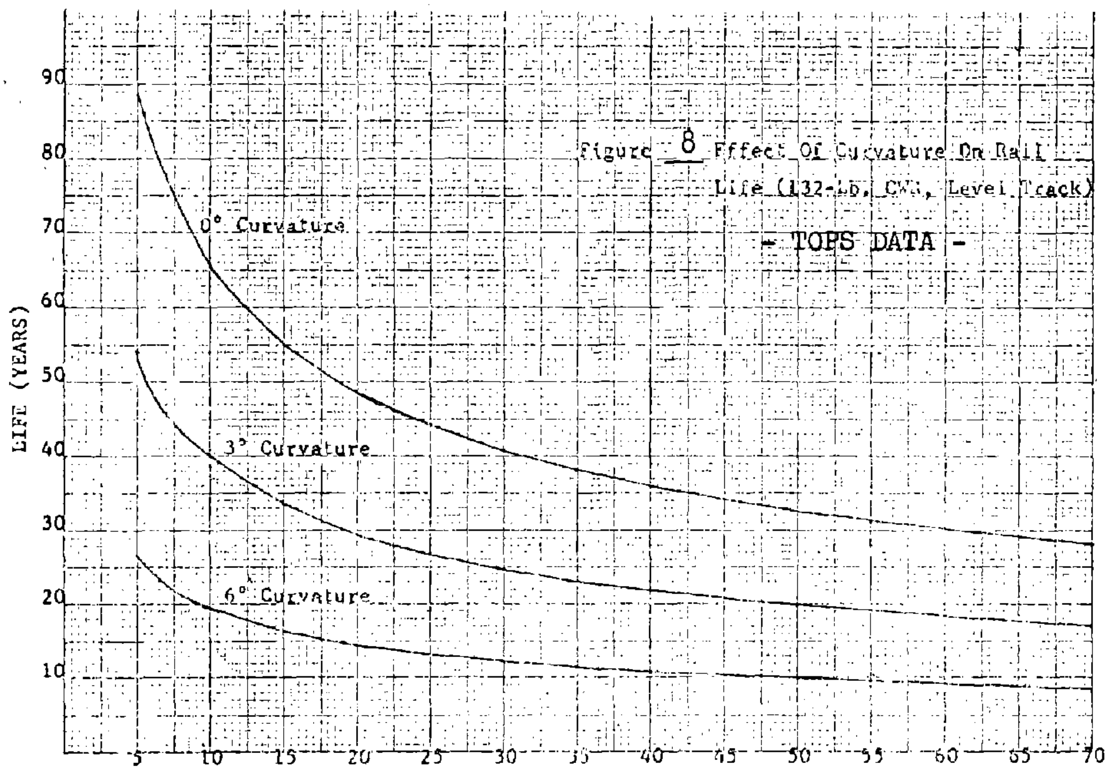


Figure 8 Effect Of Curvature On Rail Life (132-Lb. CWR, Level Track)
- TOPS DATA -
0° Curvature
3° Curvature
6° Curvature
LIFE (YEARS)
ANNUAL TONNAGE (MILLION GROSS TONS)

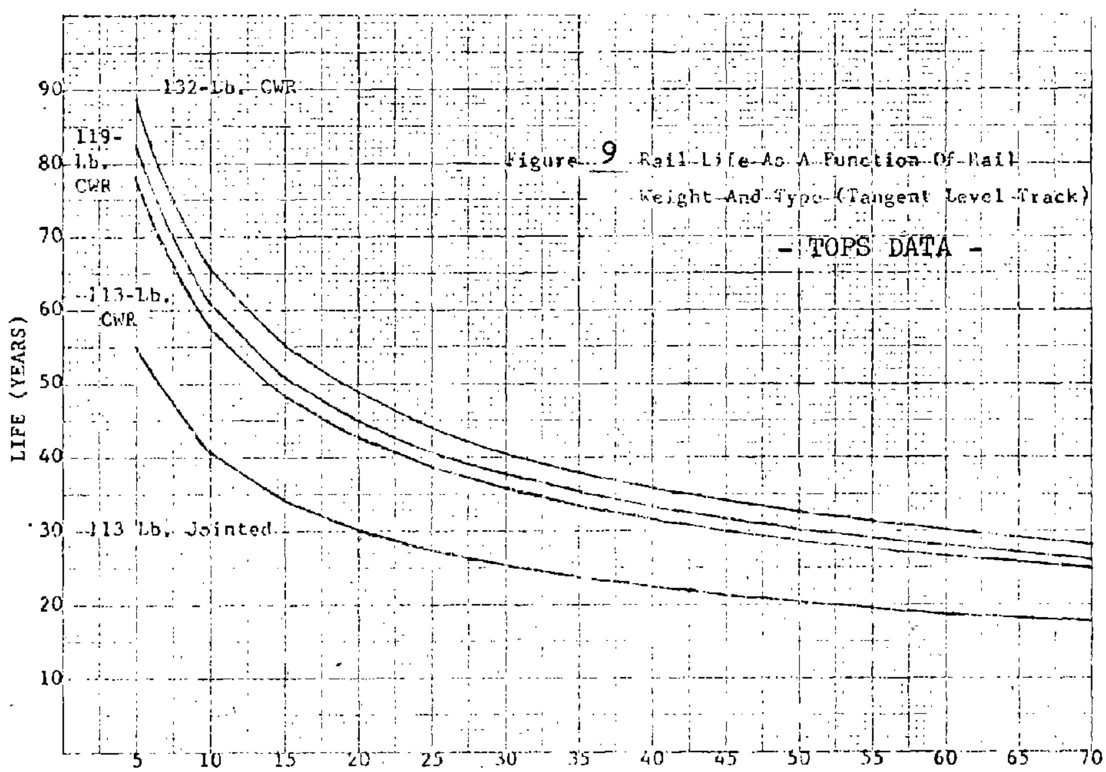


Figure 9 Rail Life As A Function Of Rail Weight And Type (Tangent Level Track)
- TOPS DATA -
132-Lb. CWR
119-Lb. CWR
113-Lb. CWR
113 Lb. Jointed
LIFE (YEARS)
ANNUAL TONNAGE (MILLION GROSS TONS)

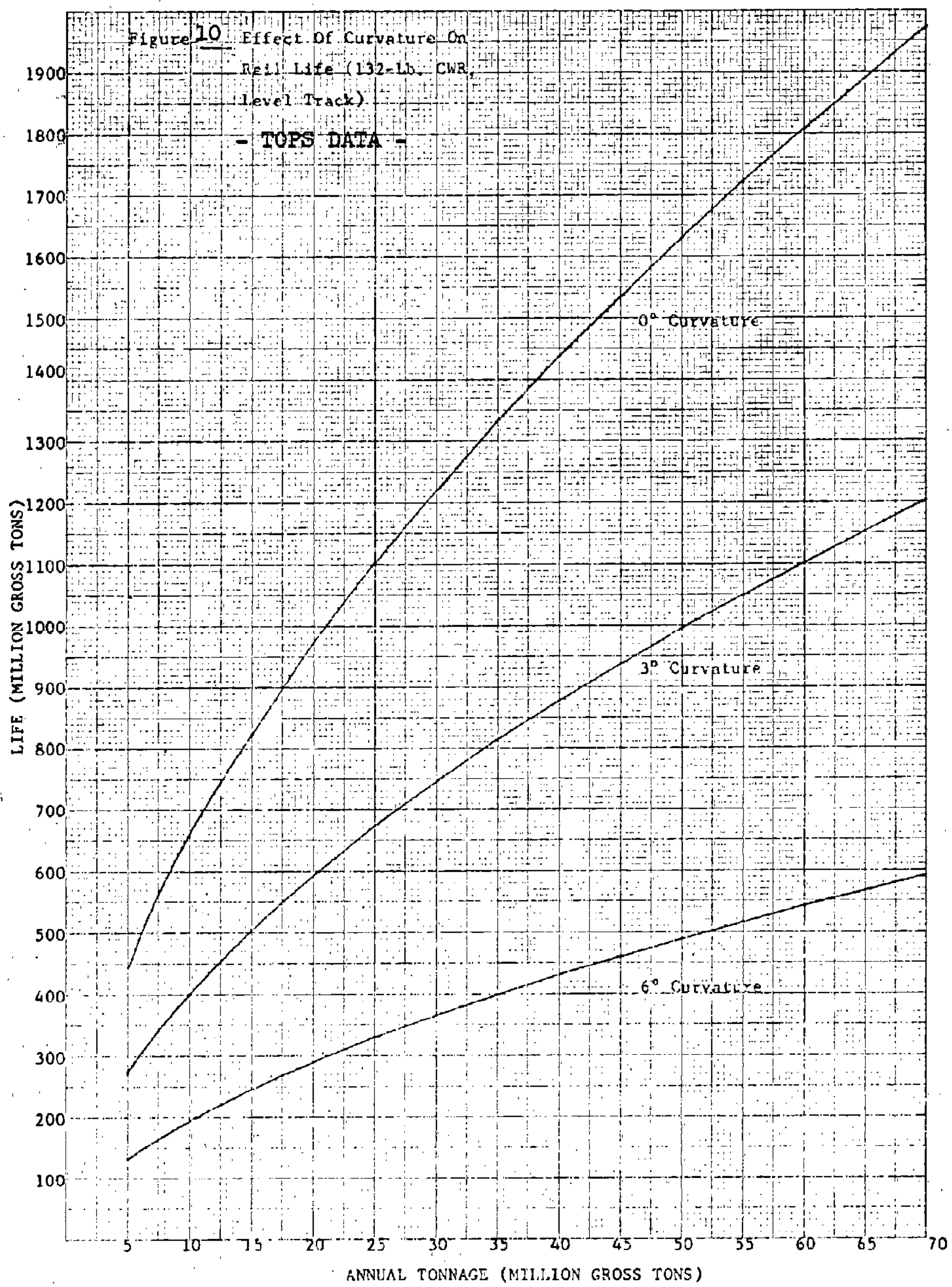


Figure 10 Effect Of Curvature On Rail Life (132-Lb. CWR, Level Track)
- TOPS DATA -
0° Curvature
3° Curvature
6° Curvature
LIFE (MILLION GROSS TONS)
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
5
10
15
20
25
30
35
40
45
50
55
60
65
70
ANNUAL TONNAGE (MILLION GROSS TONS)

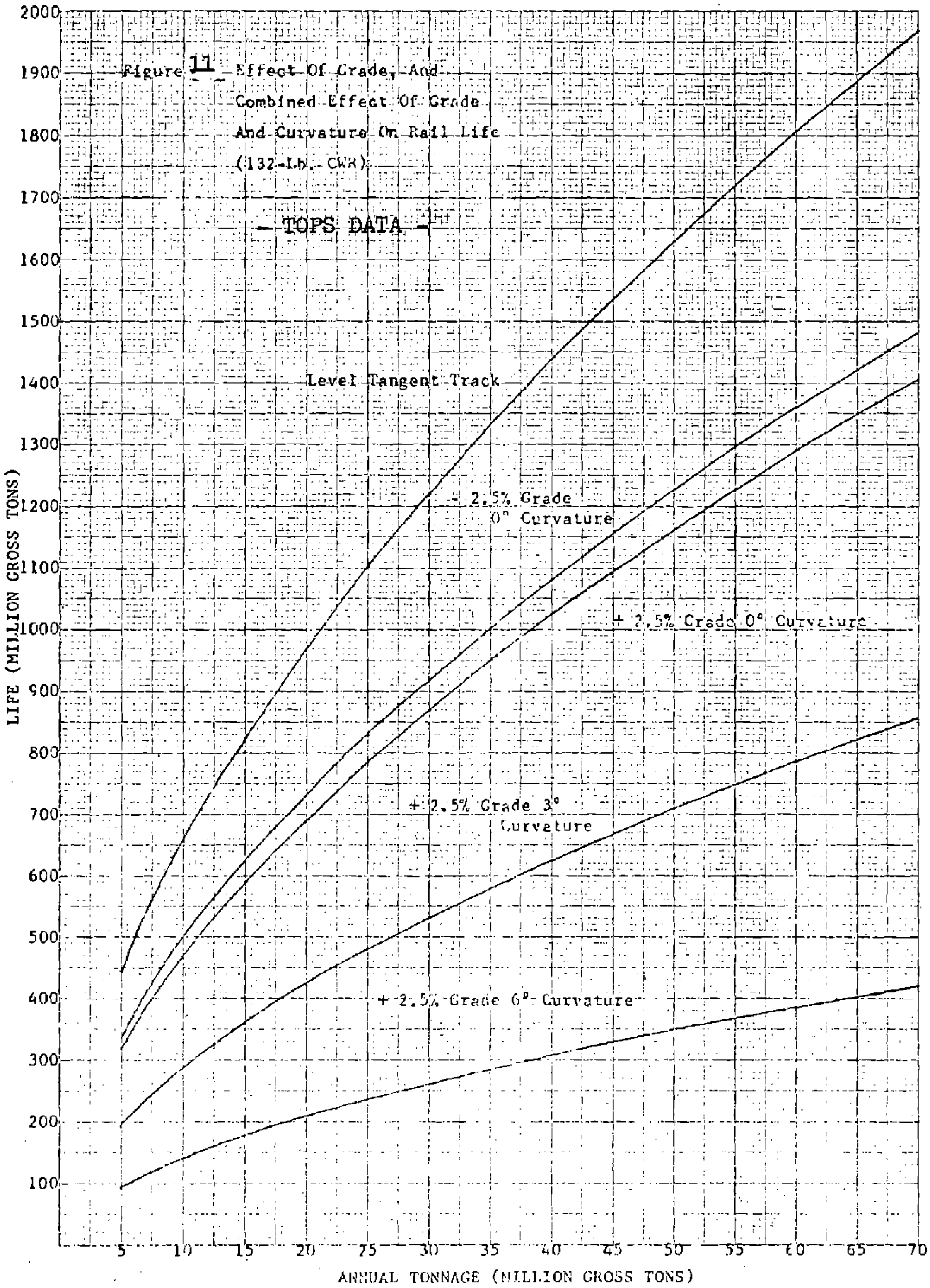


Figure 11 Effect Of Grade, And Combined Effect Of Grade And Curvature On Rail Life (132-Lb. CWR)
— TOPS DATA —
Level Tangent Track
- 2.5% Grade 0° Curvature
+ 2.5% Grade 0° Curvature
+ 2.5% Grade 3° Curvature
+ 2.5% Grade 6° Curvature
LIFE (MILLION GROSS TONS)
ANNUAL TONNAGE (MILLION GROSS TONS)
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
5
10
15
20
25
30
35
40
45
50
55
60
65
70

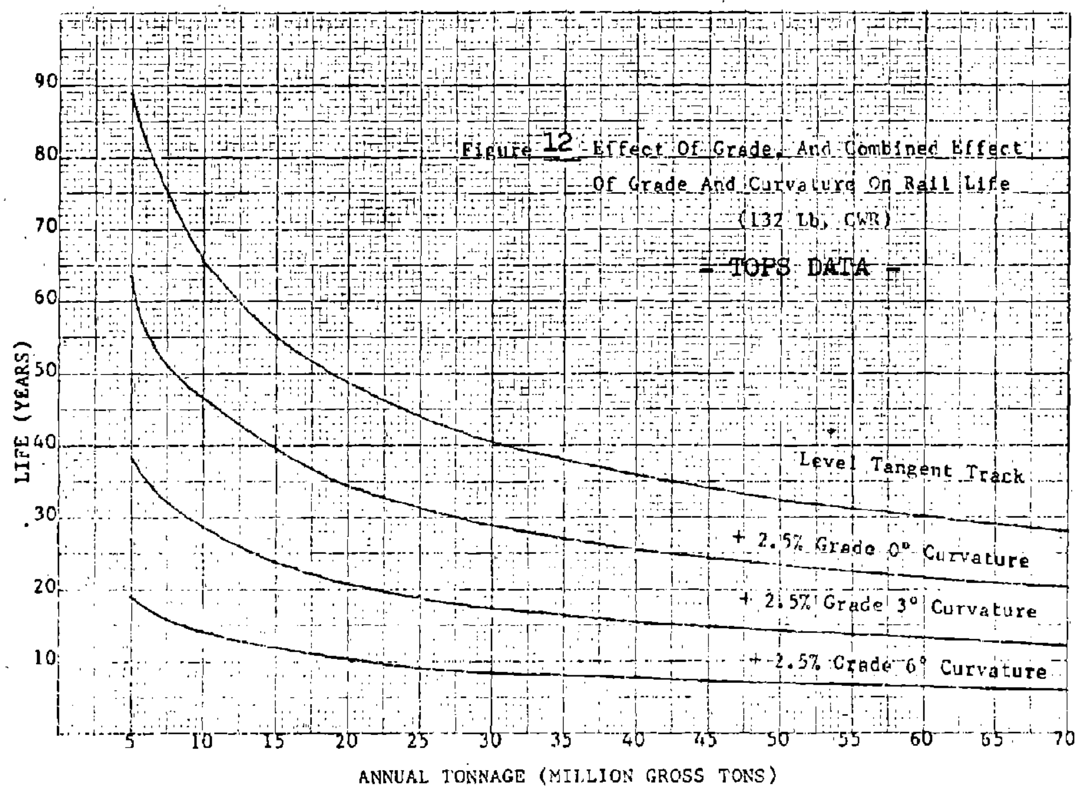



Figure 12 Effect Of Grade, And Combined Effect Of Grade And Curvature On Rail Life (132 Lb. CWR)

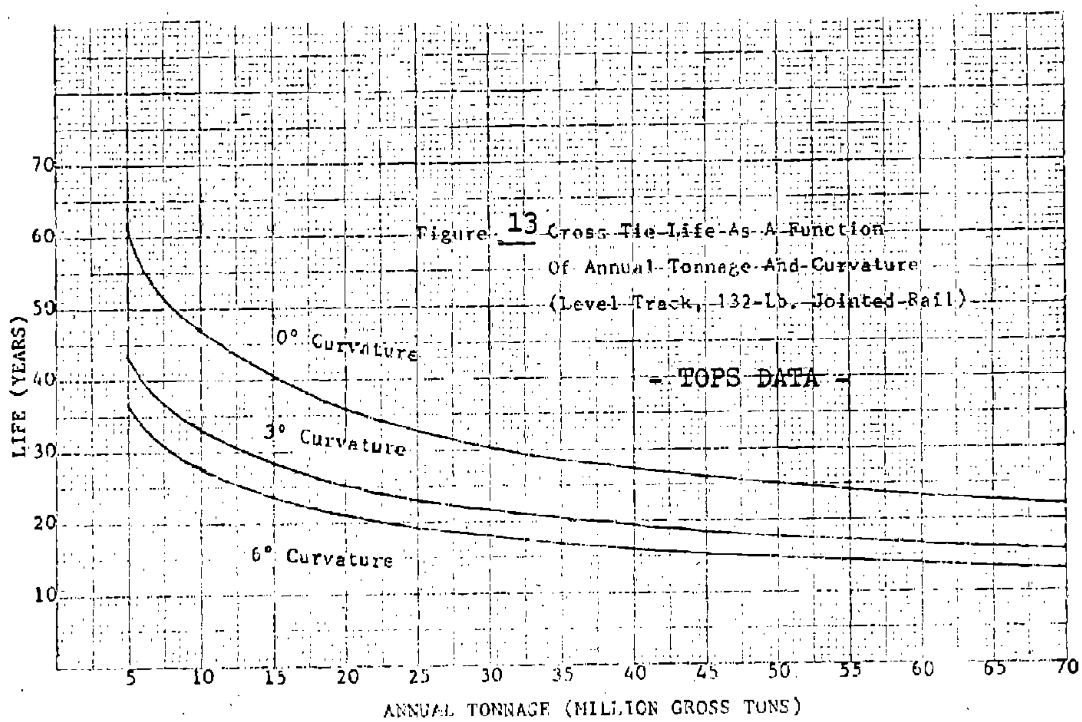



Figure 13 Cross Tie Life As A Function Of Annual Tonnage And Curvature (Level Track, 132-Lb. Jointed Rail)

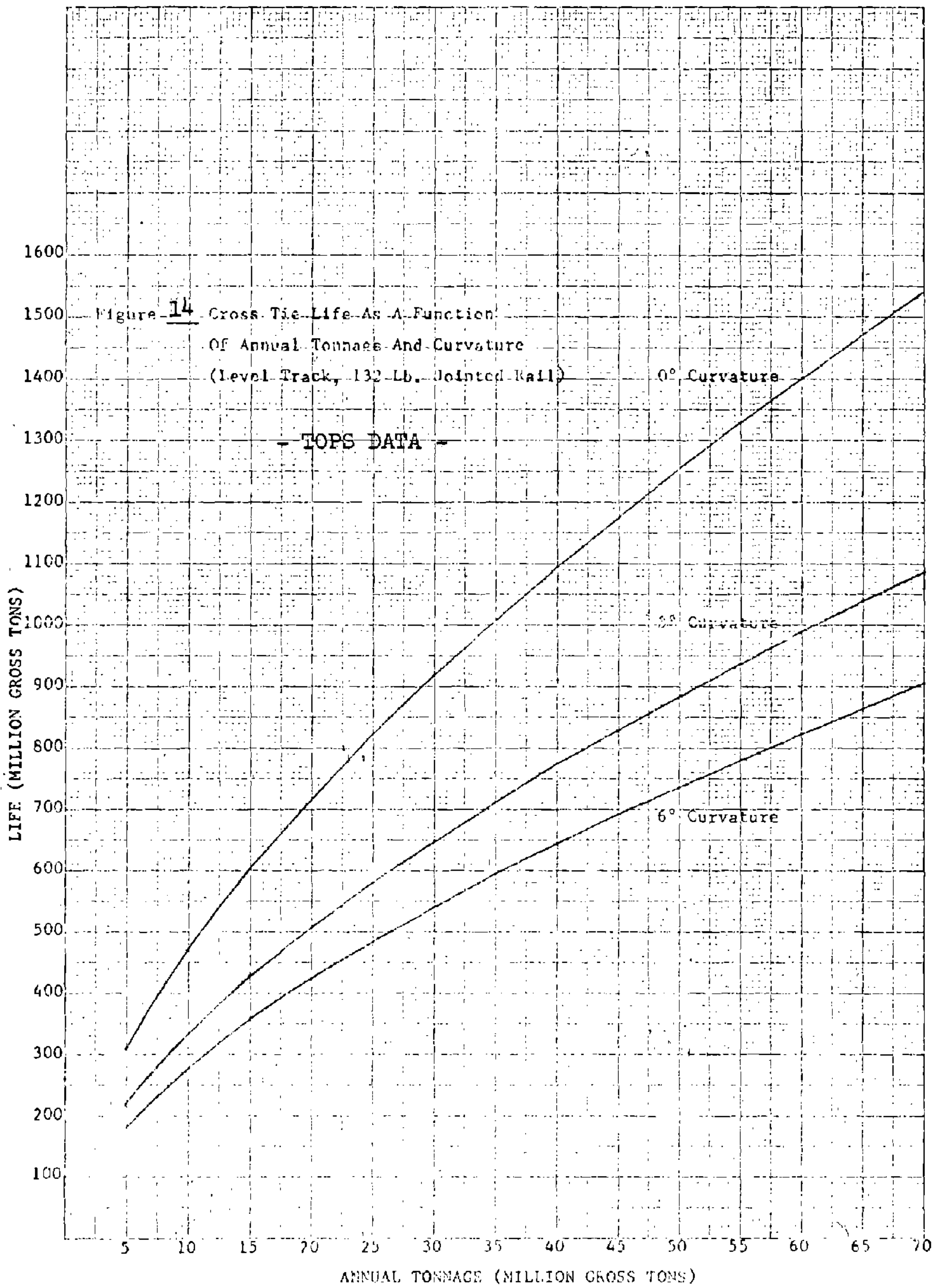


Figure 14 Cross Tie Life As A Function Of Annual Tonnage And Curvature (Level Track, 132 Lb. Jointed Rail)
- TOPS DATA -
0° Curvature
3° Curvature
6° Curvature
LIFE (MILLION GROSS TONS)
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
5
10
15
20
25
30
35
40
45
50
55
60
65
70
ANNUAL TONNAGE (MILLION GROSS TONS)

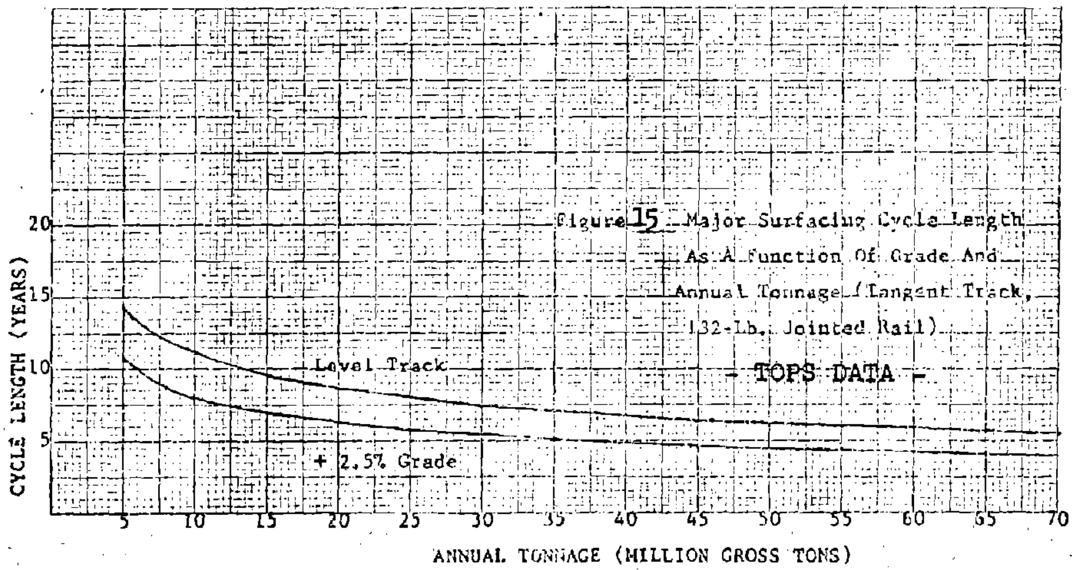



Figure 15 Major Surfacing Cycle Length As A Function Of Grade And Annual Tonnage (Tangent Track, 132-Lb. Jointed Rail)

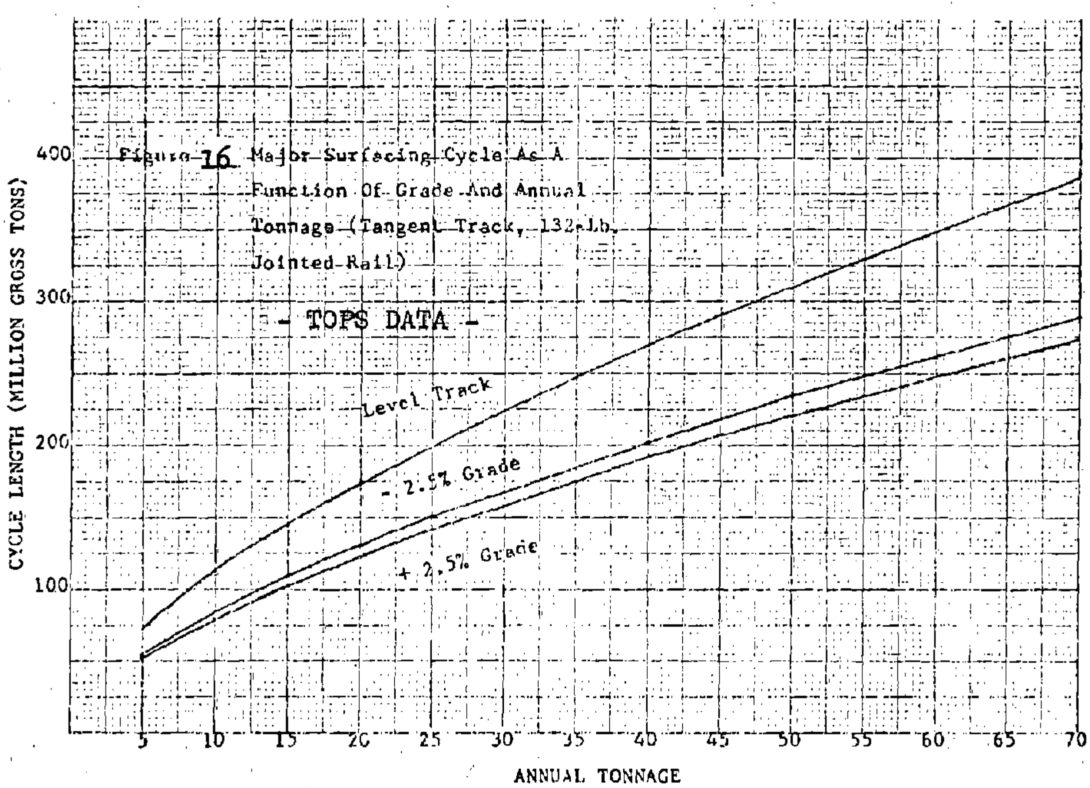



Figure 16 Major Surfacing Cycle As A Function Of Grade And Annual Tonnage (Tangent Track, 132-Lb. Jointed Rail)

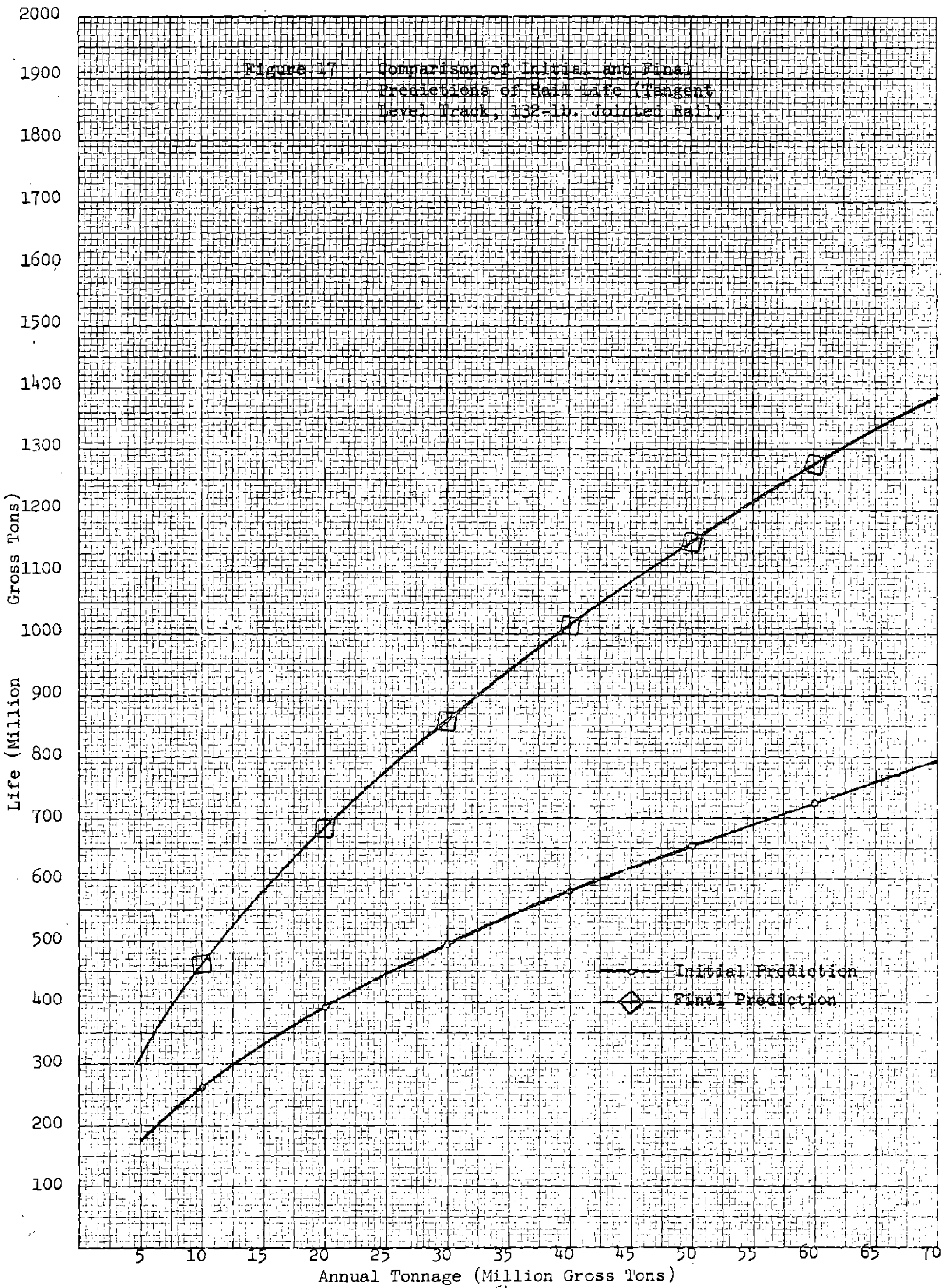


Figure 17 Comparison of Initial and Final Predictions of Rail Life (Tangent Level Track, 132-lb. Jointed Rail)
Life (Million Gross Tons)
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
5 10 15 20 25 30 35 40 45 50 55 60 65 70
Initial Prediction
Final Prediction
Annual Tonnage (Million Gross Tons)

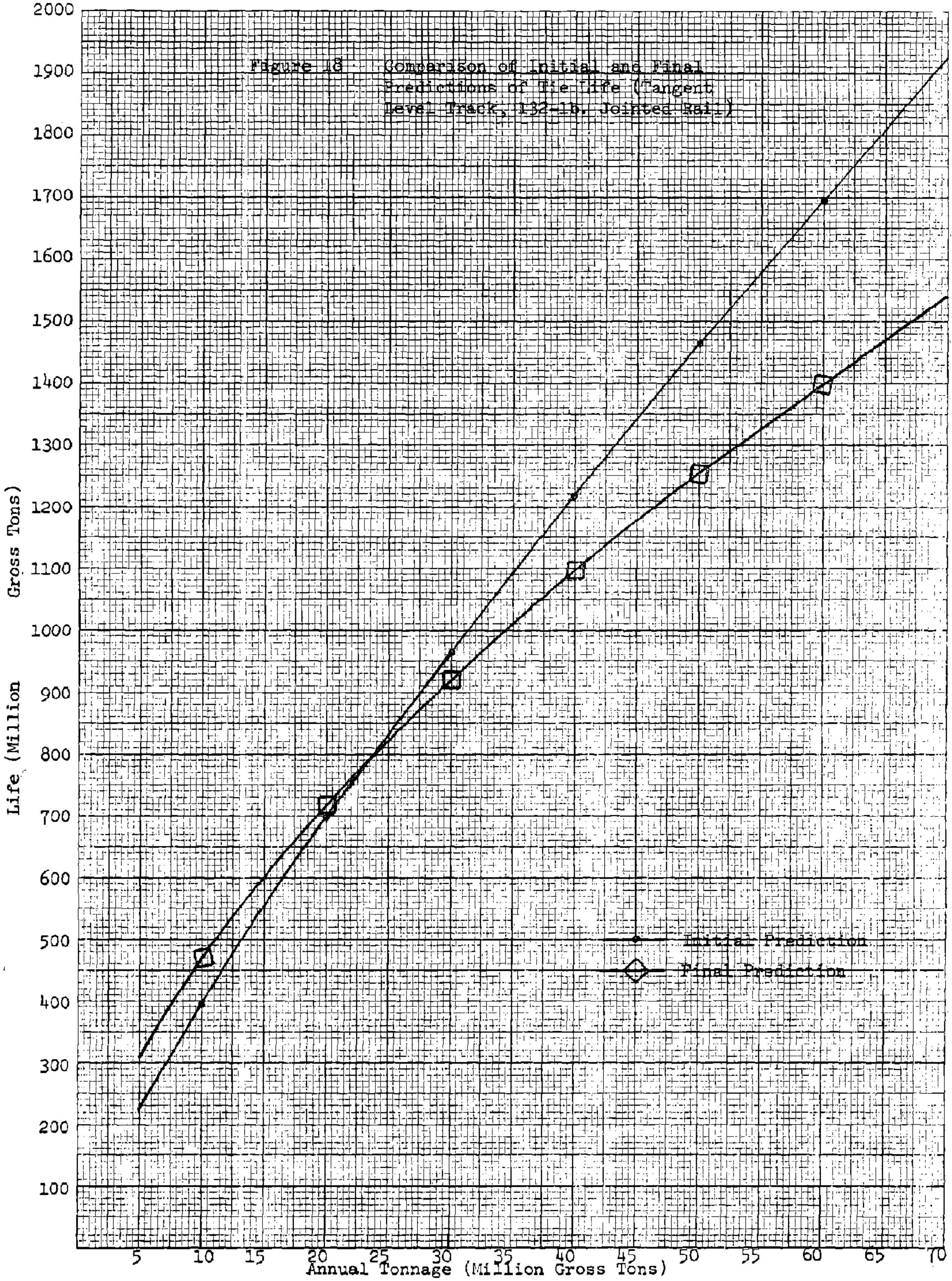



Figure 18 Comparison of Initial and Final Predictions of Tie Life (Tangent Level Track, 132-lb. Jointed Rail)

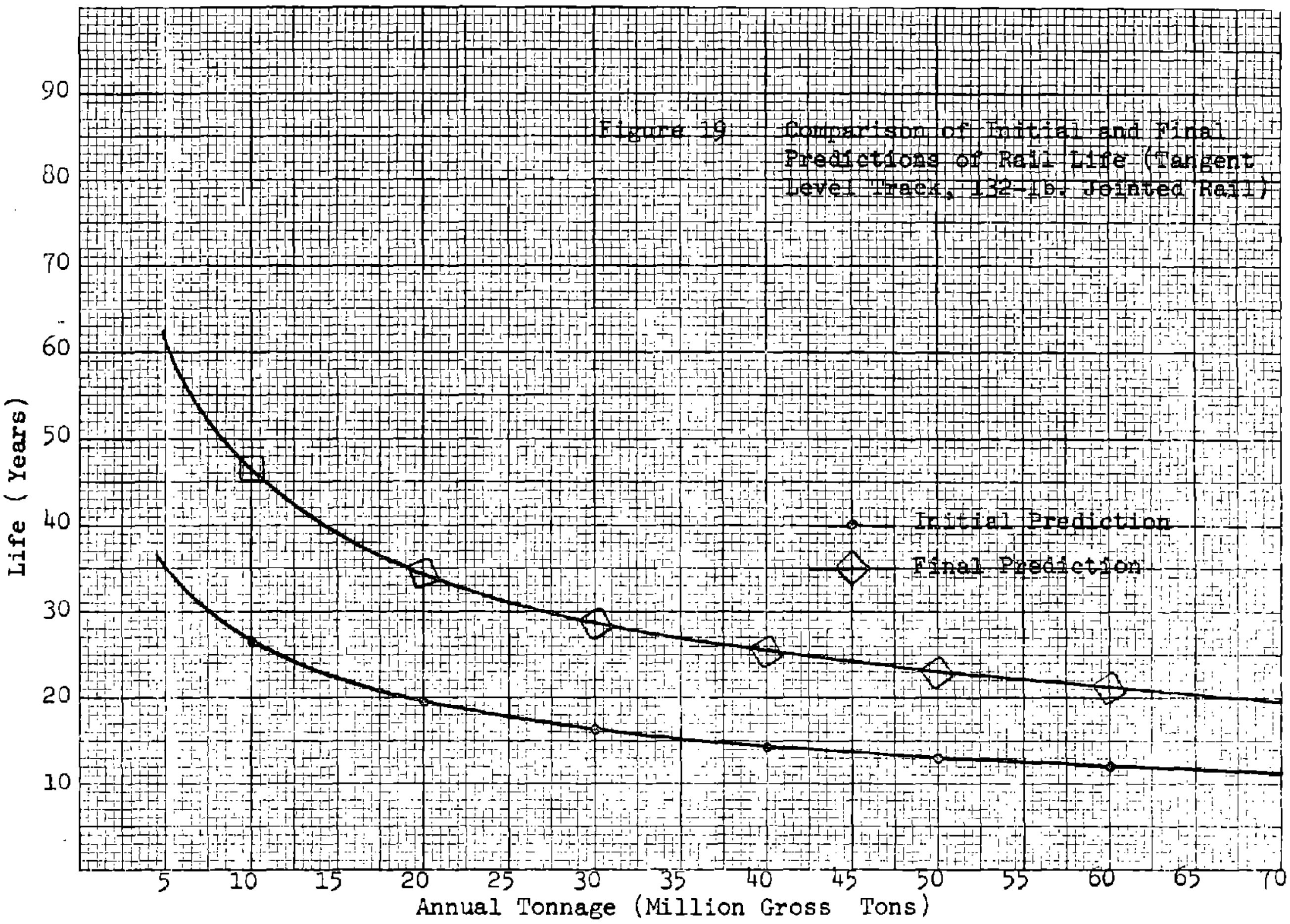


Figure 19 Comparison of Initial and Final Predictions of Rail Life (Tangent Level Track, 132-lb. Jointed Rail)
Initial Prediction
Final Prediction
Life ( Years)
90
80
70
60
50
40
30
20
10
5
10
15
20
25
30
35
40
45
50
55
60
65
70
Annual Tonnage (Million Gross Tons)

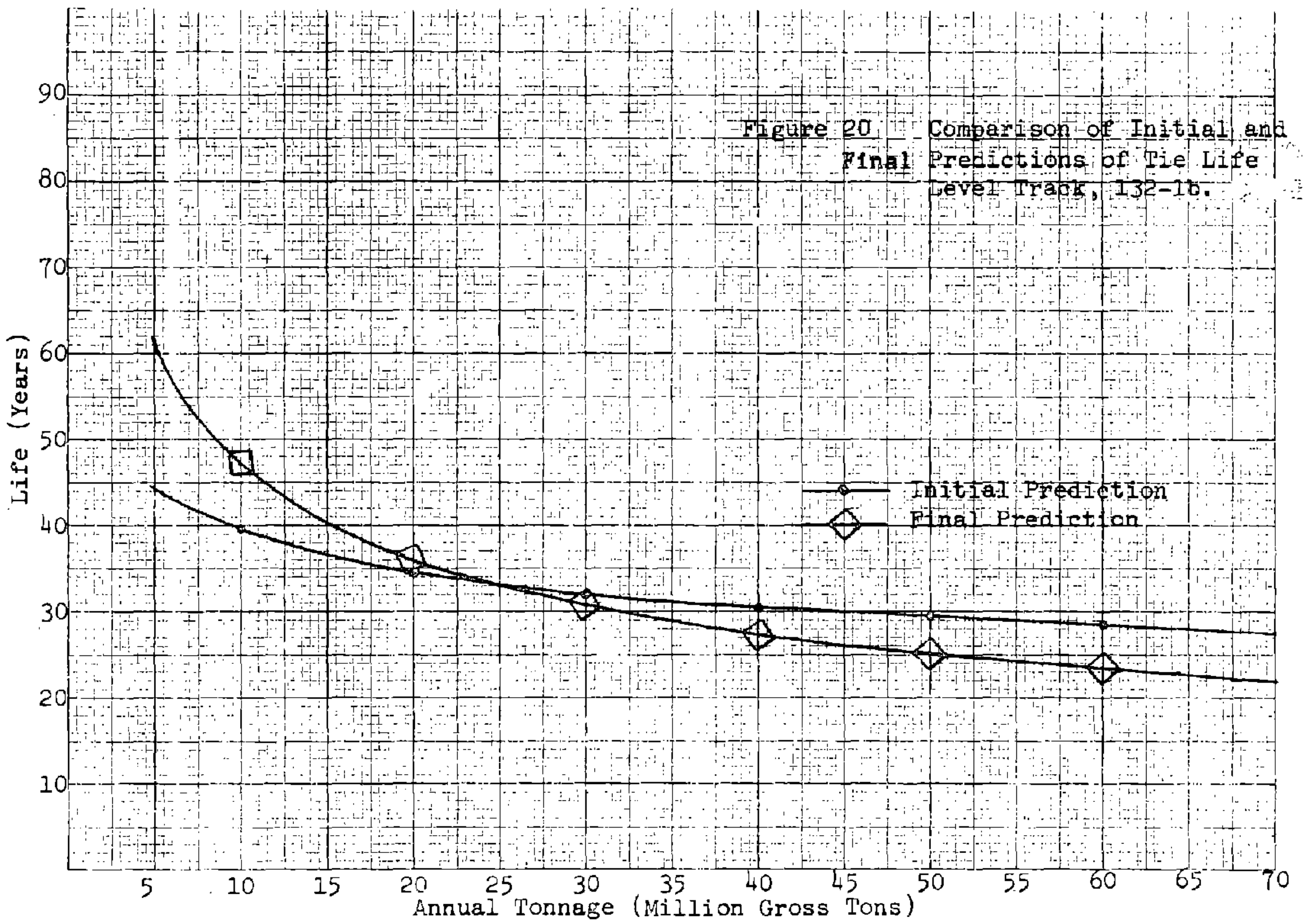


Figure 20 Comparison of Initial and Final Predictions of Tie Life Level Track, 132-lb.
Initial Prediction
Final Prediction
Life (Years)
90
80
70
60
50
40
30
20
10
5
10
15
20
25
30
35
40
45
50
55
60
65
70
Annual Tonnage (Million Gross Tons)

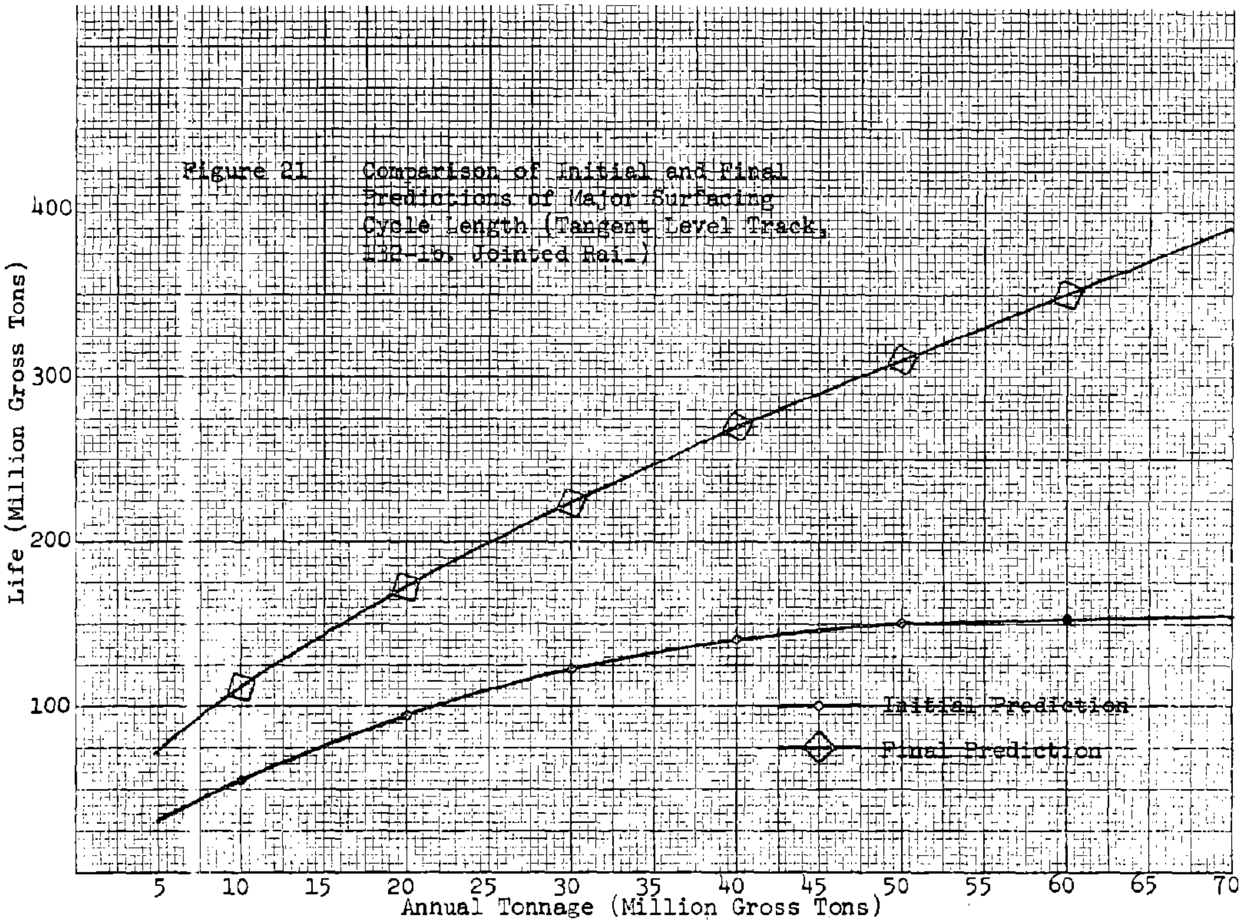



Figure 21 Comparison of Initial and Final Predictions of Major Surfacing Cycle Length (Tangent Level Track, 132-lb. Jointed Rail)

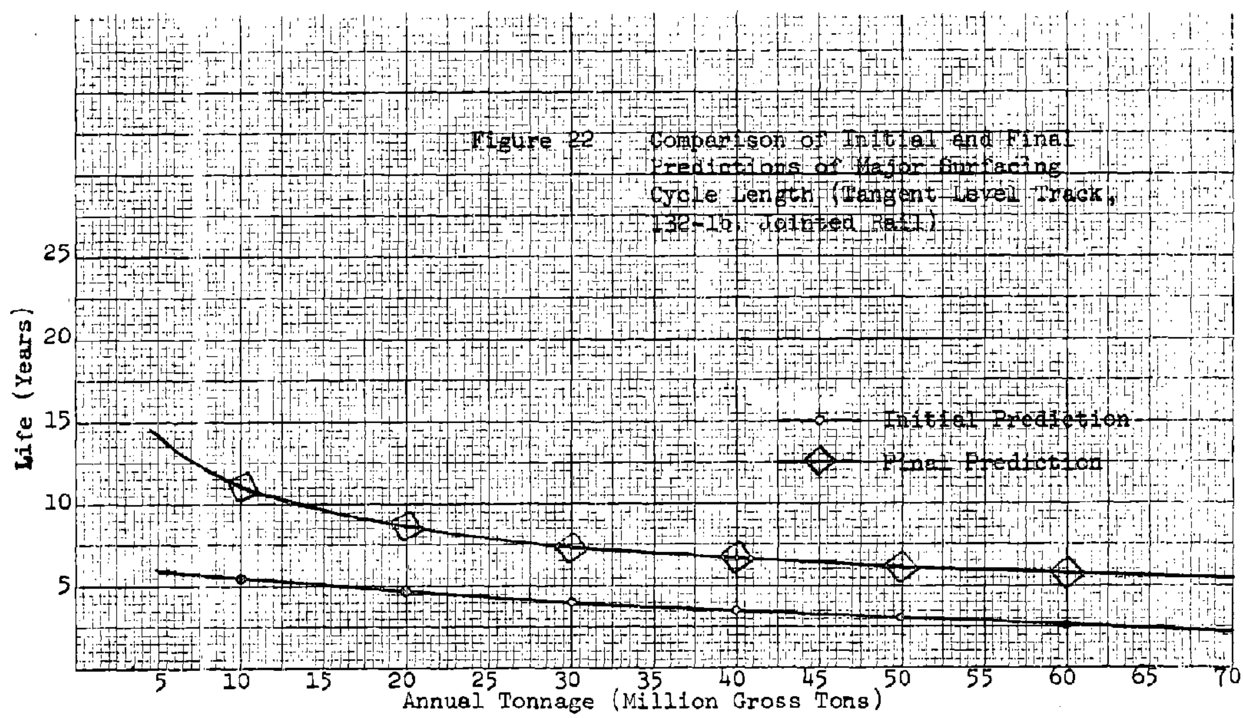



Figure 22 Comparison of Initial and Final Predictions of Major Surfacing Cycle Length (Tangent Level Track, 132-lb. Jointed Rail)

From here, the analysis uses resulting track structure data to accomplish the costing of linehaul trackage as described below.

Task 4. **Develop Techniques for Determining and Allocating the Track Structure Costs Associated with the Varying Physical Behavior of any Type of Track Under any Traffic Conditions**

This work utilizes the previously developed track renewal/maintenance factors to construct unit (gross ton mile) and total annual program-related costs for any track/traffic environment.

The following section describes the development and allocation of unit costs using rail costing in the example.

**Determination of a Unit Rail Cost**

The rail cost incurred during a given year can be determined from equation (17).

$$\text{Annual Cost Per Mile} = (C)\frac{D}{T} = \left[\frac{\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{r}\frac{D_{ijk}}{F_{ijk}}}{KWD^{.565}}\right](C) \qquad (17)$$

where:

C = the cost of renewing one mile of rail (for a particular type of track) and the other terms are as previously described in the rail life evaluation procedure (pp. 38-42 ).

The annual cost is assignable to the various traffic types on the basis of the proportion of rail wear each contributes. This is shown in equation (18) for type abc traffic.

$$\left[\frac{\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{r}\left[\frac{D_{ijk}}{F_{ijk}}\right]}{KWD^{.565}}\right]\left[\frac{\frac{D_{abc}}{F_{abc}}}{\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{r}\left[\frac{D_{ijk}}{F_{ijk}}\right]}\right](C) = \frac{(D_{abc})\,(C)}{(F_{abc})\,(KWD^{.565})} =$$

Annual Rail Cost for abc Traffic (18)

A unit cost per gross ton mile of type abc traffic is determined by dividing the annual cost from equation (17) by the annual tonnage of this (equation 19) traffic.

$$\frac{(D_{abc})\ (C)}{(F_{abc})\ (KWD \cdot 565)} \quad \frac{1}{D_{abc}} = \frac{(C)}{(F_{abc})\ (KWD \cdot 565)} = \text{Rail cost per GTM of type abc traffic} \qquad (19)$$

The rail cost associated with a given shipment may be thought of as having two parts. There is a cost directly attributable to the characteristics of the shipment, and a cost due to rail wear by locomotives and cabooses. The first part is the product of the shipment's gross weight times the appropriate unit cost as developed in equation (19). Rail cost associated with locomotives and cabooses is developed by determining the total cost associated with carload traffic, subtracting it from the total cost, and assigning the difference equally to all traffic. This is shown in equation (20) where $D^c_{ijk}$ is the annual carload tonnage with type i wheel loads, operated at class j speeds in train service-type k, and CL is the number of cars moved over the segment.

$$\frac{\sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{r} \left[\frac{D_{ijk}}{F_{ijk}}\right](C)}{(KWD \cdot 565)\ (CL)} - \frac{\sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{r} \left[\frac{D^c_{ijk}}{F_{ijk}}\right](C)}{(KWD \cdot 565)\ (CL)} =$$

$$\frac{C}{(KWD \cdot 565)}\ (CL) \left[\sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{r} \left[\frac{D_{ijk}}{F_{ijk}}\right] - \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{r} \left[\frac{D^c_{ijk}}{F_{ijk}}\right]\right] =$$

Rail cost per car mile due to locomotive and caboose caused wear. (20)

Similar procedures are used to develop functions for tie and surfacing costs based on respective component life/cycle equations and renewal/replacement costs.

## Track Structure Renewal/Replacement Costs

The determination of the appropriate value of 'C' used in the preceding equations presents complexities akin to those to be encountered in the development of service-specific track structure component lives and maintenance cycles. Once the required frequency of component renewal or replacement has been established, what is the appropriate renewal/replacement cost associated with that specific work activity? It has previously been proposed that the appropriate value to be associated with the incremental loss in track structure life or quality associated with a particular type and volume of rail traffic should be the current cost of replacing that incremental loss, in kind, no matter when the actual replacement/renewal of the total track structure component takes place.

What, then, are these "replacement" costs? How do they vary for different track/traffic environments? Where should the data come from? Is "average" cost data sufficient for these purposes? These are all questions which require definitive answers before cost data suitable for the analysis is developed.

The costs in question here may be termed "unit production costs," i.e., those costs incurred in the program replacement of a "unit" (track mile) of track structure components (rail, ties, track surface quality). The initial point to be made is that these are of necessity railroad-specific costs. No "industry-average" costs of these work activities have relevance to cost analysis of the nature described in this study. Maintenance policies, methods, production work equipment, labor and material costs -- all the components of these unit production costs combine to render potentiallly wide variations in these costs from railroad to railroad. For this reason, unit production cost data for use in the analyses described herein must be internally developed by each railroad.

Unit Production Cost "Variability"

The basic nature of these costs is that they are, of course, affected by many of the track/traffic "parameters" previously described. Material costs vary with the "type" of track structure being replaced. Equipment costs vary with the type and extent of equipment employed, maintenance practices and equipment efficiency as determined by factors such as work interference from train traffic or from the areal nature of the particular work environment. Labor costs vary with these and other factors, including climatic conditions, productivity of individual track forces, differences in prevailing wage rates, etc. Unit production costs, then, to be entirely accurate, must account for all significant variations resulting from these and other factors.

Sources of Unit Production Cost Data

An accounting structure, including the type and extent of expenditure reporting, described in Appendix F can and does provide production cost data of the type needed for application to these procedures. The important question in terms of production cost data acquisition and application is - what level of cost information is sufficient and economically justified for use in economic analysis of track structure costs? Are there cases where certain "system-level" costs are adequate given potential variations across an individual railroad's track system, or, given the unique nature of a particular maintenance district and its potential effect on unit production cost levels, must cost data specific to that district be utilized? For the present, of course, existing cost accounting systems will determine what type (if any) cost data is available for individual railroads.

The unit production cost data used in this study was not produced exclusively from accounting system data. Specific adjustments were made to reflect certain variations in unit production cost not ascertainable from available accounting records for the study trackage. These included estimated variations in labor and equipment work efficiency as a function of available on-track working time (traffic interference), development of the economic value of salvageable material and costs of replacements in kind where actual data was not available due to track upgrading policies on the study trackage. Resulting estimated unit production costs applied to the study trackage are averages to the extent that they reflect average labor and equipment productivity with respect to items such as the following:

1. Movement of forces and equipment from site to site
2. Breakdown or inefficient operation of equipment
3. Inadequate availability of work forces and equipment
4. Inadequate availability of work train and supplies
5. Undesirable weather conditions
6. Poor accessibility of work site
7. Population-related interference or interruption
8. Late arrival of trains for which track has been cleared

Resulting costs also reflect average labor rates and material costs (except ballast costs) over the study trackage territories.

There is no question that averaging of production cost data to the extent described generally renders the resulting costs less precise than desirable, although for the mainline trackage under study, significant errors are not considered to be introduced and more refined data was not available.

Complete unit production costs developed for this study are contained in Appendix C.

Task 5. Develop Aggregate Route Segment Track Structure Maintenance Costs Which can be Combined with Other Variable Roadway Costs to Establish Unit (Gross Ton Mile) Costs Suitable for Use in Pricing Decisions

The resulting equations for predicting both the unit (gross ton mile) costs and the total annual track structure program maintenance costs associated with any type of traffic on any specific track segment are presented in Appendix D. Work under this task utilizes the previously developed "Track Classification" system to calculate the program track structure costs for each "class" of track existing on each traffic "link" segment. Track "class" costs are weighted by respective mileages of each class occuring within each traffic link to develop aggregate "link" unit and annual costs. These link costs are in turn aggregated over specific train crew districts to develop resultant "crew district"-related track structure maintenance costs. This method of structuring the resulting track costs allows for the uniform calculation of most traffic-related operating costs (train crew wages, train fuel, roadway, etc.) on a consistent basis for use in day-to-day traffic costing. It also provides for measures of the total annual economic depletion of the track structure for specific train operating territories and associates this economic loss with specific types and volumes of traffic in those territories. Figure 23 depicts the interrelationship of all relevant data files in the cost calculation and assignment process.

Resulting cost reports obtainable from these procedures are shown in Figures 24 - 32. These depict link costs for each track structure component, unit costs for each traffic type on each crew district and annual variable track structure costs associated with specific types and volumes of traffic in each operating district. These costs, which may be either manually maintained or stored on computer, facilitate periodic updating through the use of appropriate cost indexes. Specific cost results are discussed in Section X of this report.

The track structure cost system developed here, including the track and traffic inventory systems previously described, provides the capability for periodic review of current physical and traffic conditions associated with any or all of the roadway system and permit the reevaluation of roadway track structure costs whenever significant changes occur in either the nature of the track structure or the nature of the operating demands being placed upon it.

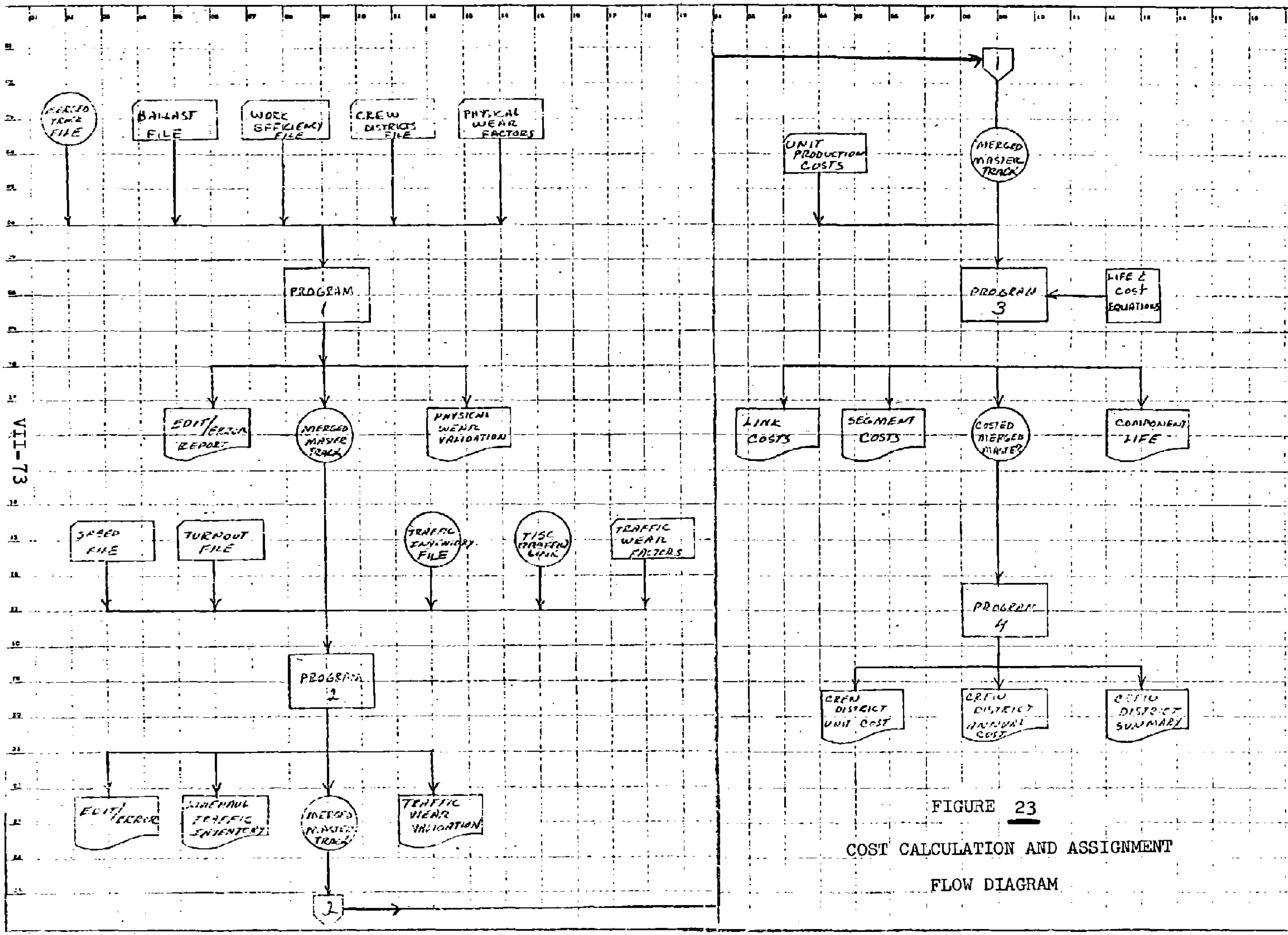



FIGURE 23

COST CALCULATION AND ASSIGNMENT FLOW DIAGRAM

VTT 74



| LINK ID | CODE | SEQ FROM | SEQ TO | MP FROM | MP TO | STA FROM | STA TO | MILES | CREW DISTRICT | DIR |
|---|---|---|---|---|---|---|---|---|---|---|
| 334 | C | 28 | 28 | 572.610 | 596.400 | 5142 | 5124 | 13.8 | HASTINGS-MIDVILLE | E |

| | BASE UNIT COSTS - $/1000 GTM | | | | | ANNUAL COSTS - $/YEAR | | | |
|---|---|---|---|---|---|---|---|---|---|
| | LABOR | MATL | OTHER | TOTAL | | LABOR | MATL | OTHER | TOTAL |
| RAIL | .0476 | .1961 | .0170 | .2613 | RAIL | 1652 | 7631 | 662 | 10168 |
| TIE | .0027 | .0407 | .0045 | .0544 | TIE | 301 | 1409 | 156 | 1884 |
| SURFACING | .0290 | .0357 | .0327 | .0981 | SURFACING | 1004 | 1236 | 1132 | 3397 |
| BALLASTING | .1497 | .1848 | .0391 | .4240 | BALLASTING | 6224 | 7683 | 3704 | 17627 |
| TURNOUTS | .0008 | .0107 | .0002 | .0117 | TURNOUTS | 31 | 416 | 8 | 455 |
| TRACK CROSS | | | | | TRACK CROSS | | | | |
| TOTAL | .2358 | .4680 | .1435 | .8495 | TOTAL | 9412 | 18375 | 5662 | 33531 |

| LINK ID | CODE | SEQ FROM | SEQ TO | MP FROM | MP TO | STA FROM | STA TO | MILES | CREW DISTRICT | DIR |
|---|---|---|---|---|---|---|---|---|---|---|
| 333 | C | 28 | 28 | 586.400 | 572.610 | 5124 | 5142 | 13.8 | HASTINGS-MIDVILLE | W |

| | BASE UNIT COSTS - $/1000 GTM | | | | | ANNUAL COSTS - $/YEAR | | | |
|---|---|---|---|---|---|---|---|---|---|
| | LABOR | MATL | OTHER | TOTAL | | LABOR | MATL | OTHER | TOTAL |
| RAIL | .0476 | .1961 | .0170 | .2613 | RAIL | 1096 | 4517 | 392 | 6019 |
| TIE | .0087 | .0407 | .0045 | .0544 | TIE | 179 | 840 | 93 | 1122 |
| SURFACING | .0290 | .0357 | .0327 | .0981 | SURFACING | 599 | 737 | 675 | 2025 |
| BALLASTING | .1497 | .1848 | .0891 | .4240 | BALLASTING | 3708 | 4577 | 2207 | 10501 |
| TURNOUTS | .0008 | .0116 | .0002 | .0126 | TURNOUTS | 18 | 267 | 5 | 290 |
| TRACK CROSS | | | | | TRACK CROSS | | | | |
| TOTAL | .2358 | .4680 | .1435 | .8504 | TOTAL | 5600 | 10938 | 3372 | 19957 |

FIGURE 24
TRAFFIC LINK BASE UNIT/ANNUAL COST REPORT

# LINEHAUL TRACK COSTS



CREW DISTRICT SIMPSON-WARNER DIRECTION W UNIT COSTS - $/PER 1000 GROSS TON MILES

ROUTE MILES 70.4

| WHEEL LOAD CLASS | | **** MIXED CONSIST TRAINS *** HP/TON CLASS 1 | 2 | 3 | 4 | 5 | ******** UNIT TRAINS *** HP/TON CLASS 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | LABOR | .0269 | .0279 | .0283 | .0291 | .0296 | .0292 | .0302 | .0312 | .0315 | .0321 |
| | MATRL | .1062 | .1100 | .1134 | .1144 | .1164 | .1147 | .1188 | .1225 | .1236 | .1257 |
| | OTHER | .0190 | .0197 | .0204 | .0206 | .0209 | .0208 | .0215 | .0222 | .0225 | .0229 |
| 15.0 | TOTAL | .1521 | .1576 | .1626 | .1641 | .1669 | .1647 | .1705 | .1759 | .1776 | .1807 |
| | LABOR | .0326 | .0337 | .0348 | .0352 | .0358 | .0354 | .0366 | .0378 | .0382 | .0388 |
| | MATRL | .1337 | .1384 | .1427 | .1439 | .1464 | .1446 | .1497 | .1544 | .1557 | .1584 |
| | OTHER | .0222 | .0230 | .0238 | .0240 | .0244 | .0242 | .0251 | .0260 | .0262 | .0267 |
| 26.0 | TOTAL | .1885 | .1951 | .2013 | .2031 | .2066 | .2042 | .2114 | .2182 | .2201 | .2239 |
| | LABOR | .0338 | .0350 | .0361 | .0365 | .0371 | .0367 | .0380 | .0392 | .0396 | .0403 |
| | MATRL | .1380 | .1428 | .1472 | .1486 | .1511 | .1493 | .1545 | .1593 | .1607 | .1635 |
| | OTHER | .0231 | .0239 | .0248 | .0250 | .0254 | .0253 | .0262 | .0270 | .0273 | .0278 |
| 30.0 | TOTAL | .1949 | .2017 | .2081 | .2101 | .2136 | .2113 | .2187 | .2255 | .2276 | .2316 |
| | LABOR | .0441 | .0456 | .0471 | .0476 | .0494 | .0479 | .0496 | .0512 | .0517 | .0526 |
| | MATRL | .1930 | .1997 | .2059 | .2077 | .2113 | .2094 | .2169 | .2234 | .2254 | .2293 |
| | OTHER | .0281 | .0291 | .0301 | .0304 | .0309 | .0307 | .0318 | .0329 | .0332 | .0338 |
| 33.0 | TOTAL | .2652 | .2744 | .2831 | .2857 | .2906 | .2880 | .2982 | .3075 | .3103 | .3157 |
| | LABOR | .0505 | .0523 | .0540 | .0545 | .0555 | .0550 | .0569 | .0587 | .0593 | .0603 |
| | MATRL | .2292 | .2373 | .2446 | .2467 | .2509 | .2492 | .2579 | .2658 | .2681 | .2728 |
| | OTHER | .0309 | .0320 | .0331 | .0334 | .0340 | .0338 | .0350 | .0362 | .0365 | .0372 |
| 35.0 | TOTAL | .3106 | .3216 | .3317 | .3346 | .3404 | .3380 | .3499 | .3607 | .3639 | .3703 |
| | LABOR | .0553 | .0578 | .0596 | .0602 | .0613 | .0608 | .0629 | .0649 | .0655 | .0667 |
| | MATRL | .2583 | .2674 | .2755 | .2779 | .2927 | .2810 | .2909 | .2997 | .3023 | .3076 |
| | OTHER | .0334 | .0346 | .0357 | .0361 | .0367 | .0365 | .0378 | .0390 | .0394 | .0401 |
| 37.5 | TOTAL | .3475 | .3598 | .3708 | .3742 | .3607 | .3783 | .3916 | .4036 | .4072 | .4144 |
| | LABOR | .0640 | .0662 | .0683 | .0690 | .0702 | .0696 | .0721 | .0744 | .0751 | .0764 |
| | MATRL | .2989 | .3094 | .3189 | .3216 | .3272 | .3253 | .3367 | .3470 | .3500 | .3561 |
| | OTHER | .0378 | .0391 | .0404 | .0408 | .0415 | .0413 | .0428 | .0442 | .0446 | .0454 |
| > 37.5 | TOTAL | .4007 | .4147 | .4276 | .4314 | .4389 | .4362 | .4516 | .4656 | .4697 | .4779 |

FIGURE 25
UNIT (GTM) PROGRAM TRACK COST REPORT

Westbound Traffic - Simpson-Warner (approx. 34% Double Track, Remainder Single Track)
Traffic Density ≅ 11 MGT, Light/Medium Curvature, 0-1.5% Grades, Good Track Support

LINEHAUL TRACK COSTS 

CREW DISTRICT SIMPSON-WARNER DIRECTION E UNIT COSTS - $/PER 1000 GROSS TON MILES

ROUTE MILES 70.4

| | | | * * * * MIXED CONSIST TRAINS * * * | | | | | * * * * * * * * UNIT TRAINS * * * | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | HP/TON CLASS | | | | | HP/TON CLASS | | | | |
| | | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| | | LABOR | .0259 | .0266 | .0275 | .0275 | .0279 | .0281 | .0289 | .0299 | .0299 | .0303 |
| | | MATRL | .1017 | .1047 | .1081 | .1081 | .1094 | .1102 | .1134 | .1172 | .1172 | .1185 |
| | | OTHER | .0183 | .0188 | .0195 | .0195 | .0197 | .0200 | .0206 | .0213 | .0213 | .0216 |
| | 15.0 | TOTAL | .1459 | .1501 | .1551 | .1551 | .1570 | .1583 | .1629 | .1684 | .1684 | .1704 |
| | | LABOR | .0314 | .0323 | .0334 | .0334 | .0339 | .0342 | .0352 | .0364 | .0364 | .0368 |
| | | MATRL | .1287 | .1325 | .1368 | .1368 | .1384 | .1397 | .1438 | .1485 | .1485 | .1502 |
| | | OTHER | .0214 | .0220 | .0228 | .0228 | .0231 | .0234 | .0241 | .0249 | .0249 | .0253 |
| | 26.0 | TOTAL | .1815 | .1868 | .1930 | .1930 | .1954 | .1973 | .2031 | .2098 | .2098 | .2123 |
| | | LABOR | .0326 | .0335 | .0347 | .0347 | .0351 | .0354 | .0365 | .0377 | .0377 | .0382 |
| | | MATRL | .1327 | .1366 | .1411 | .1411 | .1427 | .1441 | .1483 | .1531 | .1531 | .1549 |
| | | OTHER | .0223 | .0229 | .0237 | .0237 | .0240 | .0244 | .0251 | .0260 | .0260 | .0263 |
| | 30.0 | TOTAL | .1876 | .1930 | .1995 | .1995 | .2018 | .2039 | .2099 | .2168 | .2168 | .2194 |
| | | LABOR | .0425 | .0440 | .0455 | .0455 | .0461 | .0466 | .0480 | .0496 | .0496 | .0502 |
| | | MATRL | .1874 | .1929 | .1992 | .1992 | .2014 | .2039 | .2099 | .2167 | .2167 | .2191 |
| | | OTHER | .0272 | .0280 | .0289 | .0289 | .0293 | .0298 | .0306 | .0317 | .0317 | .0321 |
| WHEEL LOAD CLASS | 33.0 | TOTAL | .2574 | .2649 | .2736 | .2736 | .2768 | .2803 | .2885 | .2980 | .2980 | .3014 |
| | | LABOR | .0492 | .0506 | .0523 | .0523 | .0530 | .0537 | .0552 | .0571 | .0571 | .0578 |
| | | MATRL | .2237 | .2302 | .2376 | .2376 | .2403 | .2437 | .2508 | .2589 | .2589 | .2617 |
| | | OTHER | .0300 | .0308 | .0319 | .0319 | .0323 | .0328 | .0338 | .0349 | .0349 | .0354 |
| | 35.0 | TOTAL | .3029 | .3116 | .3213 | .3218 | .3256 | .3302 | .3398 | .3509 | .3509 | .3549 |
| | | LABOR | .0545 | .0561 | .0579 | .0579 | .0587 | .0594 | .0611 | .0632 | .0632 | .0640 |
| | | MATRL | .2527 | .2600 | .2684 | .2684 | .2714 | .2755 | .2835 | .2926 | .2926 | .2958 |
| | | OTHER | .0324 | .0333 | .0345 | .0345 | .0349 | .0355 | .0365 | .0378 | .0378 | .0383 |
| | 37.5 | TOTAL | .3396 | .3494 | .3608 | .3608 | .3650 | .3704 | .3811 | .3936 | .3936 | .3981 |
| | | LABOR | .0625 | .0643 | .0665 | .0665 | .0673 | .0682 | .0702 | .0725 | .0725 | .0734 |
| | | MATRL | .2923 | .3013 | .3110 | .3110 | .3144 | .3193 | .3285 | .3391 | .3391 | .3428 |
| | | OTHER | .0367 | .0377 | .0390 | .0390 | .0396 | .0402 | .0413 | .0428 | .0428 | .0433 |
| | > 37.5 | TOTAL | .3920 | .4033 | .4165 | .4165 | .4213 | .4277 | .4400 | .4544 | .4544 | .4595 |

FIGURE 26
UNIT (GTM) PROGRAM TRACK COST REPORT

Eastbound Traffic - Simpson-Warner (approx. 34% Double Track, Remainder Single Track)
Traffic Density ≅ 9 MGT, Light/Medium Curvature, 0-1.5% Grades, Good Track Support.

# LINEHAUL TRACK COSTS



CREW DISTRICT SIMPSON-WARNER DIRECTION W ANNUAL COSTS - $ PER YEAR

ROUTE MILES 70.4

| | | * * * * MIXED CONSIST TRAINS * * * | | | | | | * * * * * * * * UNIT TRAINS * * * | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | HP/TON CLASS | | | | | | HP/TON CLASS | | | | | |
| WHEEL LOAD CLASS | | 1 | 2 | 3 | 4 | 5 | TOTAL | 1 | 2 | 3 | 4 | 5 | TOTAL |
| | LABOR | 557 | 1503 | 1178 | 217 | 28 | 3483 | 0 | 145 | 111 | 0 | 0 | 256 |
| | MATRL | 2200 | 5935 | 4645 | 854 | 113 | 13747 | 0 | 571 | 435 | 0 | 0 | 1006 |
| | OTHER | 392 | 1061 | 832 | 153 | 19 | 2457 | 0 | 103 | 79 | 0 | 0 | 182 |
| 15.0 | TOTAL | 3149 | 8499 | 6655 | 1224 | 160 | 19687 | 0 | 819 | 625 | 0 | 0 | 1444 |
| | LABOR | 1734 | 3580 | 1906 | 374 | 40 | 7634 | 0 | 2 | 0 | 0 | 0 | 2 |
| | MATRL | 7116 | 14698 | 7809 | 1532 | 165 | 31310 | 0 | 7 | 0 | 0 | 0 | 7 |
| | OTHER | 1181 | 2438 | 1298 | 255 | 27 | 5199 | 0 | 1 | 0 | 0 | 0 | 1 |
| 26.0 | TOTAL | 10031 | 20706 | 11013 | 2161 | 232 | 44143 | 0 | 10 | 0 | 0 | 0 | 10 |
| | LABOR | 1247 | 1721 | 484 | 23 | 53 | 3528 | 0 | 0 | 4 | 0 | 0 | 4 |
| | MATRL | 5060 | 6990 | 1973 | 100 | 223 | 14346 | 0 | 0 | 16 | 0 | 0 | 16 |
| | OTHER | 858 | 1183 | 332 | 15 | 35 | 2423 | 0 | 0 | 3 | 0 | 0 | 3 |
| 30.0 | TOTAL | 7165 | 9894 | 2789 | 138 | 311 | 20297 | 0 | 0 | 23 | 0 | 0 | 23 |
| | LABOR | 669 | 1140 | 285 | 16 | 97 | 2207 | 0 | 0 | 0 | 0 | 0 | 0 |
| | MATRL | 2922 | 4970 | 1243 | 70 | 427 | 9632 | 0 | 0 | 0 | 0 | 0 | 0 |
| | OTHER | 430 | 729 | 181 | 10 | 62 | 1412 | 0 | 0 | 0 | 0 | 0 | 0 |
| 33.0 | TOTAL | 4021 | 6839 | 1709 | 96 | 586 | 13251 | 0 | 0 | 0 | 0 | 0 | 0 |
| | LABOR | 216 | 979 | 1008 | 251 | 46 | 2500 | 0 | 29 | 29 | 0 | 0 | 58 |
| | MATRL | 981 | 4441 | 4569 | 1136 | 213 | 11340 | 0 | 130 | 133 | 0 | 0 | 263 |
| | OTHER | 132 | 600 | 617 | 154 | 27 | 1530 | 0 | 18 | 18 | 0 | 0 | 36 |
| 35.0 | TOTAL | 1329 | 6020 | 6194 | 1541 | 286 | 15370 | 0 | 177 | 180 | 0 | 0 | 357 |
| | LABOR | 14 | 19 | 15 | 4 | 0 | 52 | 0 | 0 | 0 | 0 | 0 | 0 |
| | MATRL | 64 | 88 | 68 | 17 | 0 | 237 | 0 | 0 | 0 | 0 | 0 | 0 |
| | OTHER | 8 | 11 | 9 | 2 | 0 | 30 | 0 | 0 | 0 | 0 | 0 | 0 |
| 37.5 | TOTAL | 86 | 118 | 92 | 23 | 0 | 319 | 0 | 0 | 0 | 0 | 0 | 0 |
| | LABOR | 100 | 158 | 152 | 3 | 0 | 413 | 0 | 0 | 0 | 0 | 0 | 0 |
| | MATRL | 466 | 738 | 710 | 16 | 0 | 1930 | 0 | 0 | 0 | 0 | 0 | 0 |
| | OTHER | 59 | 93 | 90 | 2 | 0 | 244 | 0 | 0 | 0 | 0 | 0 | 0 |
| > 37.5 | TOTAL | 625 | 989 | 952 | 21 | 0 | 2587 | 0 | 0 | 0 | 0 | 0 | 0 |
| TOTAL | LABOR | 4537 | 9100 | 5029 | 888 | 264 | 19817 | 0 | 176 | 144 | 0 | 0 | 320 |
| TOTAL | MATRL | 18809 | 37850 | 21017 | 3725 | 1141 | 82542 | 0 | 708 | 584 | 0 | 0 | 1292 |
| TOTAL | OTHER | 3060 | 6115 | 3359 | 591 | 170 | 13295 | 0 | 122 | 100 | 0 | 0 | 222 |
| GRAND | TOTAL | 26406 | 53065 | 29404 | 5204 | 1575 | 115654 | 0 | 1006 | 828 | 0 | 0 | 1834 |

FIGURE 27
ANNUAL LINEHAUL PROGRAM TRACK COST REPORT

Westbound Traffic, Simpson-Warner (Approx. 34% Double Track remainder Single Track), Traffic Density ≅ 11 MGT, Light/Medium Curvature, 0-1.5% Grades, Good Track Support

| CREW DISTRICT SIMPSON-WARNER | | DIRECTION E | LINEHAUL TRACK COSTS ANNUAL COSTS - $ PER YEAR | PAGE 21 |
|---|---|---|---|---|

ROUTE MILES 70.4

| | | * * * * MIXED CONSIST TRAINS * * * | | | | | | * * * * * * * * UNIT TRAINS * * * | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | HP/TON CLASS | | | | | | HP/TON CLASS | | | | | |
| | | 1 | 2 | 3 | 4 | 5 | TOTAL | 1 | 2 | 3 | 4 | 5 | TOTAL |
| | LABOR | 277 | 1790 | 912 | 442 | 263 | 3692 | 0 | 338 | 0 | 0 | 0 | 338 |
| | MATRL | 1089 | 7077 | 3581 | 1730 | 1022 | 14499 | 0 | 1327 | 1 | 0 | 0 | 1328 |
| | OTHER | 196 | 1270 | 644 | 313 | 187 | 2610 | 0 | 240 | 0 | 0 | 0 | 240 |
| 15.0 | TOTAL | 1562 | 10145 | 5137 | 2485 | 1472 | 20801 | 0 | 1965 | 1 | 0 | 0 | 1906 |
| | LABOR | 951 | 3233 | 1336 | 513 | 201 | 6234 | 142 | 282 | 0 | 0 | 0 | 424 |
| | MATRL | 3899 | 13261 | 5469 | 2098 | 824 | 25551 | 581 | 1156 | 0 | 0 | 0 | 1737 |
| | OTHER | 646 | 2198 | 909 | 349 | 137 | 4239 | 97 | 193 | 0 | 0 | 0 | 290 |
| 26.0 | TOTAL | 5496 | 18692 | 7714 | 2960 | 1162 | 36024 | 820 | 1631 | 0 | 0 | 0 | 2451 |
| | LABOR | 261 | 614 | 239 | 82 | 88 | 1284 | 0 | 5 | 0 | 0 | 0 | 5 |
| | MATRL | 1070 | 2507 | 976 | 333 | 364 | 5250 | 0 | 22 | 0 | 0 | 0 | 22 |
| | OTHER | 178 | 420 | 163 | 56 | 59 | 876 | 0 | 3 | 0 | 0 | 0 | 3 |
| 30.0 | TOTAL | 1509 | 3541 | 1378 | 471 | 511 | 7410 | 0 | 30 | 0 | 0 | 0 | 30 |
| | LABOR | 93 | 369 | 143 | 81 | 121 | 807 | 0 | 5 | 0 | 0 | 0 | 5 |
| | MATRL | 408 | 1625 | 625 | 351 | 534 | 3543 | 0 | 21 | 0 | 0 | 0 | 21 |
| | OTHER | 59 | 235 | 91 | 52 | 77 | 514 | 0 | 3 | 0 | 0 | 0 | 3 |
| WHEEL LOAD CLASS 32.0 | TOTAL | 560 | 2229 | 859 | 484 | 732 | 4864 | 0 | 29 | 0 | 0 | 0 | 29 |
| | LABOR | 79 | 783 | 526 | 349 | 381 | 2118 | 15 | 113 | 0 | 0 | 0 | 128 |
| | MATRL | 361 | 3560 | 2392 | 1584 | 1729 | 9626 | 70 | 513 | 0 | 0 | 0 | 583 |
| | OTHER | 48 | 476 | 320 | 212 | 232 | 1288 | 9 | 69 | 0 | 0 | 0 | 78 |
| 35.0 | TOTAL | 488 | 4819 | 3238 | 2145 | 2342 | 13032 | 94 | 695 | 0 | 0 | 0 | 789 |
| | LABOR | 0 | 12 | 2 | 0 | 0 | 14 | 0 | 0 | 0 | 0 | 0 | 0 |
| | MATRL | 0 | 54 | 10 | 0 | 0 | 64 | 0 | 0 | 0 | 0 | 0 | 0 |
| | OTHER | 0 | 7 | 1 | 0 | 0 | 8 | 0 | 0 | 0 | 0 | 0 | 0 |
| 37.5 | TOTAL | 0 | 73 | 13 | 0 | 0 | 86 | 0 | 0 | 0 | 0 | 0 | 0 |
| | LABOR | 9 | 117 | 10 | 10 | 0 | 146 | 0 | 0 | 0 | 0 | 0 | 0 |
| | MATRL | 44 | 549 | 49 | 46 | 0 | 688 | 0 | 0 | 0 | 0 | 0 | 0 |
| | OTHER | 5 | 69 | 6 | 6 | 0 | 86 | 0 | 0 | 0 | 0 | 0 | 0 |
| > 37.5 | TOTAL | 58 | 735 | 65 | 62 | 0 | 920 | 0 | 0 | 0 | 0 | 0 | 0 |
| TOTAL | LABOR | 1670 | 6926 | 3168 | 1477 | 1054 | 14295 | 157 | 743 | 0 | 0 | 0 | 900 |
| TOTAL | MATRL | 6871 | 28633 | 13102 | 6142 | 4473 | 59221 | 651 | 3039 | 1 | 0 | 0 | 3691 |
| TOTAL | OTHER | 1132 | 4675 | 2134 | 988 | 692 | 9621 | 106 | 508 | 0 | 0 | 0 | 614 |
| GRAND | TOTAL | 9673 | 40234 | 18404 | 8607 | 6219 | 83137 | 914 | 4290 | 1 | 0 | 0 | 5205 |

FIGURE 28
ANNUAL LINEHAUL PROGRAM TRACK COST REPORT

Eastbound Traffic, Simpson-Warner (Approx. 34% Double Track, remainder Single), Traffic Density ≅ 9 MGT, Light/Medium Curvature, 0-1.5% Grades, Good Track Support

LINEHAUL TRACK COSTS — PAGE 74

CREW DISTRICT MESA-DOWNING — DIRECTION W — UNIT COSTS - $/PER 1000 GROSS TON MILES

ROUTE MILES 47.1

| WHEEL LOAD CLASS | | Mixed Consist Trains HP/TON CLASS 1 | 2 | 3 | 4 | 5 | Unit Trains HP/TON CLASS 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | LABOR | .0235 | .0237 | .0238 | .0238 | .0243 | .0250 | .0253 | .0253 | .0253 | .0259 |
| | MATRL | .0754 | .0761 | .0763 | .0763 | .0782 | .0901 | .0309 | .0811 | .0811 | .0831 |
| | OTHER | .0151 | .0152 | .0153 | .0153 | .0156 | .0162 | .0163 | .0164 | .0164 | .0168 |
| 15.0 | TOTAL | .1140 | .1150 | .1154 | .1154 | .1181 | .1213 | .1225 | .1228 | .1228 | .1258 |
| | LABOR | .0282 | .0284 | .0285 | .0285 | .0291 | .0301 | .0304 | .0304 | .0304 | .0311 |
| | MATRL | .0934 | .0943 | .0946 | .0946 | .0968 | .0996 | .1006 | .1008 | .1008 | .1032 |
| | OTHER | .0175 | .0177 | .0178 | .0178 | .0182 | .0189 | .0190 | .0191 | .0191 | .0195 |
| 26.0 | TOTAL | .1391 | .1404 | .1409 | .1409 | .1441 | .1486 | .1500 | .1503 | .1503 | .1538 |
| | LABOR | .0292 | .0295 | .0296 | .0296 | .0302 | .0312 | .0315 | .0316 | .0316 | .0323 |
| | MATRL | .0966 | .0975 | .0978 | .0978 | .1001 | .1029 | .1040 | .1042 | .1042 | .1067 |
| | OTHER | .0183 | .0185 | .0185 | .0185 | .0189 | .0197 | .0199 | .0199 | .0199 | .0204 |
| 30.0 | TOTAL | .1441 | .1455 | .1459 | .1459 | .1492 | .1538 | .1554 | .1557 | .1557 | .1594 |
| | LABOR | .0375 | .0379 | .0379 | .0379 | .0388 | .0402 | .0406 | .0407 | .0407 | .0416 |
| | MATRL | .1315 | .1328 | .1332 | .1332 | .1364 | .1410 | .1424 | .1427 | .1427 | .1461 |
| | OTHER | .0221 | .0223 | .0224 | .0224 | .0229 | .0238 | .0240 | .0241 | .0241 | .0247 |
| 33.0 | TOTAL | .1911 | .1930 | .1935 | .1935 | .1981 | .2050 | .2070 | .2075 | .2075 | .2124 |
| | LABOR | .0426 | .0430 | .0431 | .0431 | .0440 | .0457 | .0462 | .0463 | .0463 | .0473 |
| | MATRL | .1542 | .1557 | .1561 | .1561 | .1598 | .1657 | .1673 | .1677 | .1677 | .1718 |
| | OTHER | .0242 | .0245 | .0245 | .0245 | .0251 | .0261 | .0264 | .0264 | .0264 | .0271 |
| 35.0 | TOTAL | .2210 | .2232 | .2237 | .2237 | .2289 | .2375 | .2399 | .2404 | .2404 | .2462 |
| | LABOR | .0460 | .0472 | .0473 | .0473 | .0484 | .0503 | .0508 | .0509 | .0509 | .0521 |
| | MATRL | .1725 | .1742 | .1746 | .1746 | .1788 | .1857 | .1875 | .1890 | .1880 | .1924 |
| | OTHER | .0261 | .0263 | .0264 | .0264 | .0270 | .0281 | .0284 | .0285 | .0285 | .0292 |
| 37.5 | TOTAL | .2454 | .2477 | .2483 | .2483 | .2542 | .2641 | .2667 | .2674 | .2674 | .2737 |
| | LABOR | .0535 | .0540 | .0541 | .0541 | .0553 | .0575 | .0581 | .0582 | .0582 | .0596 |
| | MATRL | .1989 | .2009 | .2014 | .2014 | .2062 | .2143 | .2164 | .2169 | .2169 | .2221 |
| | OTHER | .0295 | .0298 | .0299 | .0299 | .0306 | .0318 | .0321 | .0322 | .0322 | .0330 |
| > 37.5 | TOTAL | .2819 | .2847 | .2854 | .2854 | .2921 | .3036 | .3066 | .3073 | .3073 | .3147 |

FIGURE 29
UNIT (UTM) PROGRAM TRACK COST REPORT

Westbound Traffic, Mesa-Downing (Approx. 30 % Double Track, remainder S.T.), Traffic Density ≅ 27 MGT, Light/Medium Curvature, .5-1.5% Grades, Good Track Support

LINEHAUL TRACK COSTS

CREW DISTRICT - MESA-DOWNING DIRECTION E UNIT COSTS - $/PER 1000 GROSS TON MILES

PAGE 73

ROUTE MILES 47.1

| WHEEL LOAD CLASS | | * * * * MIXED CONSIST TRAINS * * * HP/TON CLASS 1 | 2 | 3 | 4 | 5 | * * * * * * * * UNIT TRAINS * * * HP/TON CLASS 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | LABOR | .0215 | .0223 | .0226 | .0229 | .0229 | .0229 | .0238 | .0241 | .0244 | .0244 |
| | MATRL | .0687 | .0714 | .0727 | .0735 | .0735 | .0729 | .0759 | .0772 | .0781 | .0781 |
| | OTHER | .0139 | .0145 | .0147 | .0148 | .0148 | .0150 | .0155 | .0158 | .0159 | .0159 |
| 15.0 | TOTAL | .1041 | .1082 | .1100 | .1112 | .1112 | .1108 | .1152 | .1171 | .1184 | .1184 |
| | LABOR | .0257 | .0267 | .0271 | .0274 | .0274 | .0275 | .0285 | .0289 | .0292 | .0292 |
| | MATRL | .0850 | .0884 | .0899 | .0909 | .0909 | .0905 | .0942 | .0958 | .0969 | .0969 |
| | OTHER | .0162 | .0168 | .0171 | .0172 | .0172 | .0174 | .0181 | .0183 | .0185 | .0185 |
| 26.0 | TOTAL | .1269 | .1319 | .1341 | .1355 | .1355 | .1354 | .1408 | .1430 | .1446 | .1446 |
| | LABOR | .0267 | .0277 | .0281 | .0284 | .0284 | .0285 | .0296 | .0300 | .0303 | .0303 |
| | MATRL | .0879 | .0914 | .0930 | .0940 | .0940 | .0936 | .0974 | .0991 | .1002 | .1002 |
| | OTHER | .0169 | .0175 | .0178 | .0180 | .0180 | .0182 | .0188 | .0191 | .0193 | .0193 |
| 30.0 | TOTAL | .1315 | .1366 | .1389 | .1404 | .1404 | .1403 | .1458 | .1482 | .1498 | .1498 |
| | LABOR | .0341 | .0354 | .0359 | .0363 | .0363 | .0365 | .0379 | .0385 | .0389 | .0389 |
| | MATRL | .1194 | .1242 | .1264 | .1278 | .1278 | .1279 | .1330 | .1354 | .1369 | .1369 |
| | OTHER | .0204 | .0211 | .0214 | .0217 | .0217 | .0219 | .0227 | .0231 | .0233 | .0233 |
| 33.0 | TOTAL | .1739 | .1807 | .1837 | .1858 | .1858 | .1963 | .1936 | .1970 | .1991 | .1991 |
| | LABOR | .0386 | .0400 | .0407 | .0411 | .0411 | .0414 | .0430 | .0436 | .0441 | .0441 |
| | MATRL | .1397 | .1454 | .1479 | .1496 | .1496 | .1501 | .1561 | .1589 | .1607 | .1607 |
| | OTHER | .0222 | .0231 | .0234 | .0237 | .0237 | .0240 | .0249 | .0253 | .0255 | .0255 |
| 35.0 | TOTAL | .2006 | .2085 | .2120 | .2144 | .2144 | .2155 | .2240 | .2278 | .2303 | .2303 |
| | LABOR | .0423 | .0439 | .0446 | .0451 | .0451 | .0455 | .0472 | .0479 | .0484 | .0484 |
| | MATRL | .1562 | .1625 | .1654 | .1672 | .1672 | .1681 | .1748 | .1780 | .1800 | .1800 |
| | OTHER | .0239 | .0248 | .0252 | .0255 | .0255 | .0258 | .0268 | .0272 | .0275 | .0275 |
| 37.5 | TOTAL | .2224 | .2312 | .2352 | .2378 | .2378 | .2394 | .2488 | .2531 | .2559 | .2559 |
| | LABOR | .0483 | .0502 | .0509 | .0515 | .0515 | .0520 | .0539 | .0548 | .0554 | .0554 |
| | MATRL | .1801 | .1873 | .1907 | .1928 | .1928 | .1939 | .2017 | .2053 | .2076 | .2076 |
| | OTHER | .0270 | .0281 | .0285 | .0288 | .0288 | .0292 | .0303 | .0307 | .0310 | .0310 |
| > 37.5 | TOTAL | .2554 | .2656 | .2701 | .2731 | .2731 | .2751 | .2859 | .2909 | .2940 | .2940 |

UNIT (GTM) PROGRAM TRACK COST REPORT FIGURE 30

Eastbound Traffic, Mesa - Downing (Approx. 30% Double Track Main, Remainder S.T.) Traffic Density ≅ 27 MGT, Light/Medium Curvature, .5-1.5% Grades, Good Track Support

LINEHAUL TRACK COSTS 

CREW DISTRICT MESA-DOWNING DIRECTION W ANNUAL COSTS - $ PER YEAR

ROUTE MILES 47.1

| WHEEL LOAD CLASS | | Mixed Consist Trains HP/TON CLASS 1 | 2 | 3 | 4 | 5 | TOTAL | Unit Trains HP/TON CLASS 1 | 2 | 3 | 4 | 5 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | LABOR | 57 | 5024 | 2579 | 475 | 125 | 8260 | 0 | 503 | 46 | 13 | 0 | 567 |
| | MATRL | 182 | 16136 | 8285 | 1525 | 401 | 26529 | 0 | 1609 | 148 | 57 | 0 | 1814 |
| | OTHER | 36 | 3226 | 1656 | 305 | 80 | 5303 | 0 | 325 | 30 | 12 | 0 | 367 |
| 19.0 | TOTAL | 275 | 24386 | 12520 | 2305 | 606 | 40092 | 0 | 2437 | 224 | 87 | 0 | 2748 |
| | LABOR | 0 | 5792 | 4032 | 473 | 91 | 10388 | 0 | 0 | 0 | 0 | 0 | 0 |
| | MATRL | 0 | 19218 | 13379 | 1568 | 303 | 34468 | 0 | 0 | 0 | 0 | 0 | 0 |
| | OTHER | 0 | 3610 | 2513 | 295 | 57 | 6475 | 0 | 0 | 0 | 0 | 0 | 0 |
| 26.0 | TOTAL | 0 | 28620 | 19924 | 2336 | 451 | 51331 | 0 | 0 | 0 | 0 | 0 | 0 |
| | LABOR | 0 | 1789 | 553 | 60 | 45 | 2447 | 0 | 0 | 0 | 0 | 0 | 0 |
| | MATRL | 0 | 5912 | 1828 | 197 | 150 | 8087 | 0 | 0 | 0 | 0 | 0 | 0 |
| | OTHER | 0 | 1119 | 346 | 37 | 28 | 1530 | 0 | 0 | 0 | 0 | 0 | 0 |
| 30.0 | TOTAL | 0 | 8820 | 2727 | 294 | 223 | 12064 | 0 | 0 | 0 | 0 | 0 | 0 |
| | LABOR | 4 | 2164 | 551 | 93 | 27 | 2839 | 0 | 5 | 0 | 5 | 0 | 10 |
| | MATRL | 15 | 7596 | 1933 | 325 | 96 | 9965 | 0 | 16 | 0 | 16 | 0 | 32 |
| | OTHER | 2 | 1276 | 325 | 55 | 16 | 1674 | 0 | 3 | 0 | 3 | 0 | 6 |
| 33.0 | TOTAL | 21 | 11036 | 2809 | 473 | 139 | 14478 | 0 | 24 | 0 | 24 | 0 | 48 |
| | LABOR | 0 | 2204 | 1835 | 383 | 146 | 4568 | 0 | 74 | 14 | 5 | 9 | 102 |
| | MATRL | 0 | 7987 | 6653 | 1388 | 530 | 16558 | 0 | 269 | 50 | 19 | 32 | 370 |
| | OTHER | 0 | 1255 | 1045 | 218 | 83 | 2601 | 0 | 42 | 8 | 3 | 5 | 58 |
| 35.0 | TOTAL | 0 | 11446 | 9533 | 1989 | 759 | 23727 | 0 | 385 | 72 | 27 | 46 | 530 |
| | LABOR | 0 | 47 | 9 | 0 | 0 | 56 | 0 | 0 | 0 | 0 | 0 | 0 |
| | MATRL | 0 | 175 | 32 | 0 | 0 | 207 | 0 | 0 | 0 | 0 | 0 | 0 |
| | OTHER | 0 | 26 | 5 | 0 | 0 | 31 | 0 | 0 | 0 | 0 | 0 | 0 |
| 37.5 | TOTAL | 0 | 248 | 46 | 0 | 0 | 294 | 0 | 0 | 0 | 0 | 0 | 0 |
| | LABOR | 0 | 87 | 54 | 6 | 0 | 147 | 0 | 0 | 0 | 0 | 0 | 0 |
| | MATRL | 0 | 323 | 202 | 22 | 0 | 547 | 0 | 0 | 0 | 0 | 0 | 0 |
| | OTHER | 0 | 48 | 30 | 3 | 0 | 81 | 0 | 0 | 0 | 0 | 0 | 0 |
| > 37.5 | TOTAL | 0 | 458 | 286 | 31 | 0 | 775 | 0 | 0 | 0 | 0 | 0 | 0 |
| TOTAL | LABOR | 61 | 17107 | 9613 | 1490 | 434 | 28705 | 0 | 582 | 60 | 28 | 9 | 679 |
| TOTAL | MATRL | 197 | 57347 | 32312 | 5025 | 1480 | 96361 | 0 | 1894 | 198 | 92 | 32 | 2216 |
| TOTAL | OTHER | 38 | 10560 | 5920 | 913 | 264 | 17695 | 0 | 370 | 38 | 18 | 5 | 431 |
| GRAND | TOTAL | 296 | 85014 | 47845 | 7428 | 2178 | 142761 | 0 | 2846 | 296 | 138 | 46 | 3326 |

ANNUAL LINEHAUL PROGRAM TRACK COST REPORT FIGURE 31

Westbound Traffic, Mesa-Downing (Approx.30% Double Track remainder S.T.), Traffic Density ≅ 27 MGT, Light/Medium Curvature, .5-1.5% Grades, Good Track Support

LINEHAUL TRACK COSTS — PAGE 73

CREW DISTRICT MESA-DOWNING DIRECTION E ANNUAL COSTS - $ PER YEAR

ROUTE MILES 47.1

| WHEEL LOAD CLASS | | Mixed Consist Trains HP/TON CLASS 1 | 2 | 3 | 4 | 5 | TOTAL | Unit Trains HP/TON CLASS 1 | 2 | 3 | 4 | 5 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | LABOR | 67 | 3387 | 1181 | 260 | 109 | 5004 | 0 | 2 | 0 | 0 | 0 | 2 |
| | MATRL | 214 | 10873 | 3902 | 840 | 350 | 16079 | 0 | 8 | 0 | 0 | 0 | 8 |
| | OTHER | 42 | 2197 | 766 | 169 | 70 | 3245 | 0 | 2 | 0 | 0 | 0 | 2 |
| 15.0 | TOTAL | 324 | 16457 | 5849 | 1269 | 529 | 24328 | 0 | 12 | 0 | 0 | 0 | 12 |
| | LABOR | 466 | 9937 | 2543 | 595 | 167 | 13709 | 0 | 262 | 78 | 0 | 0 | 340 |
| | MATRL | 1544 | 32989 | 8463 | 1988 | 557 | 45541 | 0 | 868 | 260 | 0 | 0 | 1128 |
| | OTHER | 294 | 6262 | 1602 | 375 | 105 | 8638 | 0 | 166 | 50 | 0 | 0 | 216 |
| 26.0 | TOTAL | 2304 | 49188 | 12608 | 2958 | 829 | 67888 | 0 | 1296 | 388 | 0 | 0 | 1684 |
| | LABOR | 11 | 1050 | 203 | 13 | 0 | 1277 | 0 | 3 | 26 | 0 | 0 | 29 |
| | MATRL | 35 | 2470 | 671 | 43 | 0 | 4221 | 0 | 10 | 87 | 0 | 0 | 97 |
| | OTHER | 7 | 664 | 128 | 9 | 0 | 807 | 0 | 2 | 17 | 0 | 0 | 19 |
| 30.0 | TOTAL | 53 | 5184 | 1002 | 66 | 0 | 6305 | 0 | 15 | 130 | 0 | 0 | 145 |
| | LABOR | 26 | 1677 | 160 | 21 | 4 | 1888 | 0 | 359 | 104 | 0 | 0 | 463 |
| | MATRL | 92 | 5696 | 566 | 75 | 13 | 6644 | 0 | 1264 | 368 | 0 | 0 | 1632 |
| | OTHER | 16 | 1001 | 96 | 13 | 2 | 1128 | 0 | 216 | 63 | 0 | 0 | 279 |
| 33.0 | TOTAL | 134 | 8576 | 822 | 109 | 19 | 9660 | 0 | 1839 | 535 | 0 | 0 | 2374 |
| | LABOR | 0 | 2377 | 974 | 325 | 198 | 3874 | 0 | 101 | 25 | 0 | 0 | 126 |
| | MATRL | 0 | 8648 | 3531 | 1182 | 724 | 14111 | 0 | 306 | 93 | 0 | 0 | 459 |
| | OTHER | 0 | 1371 | 561 | 194 | 114 | 2234 | 0 | 58 | 15 | 0 | 0 | 73 |
| 35.0 | TOTAL | 0 | 12396 | 5096 | 1701 | 1036 | 20219 | 0 | 525 | 133 | 0 | 0 | 658 |
| | LABOR | 0 | 42 | 4 | 5 | 0 | 51 | 0 | 0 | 0 | 0 | 0 | 0 |
| | MATRL | 0 | 156 | 17 | 17 | 0 | 190 | 0 | 0 | 0 | 0 | 0 | 0 |
| | OTHER | 0 | 24 | 3 | 3 | 0 | 30 | 0 | 0 | 0 | 0 | 0 | 0 |
| 37.5 | TOTAL | 0 | 222 | 24 | 25 | 0 | 271 | 0 | 0 | 0 | 0 | 0 | 0 |
| | LABOR | 14 | 336 | 39 | 0 | 0 | 389 | 0 | 0 | 0 | 0 | 0 | 0 |
| | MATRL | 52 | 1257 | 148 | 0 | 0 | 1457 | 0 | 0 | 0 | 0 | 0 | 0 |
| | OTHER | 8 | 198 | 22 | 0 | 0 | 218 | 0 | 0 | 0 | 0 | 0 | 0 |
| > 37.5 | TOTAL | 74 | 1791 | 209 | 0 | 0 | 2064 | 0 | 0 | 0 | 0 | 0 | 0 |
| TOTAL | LABOR | 564 | 18806 | 5104 | 1220 | 478 | 26192 | 0 | 727 | 233 | 0 | 0 | 960 |
| TOTAL | MATRL | 1937 | 63291 | 17213 | 4153 | 1644 | 88243 | 0 | 2516 | 808 | 0 | 0 | 3324 |
| TOTAL | OTHER | 368 | 11707 | 3173 | 755 | 291 | 16300 | 0 | 444 | 145 | 0 | 0 | 589 |
| GRAND | TOTAL | 2869 | 93804 | 25500 | 6129 | 2413 | 130735 | 0 | 3687 | 1186 | 0 | 0 | 4873 |

ANNUAL LINEHAUL PROGRAM TRACK COST REPORT FIGURE 32

Eastbound Traffic, Mesa-Downing (Approx. 30% Double Track remainder S.T.), Traffic Density ≅ 27 MGT, Light/Medium Curvature, .5-1.5% Grades, Good Track Support.

## 2. Ordinary/Routine Track Maintenance Costs

### Introduction

The previous section described procedures for determining and allocating variable linehaul trackage costs associated with the major "program" elements of the track structure, i.e., those which could reasonably be viewed as functions of track component service lives or maintenance/renewal cycles. This section deals with the costs of those track-related work activities normally performed on a routine or as-required basis which are also properly related to traffic type and volume.

As differentiated from the predictive methodology applied to rail and OTM renewal, tie renewal, track surfacing and ballast cleaning/renewal, the costs associated with ordinary or routine track maintenance presently cannot be adequately determined by a track performance "model." The track maintenance activities under consideration here primarily include the following:

- spot tamping and lining
- spot tie replacement
- gauging and adjusting anchors
- repairing insulated joints
- weld grinding
- driving down spikes
- joint lubrication
- install new or reformed joint bar
- renew/tighten track bolts
- repair wheel burns
- ultrasonic inspection
- replace defective/failed rails
- rail-end welding
- rail-surface grinding
- track shimming
- welding points and frogs
- renewing other OTM

Neither the frequency with which these activities must be performed, nor the "unit costs" associated with their performance can at this point be satisfactorily related to the track/traffic parameters discussed earlier, i.e., they do not exhibit readily discernible "production functions." These costs, affected by all such parameters, are also significantly affected by the level and quality of program maintenance/renewal being carried out. (The reverse is, of course, also true). For these reasons, and while recognizing that the observed levels of expenses associated with these routine track maintenance activities are subject to the same distortions due to maintenance deferrals cited earlier, it is believed that such expenses can presently be more adequately determined by examination of recorded expenses in the various maintenance accounts.

### Affected Accounts

Referring to the expense items in the Accounting Structure outlined in Appendix F, the following items constitute the ordinary or routine track maintenance costs described above (those not treated as "program-type" costs.

| Item No. | Description |
|---|---|
| 001 | Spot Rail/Stock Rail Renewals |
| 003 | Welding and Track Grinding |
| 004 | Operating Detector Cars and Ultrasonic Test Equipment |
| 006 | Replacing Switch Ties |
| 009 | Replacing Switches and Other Material |
| 010 | Replacing Insulated Joints |
| 013 | Ordinary Ballast Repairs |
| 015 | Miscellaneous Roadway Repairs |
| 016 | Miscellaneous Track Repairs |
| 016A | Extraordinary Track Repairs - Washouts |
| 017 | Extraordinary Track Repairs - Derailments |
| 023 | Renew Bridge Ties |
| 111 | Spot Surface Track |

Of these expense items, the following is excluded as being entirely or predominately unaffected by type and volume of traffic:

016A Extraordinary Track Repairs - Washouts

In addition, Item 015, Miscellaneous Roadway Repairs should more properly be further subdivided to separate Roadbed Stabilization and Patroling Track from the remainder of the track maintenance activities included under Item 015, as these two are most appropriately considered traffic-related. This may be accomplished either by estimating the proportion of these activities to the total of expenditures for Miscellaneous Roadway Repairs or, of course, by constructing and maintaining additional expense item categories.

While it can be argued that portions of these routine maintenance activities are not materially affected by traffic-type and volume, e.g., Track Shimming, or have some relatively "fixed" element associated with their behavior, e.g. rusting or corrosion of OTM, weathering of bridge ties, etc., these portions are felt to be minimal in comparison with the truly traffic-related expenses associated with these activities. For these reasons, all the expenses found in the accounting items listed above are considered "variable" with traffic. Further refinements can, of course, be undertaken. However, these must be evaluated in light of the complexities in expenditure reporting they are likely to cause.

Level of Expense Differentiation and Assignment

While it is recognized that expenses associated with the routine track maintenance activities will potentially vary from maintenance district to maintenance district (if indeed not from track mile to track mile within a given maintenance district), it is proposed that these expenses be aggregated at the division level and assigned as division-average (gross ton mile) variable costs for pricing purposes. This aggregation is felt to be a necessary present compromise between costing accuracy and cost system complexity. Resulting division-average routine track maintenance costs can now be converted to crew-district unit (GTM) costs by weighting the linehaul track miles of each division which exist in a given crew district. This is illustrated below:

$$UC_{CD_A} = \frac{\frac{\$TM_1}{GTM_1} K_1 + \frac{TM_2}{GTM_2} K_2 + \ldots \frac{\$TM_n}{GTM_n} K_n}{K_1 + K_2 + \ldots K_n}$$

Where:

$UC_{CD_A}$ = Routine linehaul track maintenance unit (GTM) costs for crew district A

$TM_n$ = Total linehaul routine track maintenance expenses for division n

$GTM_n$ = Total division gross ton miles for division n

$K_n$ = Total linehaul track miles of division n existing in crew district A

It should be noted that these expenses are also maintained on a "labor - material - other" basis consistent with the treatment of all other roadway maintenance costs (See Appendix F).

Effects of Heavy Wheel Loads

As with the unit costs developed for the categories of "program" track maintenance/renewal described previously, reasonable distinctions between the effects of various wheel load categories can be obtained for routine track maintenance expenses as well. This can be accomplished as follows.

Prior to summing all routine track maintenance expense items at the division level, individual items may be grouped according to which areas of track maintenance each item is most nearly "related" to. This is demonstrated below.

| Routine Track Maintenance Items Related to Rail Life | Routine Track Maintenance Items Related to Rail Bending Stress or Track Deflection |
|---|---|
| 001 | 006 |
| 003 | 010 |
| 004 | 013 |
| 009 | 015 (Part) |
| | 016 |
| | 017 |
| | 023 |
| | 111 |

Division-average gross ton mile costs are then obtained for each of these two groups of expense items. Using the average wheel load determined in the analysis of program-related track costs (see pp.VII-33), the same relative wheel load factors previously developed are applied as follows:

$UC_{RR}$ = division-average rail-related unit(gtm) cost

$UC_{BS/TD}$ = division-average bending stress/track deflection-related unit (gtm) cost

| Wheel Load Class (lbs) | Rail-Related Costs($UC_{RR}$) | Bending Stress/ Track Deflection-Related Costs($UC_{BS/TD}$) | TOTAL |
|---|---|---|---|
| <15,000 | .8670 | 1.000 | .8670($UC_{RR}$)+ 1.000($UC_{BS/TD}$) |
| 15-26,000 | 1.1605 | 1.1236 | 1.1605 ($UC_{RR}$)+1.1236($UC_{BS/TD}$) |
| 26-30,000 | 1.1892 | 1.1765 | 1.1892($UC_{RR}$)+1.1765($UC_{BS/TD}$) |
| 30-33,000 | 1.8335 | 1.3158 | 1.8335($UC_{RR}$)+1.3158($UC_{BS/TD}$) |
| 33-35,000 | 2.2779 | 1.3699 | 2.2779($UC_{RR}$)+1.3699($UC_{BS/TD}$) |
| 35-37,500 | 2.6261 | 1.4286 | 2.6261($UC_{RR}$)+1.4286($UC_{BS/TD}$) |
| >37,500 | 3.0731 | 1.5873 | 3.0731($UC_{RR}$)+1.5873($UC_{BS/TD}$) |

The relative wheel load factors shown above are the mathematical reciprocals of the linehaul rail, and tie and surfacing life factors for wheel loads developed previously. These factors are based upon and average loaded car weight of 100 tons. If the average loaded car weight on a given division is significantly different from 100 tons, these factors must be modified by multiplying each factor shown by 100 ÷ the average loaded car weight on the division. For example, if the average loaded car weight on the division is 125 tons, all cost factors should be multiplied by 0.800 (100 ÷ 125 = .800).

The resulting wheel load-factored routine track maintenance costs (division-average) are then apportioned to crew districts as described on page 85 .

Although theoretically possible, no similar weighting factors are developed to distinguish the effects of train speed and train service-type on these routine linehaul track maintenance costs. Such distinctions would be essentially meaningless for division-level costs.

It should be noted that while division-level or crew district routine track maintenance costs may prove adequate for pricing purposes, knowledge of the behavior of these expenses at the maintenance district level is required for adequate maintenance planning and control.

It has been previously stated that routine track maintenance costs are most certainly a function of specific track/traffic conditions and that given the nature of associated maintenance activities, these costs do not readily lend themselves to "modeling" or other development through the use of definite "production functions." This does not, however, prevent their estimation for specific line segments. Thomas K. Dyer, Inc., Engineering Consultants, have recently estimated these other main track costs based on their review of specific lines. The Dyer cost estimates are presented below and also include costs of vegetation control, ditching, and cleaning tracks and right of way, which are excluded from the traffic-related routine track costs as utilized in this study (it will be seen that there is in fact a "fixed" component of the Dyer formula for estimating such costs). The resulting formulas for estimating the annual costs per track mile (1974 dollars) are:

| | |
|---|---|
| Single track: | $765 + 28G$ |
| Double track: | $645 + 24G$ |

Where G is the annual gross tonnage in millions, and reflects a measure of the number of trains operated (based on freight-only track).

## 3. Structures Maintenance Costs

### Introduction

Cost analysts have traditionally treated structures maintenance costs as "fixed" with respect to volume and type of traffic. The general rationale has always been that unless the design limits of the structure are exceeded, most annual maintenance would be attributable to the elements, accidents, etc. While it is recognized that structures or their specific components do wear out, the service lives involved are long enough to have precluded quantifying any specific effects which annual tonnage, train speeds or wheel loads may have on structure life/cost.

A portion of the field investigation conducted in this study (See Appendix B) was directed at determining whether structures maintenance personnel (bridge inspectors and maintenance supervisors) felt that significant variations in structure component life or maintenance were attributable to annual tonnage density, heavy wheel loadings or train speeds. While results of this survey were necessarily qualitative, the following conclusions were drawn:

a. The maintenance activities associated with tunnels, culverts, fences, snowsheds, signs, stations and office buildings and concrete bridges are essentially independent of tonnages, wheel loads and speeds. The only perceptible effects of traffic on the costs associated with the maintenance of these items were those resulting from train traffic interfering with the efficient performance of structures maintenance. This was currently felt to be a minor aspect of the maintenance costs of these items.

b. The maintenance of steel bridges and trestles was felt to be traffic-dependent to the following extent:

   1) Effects of Heavy Wheel Loads

      - increased incidence of fatigue fractures
      - substantial increase in incidence of loose and sheared rivits

   2) Effects of High Annual Tonnages

      - overall decreased member life due to accelerated fatigue
      - more frequent tightening of decks and floor beam connections

   3) Effects of Train Speeds

      - increased wear in stringer to floor beam connections on higher speed structures
      - loosening of rivets due to increased vibration at higher speeds.
      - increased slack in lateral and diagonal bracing due to sway

c. The maintenance of timber bridges and trestles was felt to be traffic-dependent as follows:

1) Effects of Heavy Wheel Loads

- increased incidence of split or broken stringers, requiring more helper stringers
- increased lateral movement in higher bents

2) Effects of High Annual Tonnages

- accelerated wear between stringers, caps and ties
- increased loosening of line, chord and anchor bolts
- more maintenance required on pilings and bracings

3) Effects of Train Speeds

- increased wear on caps, bracing and stringers for higher speed structures
- increased loosening of deck bolts

Analysis

While effects of traffic type and volume on structures maintenance cost have not been specifically determined, sufficient evidence was accumulated to consider the bulk of bridge and trestle maintenance activities included under Expense Item 022 (Minor Bridge, Trestle and Culvert Repairs) as appropriate variable maintenance items the cost of which should be considered traffic-dependent. For the Southern Pacific, bridge and trestle maintenance under this expense item is currently felt to constitute approximately 70% of the total expenditures under Item 022.

For purposes of cost analysis for pricing, these costs can be used at the division level, i.e., division-average minor bridge and trestle maintenance gross ton mile costs can be constructed in a manner identical to that described for routine track maintenance activities. Further refinement to reflect variations in these structure costs as a function of heavy wheel loads can similarly be accomplished as demonstrated below.

| Wheel Load Class (lbs) | Bending Stress/Track Deflection-Related Costs ($UC_{BTM}$) |
|---|---|
| <15,000 | 1.000 |
| 15,000 - 26,000 | 1.1236 |
| 26,000 - 30,000 | 1.1765 |
| 30,000 - 33,000 | 1.3158 |
| 33,000 - 35,000 | 1.3699 |
| 35,000 - 37,500 | 1.4286 |
| >37,500 | 1.5873 |

The factors shown are the same as those for track structure bending stress/ deflection-related costs. Similarly, distinctions in division-average structures maintenance costs for train speed and train service-type are felt to be essentially meaningless and are not developed here.

These resulting division-average structures maintenance costs may be assigned on a crew district basis either by arbitrarily assigning the division cost based on which division predominates in the crew district based on relative track miles or more appropriately, by considering which division has more timber and steel structures on the crew district line-haul trackage.

It is clear that far more precise analyses of different types of structures under varying traffic conditions can be accomplished to refine the nature of the cost treatment given herein. Such analyses can be completed by special studies with sufficient structures records reflecting the following information:

- location of structure (milepost designation)
- type of structure (timber, steel or concrete, open deck or ballast deck )
- single or multiple track structure
- structure length
- year built
- condition records of each bent, pile, cap and stringer (periodic inspection reports)
- height of bents
- type, spacing, condition of bridge ties
- record of major maintenance received
- annual repair expenses associated with the structure (obtained by special work order or other project records)

The information described above, when combined with the specific traffic characteristics attendant to particular structures, will yield much more precise data for evaluating the economic behavior of railroad structures.

4. Signal Maintenance Costs

While the cost finding procedures of both the Interstate Commerce Commission (ICC) and the Canadian Transport Commission (CTC) consider signal maintenance costs as partially traffic-related, studies by the AAR[1], as well as other recent work[2] have considered these costs to be largely fixed by the size and type of plant.

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1. A Guide to Railroad Cost Analysis, Bureau of Railway Economics, Association of American Railroads, December 1964.

2. Analysis of Track and Roadbed Maintenance Cost Variability, Rail Systems Research Associates, December 1973.

ICC procedures include signal maintenance expenses (Account 249) in a group of accounts - 201 (Superintendence) and 227 through 279 - which is regressed against tons of revenue freight. CTC procedures group signal maintenance expenses with dispatching and signal operations and regress the sum of these expenses against train-miles.

Given the nature of railway signaling systems, i.e., generally being composed of components (relays, switch machines, interlockers, detectors, etc.) which function or are activated with the passage of trains, it is intuitive to expect at least a portion of signal maintenance expenses to vary with train movement-related statistics, e.g., train-miles. There are, of course, other signal "maintenance" expenses that would be expected to be relatively fixed over some broad ranges of traffic output, e.g., signal inspection expenses incurred on a periodic basis as required by the Federal Railroad Administration, and still other expenses, e.g., cable and line replacements which are almost soley a function of time and the size and type of signal system. There are, of course, portions of all three potential categories (variable, "step-variable" and fixed) of signal maintenance costs that will reflect factors not capable of specific inclusion in any analysis. These include climatic conditions, difficulty in reaching remote areas to perform signal repairs, vandalism, etc.

In an attempt to establish the nature of the relationship (if any) between signal maintenance expenses and train movement-related statistics (in this case train-miles), the following analysis was performed.

a) The signal system across the trackage under study was inventoried in terms of the total amount of signal system complexity (measured by the presence of all the various types of signal components or devices on each division in the study trackage area). This was accomplished by recording the quantity of each type of device and weighting by the number of AAR Relative Signal Units contained in each device. The description of signal devices/components analyzed and their associated relative values is given in Table I.

b) Train mile statistics at the division level were recorded for use in a regression analysis. Signal maintenance expenses were developed from Expense Items 043-Repair of Signal Systems, 044-Repair Hot Box Detector Systems and 206-Maintenance of Hot Box Carrier Equipment for each division.

c) Signal Maintenance expenses per signal unit and expenses per signal unit value were tested against traffic output as measured by train-miles. No indication of relationship to traffic output was found in each of the three analyses, i.e., results indicated almost total randomness.

| UNIT NO. | DESCRIPTION | RELATIVE UNIT VALUE |
|---|---|---|
| 1 | SIGNAL, ARM OR LIGHT, INOPERATIVE | 1 |
| 2 | SIGNAL, COMPLETE WITH MAST, BLADE OR LIGHT, INOPERATIVE | 2 |
| 3(a) | SIGNAL, THREE ASPECTS, SEMAPHORE OR LIGHT | 6 |
| (b) | SIGNAL, TWO ASPECTS, SEMAPHORE OR LIGHT | 4 |
| (c) | SIGNAL, ONE ASPECT, SEMAPHORE OR LIGHT | 2 |
| (d) | SIGNAL, EACH ADDITIONAL ASPECT | 2 |
| (e) | SIGNAL, MECHANICALLY OPERATED, MANUAL BLOCK, TRAIN ORDER OR RAILROAD GRADE CROSSING SIGNAL, TWO OR THREE ASPECTS | 4 |
| (f) | SMASHBOARD, MECHANICAL OR POWER | 4 |
| 4 | MARKER LIGHT, OPERATED | 2 |
| 5 | GRADE SIGNAL, SEMAPHORE OR LIGHT, OPERATIVE | 2 |
| 6 | SWITCH (2 POINTS) OR DERAIL | |
| | (a) MECHANICAL | 4 |
| | (b) POWER | 8 |
| 7 | SLIP SWITCH (2 POINTS) | |
| | (a) MECHANICAL | 4 |
| | (b) POWER | 8 |
| 8 | SLIP SWITCH (4 POINTS) | |
| | (a) MECHANICAL | 8 |
| | (b) POWER | 12 |
| 9 | MOVABLE POINT FROG (4 POINTS) | |
| | (a) MECHANICAL | 8 |
| | (b) POWER | 12 |
| 10 | DERAIL, PIPE CONNECTED TO SWITCH AND OPERATED THEREBY | 1 |
| 11 | DETECTOR BAR 55 FT. IN LENGTH, OR FRACTION THEREOF | 2 |
| 12(a) | FACING POINT LOCK, MOVABLE BRIDGE LOCK OR RAIL LOCK | |
| | 1. MECHANICAL | 2 |
| | 2. POWER | 6 |
| (b) | FACING POINT LOCK, MOVABLE BRIDGE LOCK OR RAIL LOCK OPERATED WITH ANOTHER UNIT | 1 |
| 13 | SPRING SWITCH | |
| | (a) BUFFER | 1 |
| | (b) MECHANICAL FACING POINT LOCK | 4 |
| 14 | SWITCH-AND-LOCK MOVEMENT, MECHANICAL | 1 |
| 15(a) | MOVABLE BRIDGE CIRCUIT CONTROLLER OR PIPE COUPLER | |
| | 1. MECHANICAL | 4 |
| | 2. POWER | 8 |
| (b) | MOVABLE BRIDGE CIRCUIT CONTROLLER OR PIPE COUPLER OPERATED WITH ANOTHER UNIT | 2 |
| (c) | AUXILIARY CIRCUIT CONTROLLER ON MOVABLE BRIDGE WEDGE, LATCH, LIFT RAIL, ETC. | 1 |
| 16(a) | NON-CODED TRACK CIRCUIT | 2 |
| (b) | SUPERIMPOSED CIRCUIT ON TRACK CIRCUIT | 2 |
| (c) | CODED TRACK CIRCUIT | 4 |
| (d) | AUXILIARY TRACK INSTRUMENT FOR TRAIN DETECTION | 2 |
| 17(a) | ELECTRIC LEVER LOCK APPLIED TO A MECHANICAL LEVER | 1 |
| (b) | ELECTRIC LOCK ON HAND-OPERATED SWITCH OR RAILROAD GRADE CROSSING GATE | 2 |
| (c) | ELECTRIC LOCK APPLIED TO UNITS 12a, 12b AND 14 | 1 |
| (d) | MECHANICAL TIME LOCK APPLIED TO A MECHANICAL LEVER, HAND-OPERATED SWITCH AND TO UNITS 12a, 12b AND 14 | 1 |
| 18 | SKATE PLACING MACHINE | 4 |
| 19 | CAR RETARDER INCLUDING OPERATING MECHANISM PER RAIL FOOT OF BRAKING LENGTH PER RAIL | 1 |
| 20(a) | HIGHWAY GRADE CROSSING SIGNAL, BELL TYPE, WITH OR WITHOUT REFLECTORIZED SIGNS, PER MAST | 1 |
| (b) | HIGHWAY GRADE CROSSING SIGNAL, WIG-WAG OR FLASHING LIGHT TYPE (ONE PAIR OF FLASHING LIGHTS), WITH OR WITHOUT BELL OR REFLECTORIZED SIGNS, PER MAST | 2 |
| (c) | ADDITIONAL PAIR OF FLASHING LIGHTS, ILLUMINATED "STOP" SIGN, AUXILIARY ILLUMINATED SIGN OR ROTATING "STOP" DISC. | 1 |
| (d) | EACH GATE MECHANISM, AUTOMATIC | 4 |
| 21 | HIGHWAY GRADE CROSSING GATE, MANUAL, PER POST | |
| | (a) MECHANICAL | 1 |
| | (b) POWER | 2 |
| 22(a) | TRAIN CONTROL INDUCTOR OR LOOP CIRCUIT | 1 |
| (b) | TRAIN CONTROL RAMP (ENERGIZED) MAGNET | 2 |
| 23 | SWITCH CIRCUIT CONTROLLER, SIGNAL OR HIGHWAY CROSSING PROTECTION | 1 |
| 24 | INDICATOR | |
| | (a) WAYSIDE TRACK OCCUPANCY OR SWITCH | 2 |
| | (b) YARD TRACK | 4 |
| | (c) THIRD RAIL CLEARANCE, PER INSTRUMENT | 2 |
| | (d) SWITCH OR DERAIL, TARGET OR LIGHT | 1 |
| | (e) TRACK PAN LIGHTS, PER MAST | 1 |
| 25 | RAILROAD GRADE CROSSING GATE, PER GATE | |
| | (a) MECHANICAL | 2 |
| | (b) POWER | 4 |
| 26(a) | APPROACH LOCKING, PER TRACK PER DIRECTION | 2 |
| (b) | TIME LOCKING, PER TRACK PER DIRECTION | 1 |
| 27(a) | TRAFFIC LEVER (INCLUDING CIRCUIT WITHIN THE INTERLOCKING OR BLOCK STATION) | 1 |
| (b) | TRAFFIC LEVER (INCLUDING CIRCUIT WITHIN AND WITHOUT THE INTERLOCKING OR BLOCK STATION) | 2 |
| 28 | DETECTOR DEVICES | |
| | (a) SLIDE OR ROCK FALL PER 100 FT. OF DETECTION | 2 |
| | (b) HIGH WATER OR FIRE. PER INSTALLATION | 1 |
| | (c) DRAGGING EQUIPMENT. PER DETECTOR | 2 |
| 29 | SWITCH HEATERS, CONTROLLED OR AUTOMATIC, PER PAIR OF SWITCH POINTS | 2 |
| 30 | GCP UNIT | 8 |
| 31 | HOT BOX DETECTOR | |
| | (a) BASIC UNIT | 65 |
| | (b) BASIC UNIT WITH RECORDER (LOCAL) | 73 |
| | (c) BASIC UNIT WITH RECORDER (LOCAL) AND LOCATOR | 88 |
| | (d) BASIC UNIT WITH RECORDER (LOCAL) AND BY-DIRECTIONAL WITH TWO LOCATORS | 103 |
| | (e) BASIC UNIT WITH RECORDER (REMOTE) | 80 |
| 32 | Motion Sensor | 5 |

Table I SIGNAL UNIT DESCRIPTIONS

From this analysis, three possible conclusions can be drawn:

- Signal maintenance expenses are essentially plant size and type-related,
- Any existing variability of such expenses with traffic output is overshadowed by expenses arising from adverse climatic conditions, access conditions, vandalism, etc.
- Single-year data is perhaps not representative of any definitive trend in signal maintenance expense behavior.

While there is no concrete justification for claiming that other railroads would obtain similar results from such analyses, there developed no basis for consideration of signal maintenance expenses as other than fixed for the system under study here.

There is obviously room for refinement in the analysis of signal maintenance costs. Signal expenses and signal inventory data can be analyzed in special studies conducted at the Section Maintainers level. (See Figure 33). Analyses of this type may isolate several of the above-mentioned factors which tend to obscure the behavior of signal maintenance costs and lead to different conclusions regarding cost variability.

5. Other Linehaul Maintenance Costs

There are elements of variable cost which are indirect in nature and which can be reasonably allocated among the different roadway service functions developed herein. These "overhead" type costs are treated in two later sections of the study. (See pp. 123-124).

For purposes of this study, Expense Items 058-Repair of Roadway Machines and 059-Work Equipment Lease or Rentals are considered entirely variable as the incurrence of costs in these areas is predominantly a function of the level of roadway maintenance activity occasioned by traffic-related deterioration of roadway track and structures. These items are factored to exclude the estimated portion of such expenses associated with linehaul program track structure maintenance and the remaining amounts are allocated entirely to linehaul maintenance based on the presumption that a majority of roadway equipment is devoted to linehaul-related maintenance activities.

DATE ______

## MAINTAINERS SECTION DATA

SECTION ______ DIVISION ______

FROM ______ TO ______

| | | | MOTOR CAR | TRUCK |
|---|---|---|---|---|
| MILES, ROAD | MAIN | MI. | | |
| MILES, TRACK | MAIN BONDED (JOINT) | MI. | | |
| MILES, TRACK | MAIN BONDED (CONT. WELDED) | MI. | | |
| CONTROLLER | SWITCH CIRCUIT (HAND THROW) | EA. | | |
| CIRCUITS | TRACK AND OVERLAY | EA. | | |
| DETECTOR | HOT BOX - YARD | EA. | | |
| DETECTOR | HOT BOX - AUTO - SINGLE | EA. | | |
| DETECTOR | HOT BOX - AUTO - BIDIRECTIONAL | EA. | | |
| DETECTOR | HOT BOX (BI-DIR.) DIG. OR SPRAY | EA. | | |
| DETECTOR | DRAGGING EQUIPMENT, BARRICADE, FLOOD, HIGH LOAD, ETC. | EA. | | |
| DETECTOR | SLIDE AND ROCK | M.FT. | | |
| DETECTOR | FIRE | M.FT. | | |
| INDICATORS | SWITCH & MOTOR CAR SUBJECT TO VANDALISM | | | |
| LINE | POLE | MI. | | |
| LOCK | SWITCH, ELECTRIC OR MECHANICAL | EA. | | |
| MACHINE | INTERLOCKING | NO.LEVERS | | |
| PREDICTOR | GRADE CROSSING | EA. | | |
| SIGNALS | SEM. OR SL | EA. | | |
| SIGNALS | NO. OF CROSSINGS PROTECTED BY: | | | |
| | WIGWAGS | EA. | | |
| | FL & FLRD | EA. | | |
| | GATES | EA. | | |
| SWITCH | SPRING WITH OIL BUFFER & MFPL | EA. | | |
| SWITCH | SPRING WITH OIL BUFFER WITHOUT MFPL | EA. | | |
| SWITCH | POWER MACHINE ELECTRIC OR PNEUMATIC | EA. | | |
| | TOTAL | | | |

AVERAGE NUMBER OF HOURS PER MONTH ______
BRANCH LINES ______

Figure 33
SIGNAL MAINTAINERS SECTION DATA

## Roadway Maintenance in Classification Yards

The classification yard represents the second roadway "service function" as treated in this study.
A classification yard may be defined as one or more of various types of trackage and facilities combined in the operations of train break-up and distribution, sorting and classification of cars, and make-up of trains for road movement. Auxiliary facilities such as locomotive terminals, repair tracks and car shops may also be associated with a given yard. A great variety of classification yards exist. This is due to yard design, size, location and primary classification function. However, within this wide variation there exist three basic classes of yards: fully automated hump yards, economatic hump yards and flat switching yards.

### Fully Automated Hump Yards

These yards utilize a rise or hump in the lead to the sorting unit. Cars are pushed over the hump, cut off from the initial string of cars, and allowed to roll by gravity through switches in the ladder tracks to designated sorting unit tracks. Automatic or semi-automatic retarders control speed. There are generally group retarders on the ladder leads and a master retarder immediately after the hump. Switch alignment may be controlled by computer or manually operated from the crest control tower. The primary purpose of these yards is the break-up/make-up of through trains.

### Economatic Hump Yards

These yards, often called "poor man hump yards," are basically smaller, less expensive versions of fully automated hump yards. Although the operations are similar, the yards have some distinct differences. Economatic hump yards generally have only tangent point retarders rather than master and group retarders. The height of the hump is usually only about five to six feet, and the distance from the crest to the clear point, which may be as much as 1800 feet in a fully automated hump yard, is kept to a minimum (generally less than 550 feet). The number of sorting unit tracks is usually less than 24, and the yard is designed such that a hard rolling car will reach the tangent point at a speed of about four miles per hour, and the easy rolling car at a speed of about 9.5 miles per hour. Economatic hump yards are generally used for make-up/break-up of trains arriving/departing a major terminal area. These yards usually function to decrease the classification load at a major yard which may also serve the same area.

Flat Switching Yards

These yards are placed on a relatively constant grade (generally nearly level). Cars are sorted as a locomotive pushes a string of cars onto first one track and then another. The cars appropriate to a particular track are cut off and allowed to drift along the track against cars already there.

Maintenance Costs in Yards

The cost of maintaining a yard facility occurs in five basic areas:

1 - Track Structure
2 - Car Retarder System
3 - Communication System
4 - Signal System
5 - Structures (Culverts, Bridges, Buildings, etc.)

Track Structure

This area includes the cost of maintaining and replacing rail, ties, ballast, turnouts and other track material. Several different groups of tracks exist within yards. These may include yard lead tracks, ladder lead tracks, running tracks, body tracks (arrival and departure yards), hump leads, sorting unit tracks and pull-down tracks. Different activities are associated with each of these types of track.

The same traffic characteristics and physical conditions which affect track maintenance costs in linehaul service also affect yard track maintenance costs. However, the operating demands placed upon the track structure differ significantly between the two situations. For example, ladder lead tracks may be subjected to the braking and accelerating of switch engines and bowl tracks are subjected to the static loading effect of standing cars. Furthermore, time related effects on rail wear such as corrosion become more significant determinants of total cost due to the typically low annual tonnages moving across individual bowl tracks.

Drainage problems in yards are often more severe than those associated with most linehaul trackage. This is partially a result of standing locomotives leaking sand and oil. However, it should also be noted that the location of a yard is generally a function of many parameters other than quality/stability of subgrade. This clearly affects tie life and ballast condition as well as track line and surface. Speeds in yards are well within the

the range of 12 to 18 mph where dynamic track-train forces are most likely to induce rock-and-roll. This intensifies the problems of low and/or pumping joints. Laying continuous welded rail in yards tends to decrease these problems.

A large portion of maintenance expense in yards may be the result of operating damages. The most costly of these is the repair or replacement of run-through switches. Furthermore, the high utilization of yard switch machines often results in an average life of only three years before reconditioning. The cleaning and oiling of switches is a major activity in yards. However, in the present analysis this is considered an expense of "operating" the roadway and is discussed in a following section.

Car Retarder System

These systems may be completely electric or the control may be electric with the retarder shoes applied pneumatically. In either case, the maintenance expense is due to replacement of retarder shoes and maintenance of the control system. The average cost of retarder shoe replacement may range from $3500 to $7000 per year for each retarder. The cost of the control system involves maintenance of speed sensors, track occupancy sensors, computers, power supply and compressed air lines.

Communication System

The system of communications and data collection in a yard can vary from a simple series of telephones to elaborate electronic data collection, processing and communications systems tied in with closed circuit television monitors and/or automatic car identification sensors. Teletype may be used to transmit train consists and switch lists between major terminals and to various sub-units of a classification yard complex. Computer printouts may also be used for the same purpose. Car movements may be recorded in one or more computer centers established in yard offices to permit inquiry regarding car location and movement.

Various yard elements (yard office, receiving/departure yard offices, hump office, etc.) may be interconnected with pneumatic tube systems to permit interchange of physical memoranda such as waybill, train consists and switch lists. Radio and/or "squawk" boxes are used to place yard masters in voice contact with all yard forces and others including the crews on yard engines, switch runs, transfers and crews on arriving and departing trains.

The cost of maintaining these systems includes such items as maintenance of communication channels, power supply, and standby equipment as well as the repair and replacement of relays, transistors, transformers and tubes. The magnitude of these costs will vary greatly with the complexity of the system.

### Signal System

Costs in this area involve maintenance of the hump signals, yard signals, insulated joints, as well as any interlocker system. Most of these expense items are probably relatively fixed with respect to traffic volume.

### Structures

Included in this cost area is the expense of repairing all yard buildings (including hump office, arrival and departure yard offices), fences and roads. Maintenance of track scales is also considered in this category. These expenses may be totally fixed with respect to traffic.

## Current Yard Costing Procedures

### Interstate Commerce Commission (ICC)

The ICC Rail Form A Costing Procedures base yard maintenance of way costs only on expenses reported in Accounts 202 - 221. Expenses reported in these accounts for yard and way-switching tracks (as well as running tracks) are estimates based upon total expenditures in each account and equated track mileage. Equated track mileage is determined from the values for labor distribution shown in Table 1. This allocation procedure (requested by the railroads) was first allowed by the ICC in 1935. The intent was to eliminate the necessity of compiling detailed expense records for yard and way-switching tracks. The proportion of total expenses (Accounts 202 - 221) assigned to yard switching tracks is given by the ratio of equated yard switching track mileage (miles of yard switching tracks multiplied by 0.32) to total system equated mileage.

| Track Class | American Railway Engineering Association (AREA) Factor |
|---|---|
| First Main Track, Mile | 1.00 |
| Second Main Track, Mile | 0.83 |
| Branchline Track, Mile | 0.49 |
| Yard and Side Track, Mile | 0.32 |

Table 1 - Equated Values for Labor Distribution

The estimated expenses for yard and way-switching tracks are regressed against yard and train-switching hours in an equation of the form:

$$Y = a + bx + cx^2$$

where:

$Y$ = expense per mile of road

$x$ = output per mile of road

"Percent variable" factors are computed for reported expenses and output for five years using the mean output level in the expression for elasticity:

$$\frac{b = 2c\bar{x}}{a/\bar{x} + b + c\bar{x}}$$

For the years 1966 - 1970 the percent variable determined ranged from 20 - 96 percent. An average of these five years was taken yielding a 55 percent variable factor. A unit variable cost is determined by dividing total variable expense (percent variable times total expenses) by yard output (total yard and train-switching hours).

Canadian Transport Commission (CTC)

The CTC method for analyzing yard maintenance costs does not utilize a separation or allocation of yard expenses. This method regresses the sum of the accounts for all track and roadway maintenance, ties, rail, OTM, ballast, roadway buildings, small tools and supplies, public improvements and right-of-way expenses against the independent variables of miles of road, gradient index, gross ton miles and yard and train-switching miles. The unit variable cost for yards is determined from the coefficient of the yard and train-switching miles variable. Variable overhead for roadway maintenance is determined by regressing the sum of expenses (excluding administrative expenses and health and welfare expenses) against the the sum of accounts for track and roadway maintenance, tunnels, bridges and culverts, ties, rail, OTM, ballast fences, snowsheds and signs, stations and office buildings, roadway buildings, water and fuel stations, shops and engine houses, power plant systems, other structures, roadway machines, small tools and supplies, removing snow, ice and sand, public improvements and right-of-way expenses, (excluding material stores expenses, direct shop general operating expenses, administrative expenses and power plant machinery expense). The variable overhead cost is applied to all variable expenses.

Proposed Yard Costing Procedures

The proposed yard costing procedures are based on the following premises:

1 - The costs associated with yards should, in most cases, be based upon actual rather than upon estimated or predicted expenses.

2 - Yard output for maintenance of way costing may be more appropriately measured in terms other than yard-engine hours.

Cost Determination

It should be clear that "expense records" (reflecting standardized allocations and also any existing budgetary constraints) do not necessarily reflect the true economic costs associated with traffic in yards. However, although conditions of deferred maintenance may exist in yards, exactly what constitutes a deferral is not easily defined. Even during periods of relatively high earnings, there generally are not definite program maintenance or renewal cycles in yards. For example, rail laid in yards is usually secondhand rail. The economic life of such rail in yard applications is based in part on factors other than the physical and traffic characteristics associated with the rail, such as the consequences of a broken rail, and the time necessary to replace a rail.

Serious maintenance deferrals have occurred in the yards of some of the financially troubled and bankrupt railroads. It cannot be argued that the expenses reported by these roads for yard maintenance reflected the economic costs of maintaining their yards. In these cases special treatment must be given to yard rehabilitation costs to develop annual yard costs for pricing and other purposes. However, in general, the procedures necessary to develop predictive measures of yard costs for pricing purposes based on estimated component service lives may not be justified given the relative magnitude of yard costs and the costs of such procedures themselves. This is explored in further detail later.

The conditions described above point to the need to refine yard maintenance costs used for pricing by use of more precise accounting procedures. Such a determination of yard maintenance of way expenses from accounting records necessitates treatment of yards as cost centers. However, this can usually be accomplished within the structure of existing responsibility accounting systems by assigning work order numbers or other cost control documentation to specific yards. Labor expense for maintenance work done in yards can then be determined by having field engineering and maintenance forces report their time against these documents. If material is expensed at sometime other than when it is used (such as when it is charged out of system or division stores - a normal procedure), then it will still be necessary to apportion this expense between the various service functions (linehaul, yards).

Specific expense areas which occur in yards and are considered to be variable with traffic include the following:

Spot Rail and Stock Rail Renewals
Welding and Track Grinding
Replacing Cross Ties
Replacing Switch Ties
Replacing Frogs
Replacing Switch Points
Replacing Switches - Other Material
Replacing Insulated Joints
Ballast Cleaning and Plowing
Ordinary Ballast Repairs
Miscellaneous Roadway Repairs
Miscellaneous Track Repairs
Extraordinary Track Repairs - Derailments
Minor Bridge, Trestle and Culvert Repairs
Repair Car Retarder Systems
Renew Bridge Ties
Spot Surface Track

Specific expense areas which occur in yards and are virtually fixed with respect to traffic include the following:

Repair Stations and Office Buildings
Repair Switching Yard Floodlights
Extraordinary Track Repairs - Washouts

Repair Roadway Buildings
Repair Diesel Servicing Facilities
Repair Power Plants
Repair Electrical Power Transmission Systems
Repair Steam and Air Power Transmission Systems
Repair Fences and Signs
Repair Signal System
Repair Communication System Facilities
Controlling Vegetation

For this cost accounting system to be reasonably accurate, a yard must be defined in terms that provide reporting ease for field forces. Such a definition could specify all tracks (excluding main tracks) within yard limits or which originate from a turnout within yard limits to be considered yard tracks. Defining a yard in these terms could include more trackage than that directly associated with a classification yard, however. Before instituting such a reporting system, it would be useful to interview field engineering personnel to determine the following:

1 - What is the most useful definition of a yard for field personnel?

2 - What effort will be involved on the part of field forces to report expenses for yards?

3 - Will refined maintenance expenses in yards be useful to personnel charged with maintaining those facilities?

4 - Will refined yard maintenance expenses yield the cost analyst more accurate expense information than an allocation based upon track miles and equated track mile factors?

Discussions with Southern Pacific Transportation Company personnel indicate that the previously stated definition of a yard is reasonable. Furthermore, responses from field personnel indicated that if proper reporting documents are provided, it would be possible to report expenses in yards, and that this information would be useful to engineering personnel. The regression analysis (p. VII-109) of yard expenses and track miles shows that expenses and track miles are correlated (correlation coefficient = .603, $R^2$ = 0.364). However, this correlation is not good enough to accurately estimate yard expenses on the basis of track miles.

Measuring Yard Output

Yard output for determining/assigning maintenance of way costs may be measured in several ways - yard-engine hours, yard tonnage throughput, car count, "switch count" or "switch tons."

Yard-engine hours is a readily available measure of yard output. However, some points concerning its use should be noted.

1 - Total yard-engine hours reflect only the time switch engines are operating. This is not necessarily the amount of time actually spent moving cars.

2 - Yard-engine time is not a causal factor of roadway expense, nor is it necessarily directly related to these factors.

3 - The amount of switching activity which takes place within a given time period is a function of many factors, including yard crew efficiency, yard layout, etc.

However, these points do not eliminate the possibility that a meaningful statistical relationship may exist between actual yard maintenance of way expense and switch-engine hours.

Tonnage handled through a yard may be a fairly good measure of output for those cost areas where tonnage is the primary expense-causing factor. However, throughput tonnage also does not reflect the switching activity which takes place within a yard. This can result in understating the total tonnage which moves over the sorting unit tracks. The number of cars handled through a yard (car count) may be a fairly simple output measure for yard costs resulting from operating damage. However, it is probably less related to those expenses incurred as a result of tonnage.

A more sophisticated measure of yard output can be developed based upon the number of switch-engine movements (switch count) required to move cars through a yard. This tally of switch-engine movements is illustrated best by example. A given car enters a flat yard in a train. At this point there have been no switch-engine moves, therefore, the "switch" count is zero. If the car now leaves in a train without being moved to another track, the switch count remains zero. Otherwise, when it is moved to another track, the switch count becomes one. Should it be moved again, the switch count increases by one. This continues every time a car is moved from one track to another until it departs in a train. It should be noted that a car movement within a train both arriving and departing a yard does not increase the switch count as this count is only a tally of switch-engine moves. Adding one to this switch count accounts for this movement.

A system which uses this switch count requires a basis for tabulating the count. This can be done on the basis of arriving train and departing train pairs, although this would involve a large number of combinations. It should be possible to greatly simplify this by only considering local and through trains. In this way only four possible combinations would be considered: arriving and departing on a local train, arriving and departing on a through train, arriving on a local and departing on a through train, arriving on a through train and departing on a local train. Although this simplification does not accurately reflect every car move, it should adequately reflect (for roadway costing purposes) a significantly large portion of them.

This switch count is useful in areas other than maintenance of way costing, such as terminal management. A tabulation of switch counts for the various activity centers within a terminal can give the terminal superintendent a measure of the physical activity that took place in each area. This information, when combined with switch-engine time for each activity center provides him with the capability to discern problem areas and monitor changes in the performance of any part of the terminal. The value of the switch count is that it reflects the physical movement and activity taking place within a yard rather than the time or number of cars involved.

The switch count only measures the movement of cars within a yard. Adding one to a given car's switch count (to reflect the move entering or departing the yard) and multiplying this count by car weight yields an effective measure ("switch tons") of the total yard output relative to that car. Basically, this is an approximation of the tonnage going directly through a yard (no switching) which would have an effect on yard roadway components equivalent to that of the actual tonnage that goes through the yard and is switched.

Yard output may also be measured by a combination of output measurements such as tons and yard-engine minutes. Although this increases the complexity of the statistical analysis, it is a feasible alternative.

## Statistical Analysis

A statistical analysis should be undertaken to determine the measure of output best related to variable yard maintenance expenses for each type of yard. The measure which best correlates with expense data can then be used for costing purposes. Several points should be made concerning these regression analyses:

1 - Due to dependence of maintenance expenditures on net revenue, the average annual expense over several years (for example, a five-year running average indexed on a constant dollar basis) should be used as the expense data.

2 - The yards used in the analysis should be a good representation of yards across the system. Furthermore, they should be yards in which the limits of the yard for accounting purposes do not include excessive amounts of industry switching trackage. The purpose of the analysis is to estimate costs for classification yards. Therefore, those expenses associated with industry, house, team and other trackage should be excluded from the analysis to the extent this is feasible.

3 - The resulting relationships between expenses and output are not necessarily cause and effect relationships and should not be interpreted as such.

An analysis was undertaken for ten classification yards on the Southern Pacific system. Yard output data collected included switch engine hours, switch count, car count, tonnage throughput and switch tons. Expense information for the analysis was based upon reported annual expenses (calendar year 1974) and field personnel estimates of the amount of time spent maintaining yard facilities.

Expenses allocated to yards on this basis included the following:

Spot Rail/Stock Rail Renewals
Welding and Track Grinding
Replacing Cross Ties
Replacing Switch Tie
Replacing Frogs
Replacing Switch Points
Replacing Switches - Other Material
Replacing Insulated Joints
Ballast Cleaning and Plowing
Ordinary Ballast Repairs

Miscellaneous Track Repairs
Spot Surface Track

The size of yards ranged from 9.35 to 90.04 track miles and estimated annual expenses varied from a low of $53,330 to a high of $412,890. Six flat switching yards, three fully automated hump yards and one economatic hump yard were included in the analysis.

Regression analyses were performed using the data in Table II . The results of those regressions are displayed in Tables III, IV, V, and VI . Before discussing the results of the regressions, two points should be noted.

1 - The expense information is for only one year. An analysis using five years expense information could yield different results.

2 - Expenses incurred in these yards are a function of Southern Pacific yard maintenance policies and the existing condition of these yards. Other railroads could obtain different results using a similar analysis on its yards.

The results of the regression analyses indicate that the two measures of yard output best correlated with flat yard expenses are switch count and switch tons. It is interesting to note that these same two measures of output appear the best when the analysis included both hump and flat yards. However, the correlation was significantly higher in the latter case. Due to the high correlation between switch count, switch tons and track miles, a regression using more than one output variable improves the correlation but reduces the significance of the regression coefficients as measured by the partial F-ratio (t-statistic). When flat yard expenses were regressed against switch count and track miles, the resulting equation was:

$$y = 25678 + 0.05946x + 1728.9z$$

where:

$y$ = annual yard maintenance expense-dollars
$x$ = annual yard output measured by switch count
$z$ = yard track miles

The partial F-ratio associated with the switch count coefficient dropped to 0.2418.

| Yard | Type | Track Miles | Annual Expenses ($) | Car Count | Switch Count | Gross Tonnage ($10^6$) | Switch Engine Minutes | Switch Tons ($10^6$) |
|---|---|---|---|---|---|---|---|---|
| 1 | Flat | 76.95 | 196,000 | 575,874 | 992,004 | 34.707 | 1,082,640 | 94.073 |
| 2 | Flat | 15.47 | 103,500 | 543,153 | 1,061,567 | 30.791 | 1,761,006 | 91.469 |
| 3 | Flat | 9.35 | 53,330 | 636,285 | 856,700 | 38.530 | 553,540 | 89.579 |
| 4 | Flat | 22.84 | 143,200 | 245,648 | 798,226 | 14.362 | 1,928,160 | 60.545 |
| 5 | Flat | 29.35 | 94,800 | 557,349 | 554,229 | 30.163 | 2,676,960 | 60.158 |
| 6 | Flat | 46.98 | 198,200 | 434,551 | 931,385 | 26.136 | 1,427,920 | 82.154 |
| 7 | Economatic Hump | 23.84 | 77,400 | 542,919 | 1,054,599 | 30.699 | 939,432 | 90.260 |
| 8 | Hump | 90.04 | 61,900 | 712,868 | 1,986,387 | 40.816 | 4,124,640 | 153.858 |
| 9 | Hump | 85.08 | 251,100 | 1,194,310 | 2,197,611 | 72.233 | 4,087,200 | 205.145 |
| 10 | Hump | 86.59 | 412,890 | 974,688 | 3,292,939 | 58.608 | 5,116,800 | 256.611 |

Table II
Yard Maintenance of Way Expense and Measures of Yard Output Levels

| Output | Correlation Coefficient | Index of Determination ($R^2$) | Partial F-Ratio | Regression Equation |
|---|---|---|---|---|
| Car Count | -0.40136 | 0.16109 | 0.7681 | y = 214666 - (0.166720)x |
| Switch Count | 0.35241 | 0.12419 | 0.5672 | y = 32186 + (0.114729)x |
| Tonnage | -0.34104 | 0.11631 | 0.5265 | y = 200646 - (0.002375)x |
| Switch Engine Minutes | -0.01517 | 0.00023 | 0.0009 | y = 133403 - (0.001208)x |
| Switch Tons | 0.10687 | 0.01142 | 0.0462 | y = 99440 + (.000403)x |

Table III Regression Analysis of Flat Yard Expenses(y) Against Measures of Yard Output(x)

| Output | Correlation Coefficient | Index of Determination ($R^2$) | Partial F-Ratio | Regression Equation |
|---|---|---|---|---|
| Car Count | 0.53540 | 0.286665 | 3.2147 | y = 17750 + (0.22045)x |
| Switch Count | 0.74268 | 0.55158 | 9.8405 | y = 26780 + (0.096499)x |
| Tonnage | 0.56407 | 0.31818 | 3.7333 | y = 17260 + (0.003765)x |
| Switch Engine Minutes | 0.59489 | 0.35389 | 4.3819 | y = 59575 + (0.042053)x |
| Switch Tons | 0.74445 | 0.55421 | 9.9457 | y = 10614 + (0.001255)x |

Table IV Regression Analysis of Flat Yard and Hump Yard Expenses(y) Against Measures of Yard Output(x)

| | Expenses | Car Count | Switch Count | Tonnage | Switch Engine Minutes | Switch Tons | Track Miles |
|---|---|---|---|---|---|---|---|
| Expenses | 1.000 | 0.535 | 0.743 | 0.564 | 0.595 | 0.744 | 0.603 |
| Car Count | 0.535 | 1.000 | 0.782 | 0.997 | 0.692 | 0.873 | 0.658 |
| Switch Count | 0.743 | 0.782 | 1.000 | 0.787 | 0.852 | 0.985 | 0.748 |
| Tonnage | 0.564 | 0.997 | 0.787 | 1.000 | 0.673 | 0.879 | 0.663 |
| Switch Engine Minutes | 0.595 | 0.692 | 0.852 | 0.673 | 1.000 | 0.833 | 0.732 |
| Switch Tons | 0.744 | 0.873 | 0.985 | 0.879 | 0.833 | 1.000 | 0.756 |
| Track Miles | 0.603 | 0.658 | 0.748 | 0.663 | 0.732 | 0.756 | 1.000 |

Table V Correlation Coefficients for Measures of Yard Output and Yard Expenses (Hump Yards and Flat Yards)

| | Expenses | Car Count | Switch Count | Tonnage | Switch Engine Minutes | Switch Tons | Track Miles |
|---|---|---|---|---|---|---|---|
| Expenses | 1.000 | -0.401 | 0.352 | -0.341 | -0.015 | 0.107 | 0.760 |
| Car Count | -0.401 | 1.000 | 0.094 | 0.985 | -0.361 | 0.602 | -0.092 |
| Switch Count | 0.352 | 0.094 | 1.000 | 00.190 | -0.600 | 0.835 | 0.237 |
| Tonnage | -0.341 | 0.985 | 0.190 | 1.000 | -0.511 | 0.692 | -0.038 |
| Switch Engine Minutes | -0.015 | -0.361 | -0.600 | -0.511 | 1.000 | -0.770 | -0.117 |
| Switch Tons | 0.107 | 0.602 | 0.835 | 0.692 | -0.770 | 1.000 | 0.181 |
| Track Miles | 0.760 | -0.092 | 0.237 | -0.038 | -0.117 | 0.181 | 1.000 |

Table VI Correlation Coefficients for Measures of Yard Output and Yard Expenses(Flat Yards)

Costs for Pricing Purposes

The variable yard maintenance cost for rate-making purposes is determined by directly assigning variable yard expenses on the basis of the best correlated measure of output determined from the statistical analysis. Based on the previous analysis, the cost for a given flat yard would be determined by dividing total annual variable expenses for the yard by total annual switch count. Similarly, the cost for a given hump yard would be determined using total annual variable expenses for the yard and total annual output in terms of the best correlated measure of output.

It may be argued that these costs should not be considered 100 percent variable with traffic. However, even though time-related deterioration of the roadway does occur in yards, the maintenance expense incurred is of the same basic type as variable routine roadway maintenance in linehaul service. These costs are incurred in a yard as a direct result of the traffic moving in the yard.

Heavy Wheel Load Effects

The effect of wheel loads on yard costs can be costed using both an aggregation of accounts procedure and the relative life/cost factors developed for use in costing linehaul trackage. Two categories of variable cost can be designated based upon the relative effect of wheel loading.

1. Costs affected by wheel loading in the same way wheel loading affects rail life (contact pressure-related costs). Included in this category are:

   Spot Rail and Stock Rail Renewals
   Welding and Track Grinding

2. Costs related to rail bending stress and track deflection. Included in this category are:

   Replacing Frogs, Switch Points, Switches and Other Material
   Replacing Insulated Joints
   Replacing Cross Ties, Switch Ties, Bridge Ties
   Ballast Cleaning and Plowing
   Ordinary Ballast Repairs
   Spot Track Surfacing
   Miscellaneous Roadway Repairs (Stabilization)
   Miscellaneous Track Repairs (Derailments)
   Minor Bridge, Trestle and Culvert Repairs
   Repair Car Retarder Systems

The variation in costs related to track deflection and rail bending stress is directly related to car weight. For this reason car retarder costs are included in this category.

Unit costs are determined for both of these categories in the same manner as described in the previous section. These costs are then multiplied by the appropriate wheel load factor shown in Table VII. The sum of the two factored unit variable costs is the total unit variable cost for the specific wheel load class.

| Wheel Load (lbs) | Rail Life-Related Cost | Rail Bending and Stress Track Deflection-Related Costs |
|---|---|---|
| <15,000 | 0.8670 | 1.000 |
| 15,000-25,999 | 1.1605 | 1.1236 |
| 26,000-29,999 | 1.1892 | 1.1765 |
| 30,000-32,999 | 1.8335 | 1.3158 |
| 33,000-34,999 | 2.2779 | 1.3699 |
| 35,000-37,500 | 2.6261 | 1.4286 |
| >37,500 | 3.0731 | 1.5873 |

Table VII.
Wheel Load Cost Factors for Yard Maintenance Costs

The cost factors in Table VII are the mathematical reciprocals of the linehaul rail, and tie and surfacing life factors for wheel loads. These factors are based upon an average loaded car weight of 100 tons. If the average loaded car weight in a given yard is significantly different from 100 tons, then these factors should be modified. This can be accomplished by multiplying each factor in Table by 100 ÷ by the average loaded car weight in the yard. For example, if the average loaded car weight in the yard is 125 tons, then all the cost factors in Table VII should be multiplied by 0.800 ( 100 ÷ 125 = 0.800).

Cost Determination Under Conditions of Severe Maintenance Deferral

In some cases yard maintenance has been deferred to such an extent that a complete reconstruction of the track structure is necessary. Under these conditions, accounting records should not be used to determine the variable cost of maintaining the roadway. For these costs it is probably necessary to base the annual variable cost level on the annualized cost of the necessary track work. It is possible to base the track costs on predicted service lives of the various components. However, this requires analyzing each class of yard track separately and developing unit costs for each component in each track type based upon the traffic activity and physical characteristics of the track. Yard expenses (as estimated) for the track accounts (202, 212, 214, 216, 218, and 220) typically constitute less than 10% of total track account expenses. The magnitude of these expenses probably does not justify developing yard costs on the basis of predicted service lives of components.

Additional Methods for Determining Yard Track Costs

Thomas K. Dyer, Inc. Engineering Consultants, have recently developed predictive formulas for several classes of yard and switching tracks. These formulas relate estimated track costs (annual cost of accounts 202, 212, 214, 216, 218 and 220) to the size and type of yard, with implied levels of yard/switching activity (output) associated with each class of yard or switching track. These formulas for annual yard/switching track costs (1974 dollars) are presented below.

| Class of Yard/Switching Track | Cost Formula |
|---|---|
| Heavy Duty Classification Yard | 4,270M + 720N |
| Industrial Switching Yard | 3,630M + 600N |
| Equipment Servicing Tracks | 3,000M + 470N |
| Storage Tracks | 2,580M + 350N |

Where M equals miles of track and N equals number of turnouts. These costs, taken as appropriate measures of variable yard/switching track costs would be allocated to the freight car in order to estimate route-specific costs.

## Miscellaneous Trackage Maintenance

### Introduction

The trackage considered under this roadway service function includes all trackage involved in the gathering, storage, and distribution of rail carload/train load traffic, and that associated with the servicing or repair of railroad rolling stock. This roadway service function excludes yard trackage and linehaul trackage as defined above. This includes the following different types of trackage:

1. industrial sidings
2. drill tracks
3. spur tracks
4. team tracks
5. car repair (rip) tracks
6. storage tracks
7. support tracks for shops, intermodal facilities, etc.

While it is recognized that the service environments associated with each of these types of track can be substantially different from one another, it is felt there is sufficient homogeneity to warrant treatment of these type of tracks and any related structures items as a single roadway service function.

### Analysis

Utilizing the accounting structure described in Appendix F, all variable Expense Items previously developed are recorded at the division level. This analysis proposes the segmenting of all non-recollectible labor associated with the miscellaneous trackage service function in a manner similar to that developed for the linehaul and yard service functions. Applicable Expense Items for this service function are listed below.

| Item No. | Description |
|---|---|
| 001 | Spot Rail/Stock Rail Renewals |
| 003 | Welding and Track Grinding |
| 005 | Replacing Cross Ties |
| 006 | Replacing Switch Ties |
| 007 | Replacing Frogs |
| 008 | Replacing Switch Points |
| 009 | Replacing Switches - Other Material |
| 010 | Replacing Insulated Joints |
| 011 | Surface Track-Out-of-Face |
| 012 | Ballast Cleaning and Plowing |

| Item No. | Description |
|---|---|
| 013 | Ordinary Ballast Repairs |
| 015 (Part) | Miscellaneous Roadway Repairs |
| 016 | Miscellaneous Track Repairs |
| 017 | Extraordinary Track Repairs - Derailments |
| 022 (Part) | Minor Bridge, Trestle and Culvert Repairs |
| 023 | Renew Bridge Ties |

Subsequent to determining the track labor associated with the miscellaneous trackage service function, material costs found in the basic Expense Items may be allocated to each service function based on the resulting track labor distribution (linehaul, yard, miscellaneous trackage). While some distortions in material costs of each service function are likely to result from this procedure, without the ability to routinely record material applications on a service function basis, there would seem to be no other appropriate allocation procedure available without special study.

Cost Assignment

Division-average miscellaneous trackage variable costs must be assigned to traffic units on a basis appropriate to the nature of the roadway service provided. It is proposed that the number of originating or terminating carloads most adequately represents the basis on which these costs should be assigned, since it is this measure of traffic which most nearly represents the level of gathering/distribution activity. This cost determination and assignment process is illustrated below.

$$UC_{MT_1} = \frac{\$VMT_1}{C_{O_1} + C_{T_1}}$$

Where:

$UC_{MT_1}$ = Average Unit Miscellaneous Trackage Cost on Division 1.

$\$VMT_1$ = Total Variable Miscellaneous Trackage Expenses on Division 1.

$C_{O_1}$ = Number of Originating Carloads on Division 1.

$C_{T_1}$ = Number of Terminating Carloads on Division 1.

Refinements may be made to these resulting division-average unit costs to reflect distinctions in Miscellaneous Trackage Costs associated with the various wheel load categories, as described previously for routine linehaul track maintenance and yard track maintenance costs. It should be noted that the additional effort required to group these Miscellaneous Trackage Expense Items according to those which are rail life-related vs. those which are bending stress/deflection-related in order to properly assign the developed wheeel load factors <u>may</u> not prove cost effective given the relative magnitude of these Miscellaneous Trackage Costs compared to total variable service function costs.

## Roadway Facility/System Maintenance

### 1. Service-Related Facility Maintenance

Service-related facilities are the structures, machinery, and associated terminal areas which are used to provide a particular type of service or to handle a particular type of commodity. These facilities include, but are not necessarily limited to TOFC/COFC terminals, docks and wharves, grain elevators, storage warehouses and automobile loading/unloading facilities. The type and number of these facilities which exist on a given railroad is a function of the region served, traffic commodity mix and marketing policies. A railroad that predominately serves a major grain cultivating region such as the Midwestern United States will be likely to have significantly more grain handling facilities than a railroad serving the Southwest. Similarly, a railroad which serves several major ports will be likely to have major intermodal facilities associated with them.

#### Cost Areas

To the extent that there are railroad tracks at these facilities, there are costs associated with the maintenance of the track structure. These variable costs include the following:

- Spot Rail and Stock Rail Renewals
- Welding and Track Grinding
- Replacing Cross Ties, Bridge Ties, Switch Ties
- Replacing Frogs, Switch Points, Switches -Other Material
- Replacing Insulated Joints
- Ballast Cleaning and Plowing
- Ordinary Ballast Repairs
- Miscellaneous Roadway Repairs (Stabilization)
- Miscellaneous Track Repairs
- Extraordinary Track Repairs - Derailments
- Minor Bridge, Trestle and Culvert Repairs
- Spot Surface Track

Other costs of maintaining these facilities will vary with both the type and size of the facility. As an example, the maintenance costs associated with a major TOFC/COFC terminal may involve the following areas:

- Structures
- Overhead Cranes and Lifts
- Ramp Tractors
- Piggy Packers
- Parking Areas

## Current Service-Specific Facility Maintenance Costing Procedures

### Interstate Commerce Commission (ICC)

The ICC Rail Form A Costing Procedures base service-specific facility maintenance costs on expenses reported in Accounts 237, 239, 241,243, 244 and 265 (Grain Elevators, Storage Warehouses, Wharves and Docks, Coal and Ore Wharves, TOFC/COFC Terminals, Miscellaneous Structures). Expenses in Accounts 201 and 227 through 279 were found to be 60 percent variable (on the average) with tons of revenue freight. This was developed using second degree curvilinear regression equations of the form:

$$y = a + bx + cx^2$$

Where:

$y$ = expense per mile of road
$x$ = output per mile of road

The percent variable factors were computed for a five-year average of 1966-1970 Form A reported expenses using the mean output level in the expression for elasticity:

$$\frac{b + 2c\bar{x}}{a/\bar{x} + b + c\bar{x}}$$

### Canadian Transport Commission (CTC)

There are two costing techniques used by the Canadian National Railway to analyze service specific facility cost for proceedings before the CTC. These are direct assignment and direct analysis. Direct assignment is the process of assigning to an operation an amount of expense which corresponds to that recorded on an accounting document. Direct assignment is used when the traffic under study requires the use of Canadian National grain elevators. Direct analysis is used when the expense under study is or is assumed to be 100 percent variable with some service unit or units. This technique is used for wharve maintenance costs using cars handled as the service unit and one year expense data.

## Proposed Service-Specific Facility Maintenance Costing Procedures

The track-related costs associated with the facilities are costed using the procedures described for miscellaneous trackage. That is, the track used within these facilities or in gaining access to these facilities is included in the category of miscellaneous trackage. Therefore, the track maintenance cost associated with any given shipment utilizing such a facility is determined from the unit cost for miscellaneous trackage maintenance on the division which the facility is located.

Other maintenance costs associated with the specific type of facility are:

Repair TOFC/COFC Terminals

Labor and material to repair TOFC/COFC facilities including structures, fixtures, machinery, platforms, roads and walks serving these facilities and other appurtenances.

Repairing Docks and Wharves

Labor, material and other expenses to repair docks, wharves and ferry slips; dredging waterways to approaches and around such structures; cribwork, rocks, caissons, guards, pilings, and other protection.

Repair Grain Elevators

Labor, material and other expenses to repair grain storage facilities including structures, on loading and off loading equipment, fixtures and roads and walks serving these facilities.

Repair Storage Warehouses

Labor, material and other expenses to repair storage warehouses including structures, fixtures and machinery.

Repair Automobile Loading/Unloading Facilities

Labor, material and other expenses to repair automobile loading and unloading facilities including structures, fixtures, machinery and roads and walks serving these facilities and other appurtenances.

Expenses incurred in each of these areas should generally be aggregated at the division level and a unit cost determined by dividing total expenses by carloads or containers/trailers originating and/or terminating at these facilities on the division. The exception to this is a major facility which should have separately maintained expenses and traffic statistics. Expenses can be determined by assigning work order numbers or other cost control documentation to those specific major facilities. For example, a railroad may have two major intermodal facilities located at ports which it serves and several minor ramps (fixed or movable) located elsewhere throughout its system. The unit maintenance cost associated with either of the major facilities is determined by direct analysis using total annual maintenance expenses incurred in the facility and the total annual number of containers/trailers originating or terminating at the facility. Unit maintenance costs for the minor ramps are determined using total annual costs incurred for these facilities on each division and the annual number of containers/trailers originating or terminating at these facilities on the division.

The accounting system presented in this report does not allow for the separation of maintenance expenses within a service specific facility. That is, those maintenance expenses which may be relatively fixed with respect to traffic as well as those which may be totally variable with traffic are reported under the same detail expense identification number. Intermodal terminal maintenance expenses which are most likely variable with traffic include ramp maintenance, crane maintenance, tractor maintenance and parking area (pavement) maintenance. Relatively fixed expenses (with respect to traffic) will include maintenance of fences, offices and other fixed structures. It should be clear that the variable expenses will generally represent the major portion of the maintenance expenses in such a facility. If a railroad should consider it desirable to determine the variable expenses associated with service specific facilities, it can be accomplished by reporting expenses against two detail expense identification numbers for each type of facility. One detail expense identification would include the expenses considered fixed with respect to traffic and the other would include the expenses considered variable with respect to traffic. Unless this information is needed for purposes other than the determination of the variable cost for pricing purposes, it does not seem likely that the magnitude of these expenses justifies their separation in the accounting system.

## 2. Maintenance of Nonservice-Related Roadway Facilities and Systems

### Introduction

Maintenance costs associated with roadway facilities and systems not related, or only very indirectly related, to particular roadway services or service functions are generally categorized as a portion of Maintenance of Way "Overhead." These facilities and systems, identified by Interstate Commerce Commission Accounts are:

| ICC Account No. | Description |
|---|---|
| 227 | Station and Office Buildings |
| 229 | Roadway Buildings |
| 231 | Water Stations |
| 233 | Fuel Stations |
| 235 | Shops and Engine Houses |
| 247 | Communications Systems |
| 253 | Power Plants |
| 257 | Power Transmission Systems |
| 265 | Miscellaneous Structures |

It can be seen that several of the above accounts are in reality not Maintenance of Way or Roadway-related but relate more closely as overhead items to Equipment Maintenance (Account 235), Transportation (Accounts 231 and 233) or General Overhead (Account 247).

### Current Procedures

The Interstate Commerce Commission finds these expenses (as a group and including Account 201, Superintendance) to be 60 percent variable with tons of revenue freight.[1]

Procedures used under Canadian Transport Commission jurisdictions attempt to statistically determine the relationships between these expenses and various other expenses to which they relate. These relationships are described below.

| Dependent Variable | Independent Variable(s) |
|---|---|
| Account 227 | Sum of the labor portions of Account 272, Station Employees and 376, Station Supplies and Expenses. |

1. 1970 Carload Cost Scales, Interstate Commerce Commission Statement No. 1C1-70.

| Dependent Variable | Independent Variable(s) |
| --- | --- |
| Account 229 (as a group and including the Road Maintenance Accounts) | Miles of roadway, Gross Ton-Miles, yard and train switching-miles, gradient index. |
| 231 and 233 | Sum of Accounts 382-Yard Fuel, 384-Yard Power, 394-Train Fuel, 396 Train Power. |
| Account 235 | Sum of labor portions of Accounts 311-Locomotive Repairs, 314-Freight Car Repairs, 317-Passenger Car Repairs, 326-Work Equipment Repairs, 386-Yard Locomotive Other Supplies (CTC Account), 388-Yard Engine House Expenses (CTC Account), 398-Train Locomotive Other Supplies (CTC Account) and 400-Train Engine House Expenses (CTC Account). |
| Account 247 (as a group and including Account 407-Communications System Operations) | Considered 70% variable with total labor dollars. |
| Account 253 and 257 | Sum of the labor portions of the accounts used in the analysis of Account 235, above, and including Account 373-Station Employees and 376-Station Expenses. |
| Account 265 | Considered fixed. |

Discussion

Consistent with the principle of determining variable cost from the change in output over some relevant time period and range of volume, those portions, if any, of "overhead" which can be identified with specific changes in output are a variable cost.

By their nature, however, overhead costs are not generally traceable to particular segments of output. The term "overhead cost" implies a commonness to all or large segments of output and operations, rather than a causal relationship to smaller segments. Routine statistical apportionments of non-traceable overheads that do not vary with volume changes have the same basic infirmity as arbitrary apportionments of any fixed costs and computations of "fully-distributed" costs.

No uniform prescription as to the covariation of these associated overheads with volume changes can be made, for circumstances may differ substantially among the various overhead items, as well as from one railroad to another. Nor can it be assumed that the variability of the associated overheads with volume change is the same as that for the expense groups to which these overheads pertain. To the contrary, the nature of these overheads indicates a much lower degree of variability with volume (i.e., a higher degree of constancy) than for their related operating expense groups.

Statistical correlations may or may not be useful in indicating the extent of variability in the associated overhead expenses. Overheads may be significantly affected by budgetary considerations and constraints, or by measures designed to improve efficiency rather than by volume change. For this reason, superficial statistical correlations should not be taken at face value, but should be checked against the judgment of those in management who are intimately informed as to the factors influencing the costs.

Those remaining items of "Roadway Overhead," (those accounts discussed above which are not deemed to be more properly considered as portions of Equipment, Transportation or General Overhead) and the portions of these items individually determined to be "variable" may be allocated to respective roadway service functions either on the basis of total variable direct cost distribution or on more refined bases as appropriate.

## Other Variable Roadway Maintenance Overhead and Additives

### Introduction

Additional overhead and additive expense items must be considered in the determination and allocation of variable roadway maintenance for pricing.

Additional overhead and additive items, all or portions of which may vary with traffic output, may be categorized (by ICC Accounts) as follows:

| ICC Account No. | Description |
|---|---|
| 201 | Superintendance |
| 271 | Small Tools and Supplies |
| 274 | Injuries to Persons |
| 275 | Insurance |
| 276 | Stationery and Printing |
| 277 | Health and Welfare Benefits |
| 457 | Pensions |
| 532 | Payroll Taxes |

Adequate analysis of the variability of several of these categories of expenses requires that their individual components be described with a structure of accounts and expense identifications of the nature described in Appendix F . In general, these expenses may be separated into a system of roadway maintenance overhead items and labor or payroll additives which must be applied to the different classes of roadway maintenance labor associated with the Expense Items represented in Appendix F.

With respect to "overhead" items, the following guidelines should apply:

#### Superintendance

The labor, supplies, and expenses associated with this category roadway cost must be scrutinized in terms of which specific supervisory positions on the roadway system (and associated supplies and expenses) are generally totally or predominately unaffected by traffic levels or the amount of roadway maintenance work associated with increases or decreases in traffic levels. This is necessarily an analytical task specific to individual railroads and one which should be conducted in recognition of the effects of budgetary and personnel policy constraints. Resulting variable superintendance expenses may be accumulated on a division or regional reporting basis and allocated to service functions based on the distribution of total direct variable service function costs within each division.

Linehaul costs on a crew district basis would then reflect weighted division gross ton mile costs as described previously, including allocated supervision costs.

Small Tool and Supplies (Including Applicable Allowances)

While individual components of this cost category can be analyzed to determine statistical relationships with traffic output levels, it is felt that the vast majority of these expenses are incurred as a result of the traffic-related maintenance and renewal activities described previously and therefore should appropriately be considered entirely variable with traffic. These expenses may be accumulated at the division or regional level and allocated to service functions in a manner similar to that described above for superintendance costs.

Stationary and Printing/Insurance/Injuries to Persons (Other Than Employees)

Expenses recorded for these cost categories can be statistically examined for potential relationship to traffic output levels or to other roadway expenses so related. Any resulting variable portions may be allocated to service functions as described previously. Judgemental determinations of portions of these costs as variable may also be undertaken.

The additional overhead or additive items, Injuries to Employees, Health and Welfare Benefits and Pensions may be combined with other appropriate expense items as listed in Appendix F to contruct labor or payroll additives appropriate to separate classes of roadway labor. Specific items of expense appropriate for inclusion on a labor additive basis would include the following:

- Injuries to Employees
- Time Paid For But Not Worked: Vacation, Sick Pay, Holiday Pay
- Pensions and Stock Contributions
- Payroll Taxes (Railroad Retirement, Unemployment, Supplemental Annuity Taxes)
- Health and Welfare Benefits

These expenses may be calculated as a percentage of all labor (straight time and overtime), by labor class, and applied on an additive basis to all variable roadway labor.

Summary - Roadway Maintenance Costs

The resulting roadway maintenance costing procedures may be viewed merely as a module or sub-system of a total railroad costing system for pricing purposes. The elements of these roadway maintenance costing procedures may be summarized schematically as shown in Figure 34, representative of the elements of roadway maintenance costs which must be considered for pricing decisions. There would seem to be little question that roadway maintenance costs calculated on a specific service function basis, particularly when viewed as costs which must be periodically updated to reflect inflationary trends as well as structural changes in roadway track and traffic conditions, should be programmed for computer storage and application. With such a costing system, costing refinements of the nature proposed and demonstrated here remove roadway cost analysis for pricing from the realm of simplified system-average cost assignment and places such analysis more properly in a framework both reflective of and responsive to the variant nature of railroad roadway service.

| | SERVICE FUNCTION | | | |
|---|---|---|---|---|
| | LINEHAUL | YARDS | MISCELLANEOUS TRACKAGE | SERVICE SPECIFIC FACILITIES |
| Service Unit | GTM | Switch Count | Orig./Term. Carload | Carload |
| Basis | Crew District | Yard | Division | Facility |
| Variable Cost Elements | Track Structure Renewal Costs<br>+<br>Ordinary Track Maintenance Costs<br>+<br>Allocated Non Service-Specific Facility/System Costs<br>+<br>Allocated Var. O'head.<br>+<br>Labor Additives | Track Structure Costs<br>+<br>Minor Bridge & Trestle Maintenance Costs<br>+<br>Allocated Non Service-Specific Facility/System Costs<br>+<br>Allocated Var. O'head.<br>+<br>Labor Additives | Track Structure Costs<br>+<br>Minor Bridge & Trestle Maintenance Costs<br>+<br>Allocated Variable Overhead<br>+<br>Labor Additives | Facility Maintenance Costs<br>+<br>Allocated Non Service Specific Facility/System Costs<br>+<br>Allocated Variable Overhead<br>+<br>Labor Additives |
| Total Unit Variable Costs | Labor Material Other | Labor Material Other | Labor Material Other | Labor Material Other |

Figure 34

ROADWAY MAINTENANCE COST ELEMENTS

# VIII - ROADWAY OPERATING COSTS

Current methods of railroad cost analysis generally consider roadway costs as either investment or maintenance. However, there are costs which are a function of operating the roadway. Roadway operating costs are those costs which do not result from a change in the physical properties or condition of individual roadway components, but which are incurred if the roadway is utilized. In other words, these costs are incurred due to utilization of the roadway rather than capacity requirements or time and traffic-related deterioration of the roadway.

In accordance with this definition, the following should be considered roadway operating costs:

## Signal and Interlocker Service and Operation

Labor and other expenses to operate and service signal facilities including the costs of testing systems and cleaning signal roundels, lenses, reflectors, lamp bulbs and contacts.

Labor and other expenses to operate interlocker facilities.

## Switch/Turnout Cleaning and Service

Labor and other expenses to service switch lamps including the cost of refueling founts and cleaning and replacing lenses.

Labor and other expenses to clean and oil switch plates and other moving switch parts.

## Communication System Summary

Labor and other expenses to service communications facilities including expenses incidental to the operation of inside communications facilities, rental of telephone and telegraph circuits, rental of space or facilities occupied by radio microwave and servicing of fuel tanks, batteries and tubes.

## Derailment Costs

Labor and services required to rerail locomotives and cars.

Labor and other expenses required to clear right-of-way of spilled freight.

## Removal of Snow, Ice and Sand

Labor and other charges necessary for snow, sand and ice removal including train crew wages for snow service.

Crossing Protection Operation

Labor and other expenses to service grade crossing protection facilities including the cost of cleaning lenses, reflectors, lamp bulbs, contacts and electronic track circuits.

Labor expense of crossing gatekeepers and flagmen.

Drawbridge Operation

Labor and other expenses to service drawbridge control facilities such as electric motors, air lines, control systems and lubricating systems.

Labor expense of drawbridge operation.

Hot Box Detector Operation

Labor and material to service hot box detectors including the cost of cleaning and testing scanners, bolometers, shutters, transducers, carriers, locators and pumps.

Automatic Car Identification (ACI) System

Labor and other expenses to test electronic equipment associated with and incidental to the operation of the ACI System.

Car Retarder Systems

Labor and other expenses to service automatic car retarder systems including the cost to clean and oil electronic equipment and service hydraulic lines and pumps.

Disposal of Dead Livestock

Labor and other expenses to remove and dispose of dead livestock from right-of-way.

It may be argued that other costs such as train dispatching should also be considered roadway operating costs. However, it seems valid to consider these to be train movement costs rather than roadway operating costs.

## Current Costing Procedures for Analyzing Roadway Operating Costs

### Interstate Commerce Commission (ICC)

Current ICC Rail Form A costing procedures separate roadway operating costs into three cost categories - other maintenance of way and structures expense, yard expense and other transportation expenses.

The maintenance of way and structures expenses include those expenses reported in Accounts 247, 249, and 272 (Communication Systems, Signals and Interlockers, Removing Snow, Ice and Sand). Roadway operating expenses reported in Account 379 (Yard Switch and Signal Tenders) are considered yard expenses and those expenses reported in Accounts 404-407, 415, 417 and 418 (Signal and Interlocker Operation, Crossing Protection, Drawbridge Operation, Communication System Operation, Clearing Wrecks, Damage to Livestock on Right-of-Way and Loss and Damage of Freight) are considered other transportation expenses.

Percent variability factors for each category of expense were developed from second degree curvilinear regression equations of the form:

$$y = a+bx+cx^2$$

where:

$y$ = expense per mile of road

$x$ = output per mile of road

The percent variable factors were computed for a five-year average of 1966-1970 Form A - reported expenses and output level in the expression for elasticity:

$$\frac{b + 2c\bar{x}}{a/\bar{x} + b + c\bar{x}}$$

Maintenance of way expenses in Accounts 201 and 227-282 were found to be 60 percent variable (on average) with tons of revenue freight. Yard expenses in Accounts 377-389 were found to be 96 percent variable (on average) with yard switching hours and other transportation expenses in Accounts 371-376 (except 373), 390, 391, 403-420 were found to be 44 percent variable (on average) with tons of revenue freight.

Canadian Transport Commission (CTC)

One or more of three costing techniques are used to determine variable costs before the CTC. These are: (1) direct assignment, (2) direct analysis, and/or (3) regression analysis. Direct assignment is the process of assigning to an operation an amount of expense which corresponds to that recorded on an accounting document. Direct analysis is used when the expense under study is or is assumed to be 100 percent variable with some service unit or units.

Regression analysis is used when an item of expense is not known to be 100 percent variable with the service units and/or when the item of expense is related to more than one variable.

Roadway operating expenses not considered variable with traffic level include those reported in U.C.A. Accounts 272, 405, and 406 (Removing Snow, Ice and Sand, Crossing Protection, Drawbridge Operations). These expenses are not a part of the variable cost used before the CTC.

Direct analysis is used for expenses reported in U.C.A. Accounts 247 and 407 (Rail Communications Systems, Rail Communications System Operation). These expenses are charged against all system variable expenses for U.C.A. Accounts 201-446 excluding 247 and 407, 351-359 (Traffic), 266, 305 and 331 (Depreciation), 275, 333, and 414 (Insurance) and 278, 279, 336, 337, 390, 391, 412 and 413 (Joint Facilities). Direct analysis is also used for expenses reported in U.C.A. Accounts 379 (Yard Switchmen) and 418 (Loss and Damage of Freight) with yard switching-miles and carloads (by commodity) as the respective independent variables.

Expenses reported in U.C.A. Accounts 249 (Signals) and 404 (Signal Operation) are regressed against train-hours and yard and train switching-miles. Expenses and output units are averaged for the three most recent years. Separate regression equations are developed for labor and material. For costing purposes, the yard and train switching-minute coefficient is converted to a switching-minute coefficient by a factor of six miles per hour.

Proposed Procedures for Analyzing Roadway Operating Costs

The basic premise underlying these procedures is that the economic cost of operating the railroad roadway is adequately reflected by the expenses reported in those cost areas. The rationale for this is twofold.

1. These costs are generally non-deferrable.

2. It is reasonable to consider the roadway operating expense reported during a given year to be associated with the traffic moved during that year.

Although operating costs can occur in each of the roadway output service blocks, they predominately occur in linehaul and yard service. The cost accounting system should be structured to maintain separate expenses for these various service functions. An exception to this are communication system expenses. These expenses cannot be accurately identified with a specific service.

## Roadway Operating Costs Relevant For Pricing Purposes

Roadway operating costs are generally related to the traffic level as reflected by train movements. These costs are relatively independent of train length, weight and service-type. As the number of train movements increases, these costs will tend to increase. However, on a given route segment they may remain relatively constant over wide ranges in the traffic level. In spite of this, the roadway operating costs associated with signals and interlockers, the communication system, derailments, car retarder systems, turnouts and the removal of dead livestock are sufficiently variable with traffic level to warrant inclusion in the variable cost for ratemaking.

The remaining costs, although traffic-related, are primarily influenced by non-traffic factors. Costs of hot box detector operation and service to the ACI System are more closely related to railroad plant size than to traffic level. The annual costs of snow, ice and sand removal are more significantly influenced by weather conditions than traffic level. Similarly, it should be clear that traffic level will influence the annual costs of grade crossing protection to a much lesser extent than highway traffic levels and the political jurisdictions through which a railroad operates. Finally, drawbridge operation costs will be significantly affected by train scheduling. If there are three trains a day over a given drawbridge, the operation costs can vary from the cost of one operator to three operators depending on whether all three trains arrive during one shift or three shifts. These five cost areas, although traffic-related, should not be included in the variable cost for pricing purposes.

## Linehaul Service

Roadway operating costs incurred in the provision of linehaul service are those associated with signals and interlockers, switches and turnouts, removal of dead livestock, derailments and the communication system. Annual main track expenses for each of these cost areas can be aggregated at the division level. Although most of the track-related expenses are assignable at the roadmaster district level, many other expenses can only be reported at the division level. These expenses would include those for which the division signal supervisor and the division electrical supervisor have responsibility.

Roadway operating expenses (except communication system expenses) can then be regressed against train-miles for each division. Annual communication system expense for each division should be regressed against division train-miles and yard and train switching-hours. This is necessitated by the inability to segregate communication system expenses by output service block. The sum of the resulting train-mile regression coefficients is the variable roadway operating cost per train-mile.

## Yard Service

Roadway operating costs occurring in yards are the same as in linehaul service with the addition of car retarder system expenses. These expenses should be reported for yards in the same manner as it is proposed to report maintenance expenses. Yard roadway operating expenses should then be regressed against yard switching hours. The resulting yard switch engine hour regression coefficient is added to the yard and train switching hour coefficient determined for communication system expenses. This total is the variable roadway operating cost per yard switching hour.

## Service Specific Facilities

Roadway operating costs which may occur in these facilities (TOFC/COFC, auto loading/unloading, wharves, passenger terminals, grain elevators) are the same as in linehaul service. The yard and train switching hour regression coefficient determined previously for communication system expense is used for these facilities as well. Other roadway operating expenses should be maintained for specific facilities and directly assigned on an appropriate basis. For example, roadway operating expenses arising from an intermodal terminal, auto loading/unloading facility, wharf, or grain elevator should be assigned on a per carload/container basis.

## Miscellaneous Trackage

The roadway operating costs associated with these tracks is likely to include only costs of the communication system, switches and turnouts, removing dead livestock and derailments. Costs other than the communication system should be aggregated at the division level and regressed against carloads originating and terminating on the division.

## Summary and Overview

Four major points have been made concerning roadway operating costs.

1. There exist costs associated with the roadway which result from utilization of the roadway rather than time and traffic deterioration or capacity requirements.

2. Roadway operating costs are related to traffic although they may not be continuously variable with traffic level.

3. The roadway operating costs associated with signals and interlockers, communication system, derailments, car retarder systems, switches and turnouts and the removal of dead livestock from the right-of-way should be included as part of the variable cost for pricing purposes.

4. The costs and proper basis on which to assign these costs vary with roadway output service function.

# IX - ROADWAY INVESTMENT COSTS

## Introduction

The purpose of this section is to provide a methodology for the determination of those roadway investment costs which are relevant to long-run variable cost calculations for pricing purposes.

The term "investment" is interpreted to mean those assets or roadway components having a life greater than one year. Associated with the cost of such investments must be the cost of capital incurred in their financing. Thus, the question addressed by this section is: "To what extent should the recovery of the cost of capital be included in the calculation of long-run variable costs?"

This section explores current regulatory procedures for calculating roadway investment costs as practiced by the Interstate Commerce Commission and the Canadian Transport Commission. Proposed procedures are then presented for calculating those roadway investment costs which are relevant for inclusion in long-run variable cost calculations.

CURRENT REGULATORY PROCEDURES FOR CALCULATING ROADWAY INVESTMENT COSTS

A. Procedures of the Interstate Commerce Commission:

1. Calculations for Pricing Purposes

The costing procedures utilized by the Interstate Commerce Commission as described in its Rail Form A assume that roadway investment is partially variable with volume. Investment costs are calculated by applying the carrier's cost of capital (calculated by the ICC as the cost of embedded debt) to 50 percent of the total amount in the system roadway, net investment accounts. These costs are then distributed to each carload on the basis of gross ton miles (GTM). The specific amount to be charged is thus calculated as shown in the following equation:

$$RI_j = (GTM_j) \times (i) \times (SRI/GTM_s) \times (50\%)$$

where: $RI_j$ = roadway investment variable with carload j.

$GTM_j$ = gross ton miles generated by carload j.

i = carrier's cost of capital.

SRI = amount in System Roadway Investment Accounts.

$GTM_s$ = systemwide gross ton miles.

50% = the percentage of roadway investment considered to be variable.

For separate assumptions underly the above equation:

(1) Roadway investment is incrementally variable with volume and at a 50 percent rate for all volume levels;

(2) The amounts in the roadway investment accounts accurately reflect the expected cost of additions to Roadway investment;

(3) Roadway investment requiremenets are a function of ton-miles; and

(4) The carrers' cost of capital is identical to their average cost of long-term debt.

Investment-Incrementally Variable

The Commission's procedures purport to measure the amount of roadway investment occasioned by an added piece of traffic. They imply that the investment will vary with each ton and mile of service generated; this is a crude measure of output, at best. It suggests that the amount of roadway investment will be measurably different when the added traffic is (a) one carload with 80 tons moving 100 miles than when the added traffic is (b) one carload with 79 tons moving 95 miles.

But roadway investment is not made in incrementally small amounts. It is made in large lump-sums because it is more economical (less costly) to make one large investment than it is to make numerous small investments. The result is a discontinuous investment function that is fixed over ranges of output, then variable, then fixed again, etc. This gives rise to periods of "unused" capacity during which volume may substantially increase with no change in roadway investment. Therefore, the Commission's conclusion that investment is incrementally variable ignores the possibility of unused capacity, as well as the possibility of overtaxed capacity.

The Fifty Percent Variability Assumption

We have been unable to determine that the fifty percent variability figure is supported by a rigorous study. Even were this figure adequately supported, however, we believe the application of such an unchanging percent variable presents mathematical difficulties which affect the formula's validity. Thus, the presumption that plant is fifty percent variable and fifty percent fixed "with respect to traffic volume" translates into the following mathematical function:

$$Y = X + .5X \left[\frac{V' - V}{V}\right]$$

where: X = original plant investment

Y = the plant investment after changes in volume

V = some non-zero original volume

V' = ending volume

It is the case that for different successions of changes in volume, $V' - V$, with a final volume that is equal for all successions, different Y's will result. In other words, this formula produces non-unique results for different sets of volume changes even though all may lead to the identical ending volume.

Roadway Investment Accounts Reflect Historic, Non-constant Dollars

In calculating the variable roadway investment cost of handling traffic, the Commission's procedures utilize the net investment accounts for roadway. These accounts are maintained on an original cost basis. As such, they do not reflect present-day investment costs, nor do they contain any constant dollar adjustments designed to eliminate the effects of inflation.

Yet investment variability (if it exists) suggests a forward-looking cost concept must be utilized in order to calculate the costs of handling added traffic at some future time. Considering the rapid rate of inflation, accounts unadjusted for price level changes cannot provide an economically sound result.

To illustrate, assume rail is a variable investment: A line is built with 75-lb. rail costing $27/ton in 1914. 30 years later it is replaced with 112-lb. rail at $56/ton. 25 years later it is replaced with 136-lb. rail CWR at $170/ton. Today, the cost of 136-lb. CWR is $250/ton. The investment cost recorded in the carrier's accounts for this line is calculated as:

75/136th of the rail is carried in the rail investment account at $27/ton,

(112-75)/136th of the rail is carried at $56/ton, and

(136-112)/136th of the rail is carried at $170/ton.

Thus, the average investment in the 136-lb. CWR is not $27/ton or $170/ton or $250/ton, but

$$\left(\frac{75}{136} \times \$27\right) + \left[\left(\frac{112-75}{136}\right) \times \$56\right] + \left[\left(\frac{136-112}{136}\right) \times \$170\right] = \$60.13/\text{ton}.$$

The cause of this rather meaningless result is that railroads are required to keep accounts on an original cost basis plus "additions and betterments" despite continuing inflation in price levels.

Output Variables

The Commission's procedures assume that plant investment is a function of gross ton-miles. This is obviously a simplifying assumption. However, certain other key factors influencing the dimensions of plant capacity should also be considered.

For example, line capacity on a single track, CTC railroad is a function of the number of trains, their length and speed, and siding length and spacing. Thus, although gross tonnage (times miles) does partially explain the amount of capacity required, it is clearly a crude and incomplete measure of plant output.

Cost of Capital

The Commission's procedures (as applied to plant investment) calculate a carrier's cost of capital using the average cost of outstanding debt by region. This procedure has several weaknesses.

First, the cost of equity is assumed by the Commission to equal the cost of outstanding debt. The Commission's calculated cost of outstanding debt is about five percent before allowance for income taxes; yet many carriers consider their cost of equity to be approximately fifteen percent after income taxes, or 30 percent before taxes at a fifty percent tax rate.

Second, the use of a five percent cost of embedded debt as the basis for calculating a forward-looking cost of variable investment again understates even a carrier's current cost of debt. Today, the current cost of debt is between 9 and 11 percent. Thus, to use an historic five percent cost of debt to calculate the cost of required, future plant additions is clearly incorrect.

In Ex Parte 271, "Net Investment - Railroad Rate Base and Rate of Return," the Commission is expected to determine the railroad industry's fair rate of return. In that proceeding, the industry has argued that it's market cost of capital is 10 percent after taxes; again, at a 50 percent tax rate, this translates into a 20 percent before tax cost of capital. However, until a final decision is issued in Ex Parte 271, the Commission's only available cost of capital calculation is that prescribed by Rail Form A procedures.

### 2. Calculation for Abandonment Studies

The Interstate Commerce Commission's treatment of roadway investment for abandonment purposes is somewhat different. Plant investment is divided into off- and on-branch investment. Off-branch plant may be treated using Form A costing as described above: more commonly, investment costs are included in the costs calculated using the "50%-of-revenue" rule of thumb employed in abandonment proceedings. The degree of ambiguity assumed by this "50% rule," as to which costs are really costs much less which costs are variable costs, renders it difficult to explore usefully.

On-branch investment is treated as fixed. This treatment rests on the assumption that volume will not change appreciably, and that any volume change will not require plant changes. However, when considering the abandonment of a branch line, the concern is not with an investment response to increases in traffic volume. On the contrary, total dis-investment due to a loss operation is being considered. Thus, no roadway investment costs are fixed, and they should be considered 100 percent variable.

## B. Procedures of the Canadian Transport Commission (CTC)

### 1. Calculations for Pricing Purposes

The costing methodology analyzed here is described in the CTC's "Reasons for Order No. R-6313 Concerning Cost Regulations" (August 1969). Like the ICC Rail Form A, this approach assumes that some roadway investment costs vary with traffic volume, with the remainder fixed over the time span employed for analysis. Variable items include the track structure (composed of total expenditures for rail and ties in Canada; ballast; and OTM), grading, signals, and maintenance facilities, such as roadway buildings, machinery and tools.

Fixed items, which do not vary with the volume of traffic, include mostly land and structures such as bridges, tunnels, culverts, fences, sheds, etc.

The functional cost relationships are:

Investment cost = f (Investment), and

Investment = a + b + c (GTM) + d(TH)

where: a and b = fixed costs associated with plant size as expressed by gradient indexes and route miles.

c and d = coefficients for gross ton-miles and train/yard hours, respectively. c and d <u>may</u> be of a form that expresses curvilinearity.

As expressed by the functional cost relationships, the investment in track, grading and several other items equals a fixed amount that is determined by the length and physical nature of the route, plus a variable amount that is dependent upon gross ton miles and train/yard hours.

Investment additions over a three or five-year period (depending on the account) are regressed against the output variables to determine the values for a, b, c, and d. These coefficients are then applied to the ratio of net to gross investment times the cost of capital.

There are at least four assumptions upon which the validity of the CTC procedures rest:

(1) the amount in the asset accounts accurately reflects the value of the roadway investments;

(2) four parameters sufficiently explain the magnitude of and variations in investment;

(3) investment items excluded, such as structures, do not vary with service output; and

(4) roadway investment varies in small increments.

<u>Accounting Aspects</u>

The amounts recorded in the investment accounts as presented by the CTC, represent the historic valuation of the dollars invested. The failure to reflect these investments in constant dollars leads to a distortion when applying regression analysis to explain the investment response to changes in traffic volume similar to that discussed above with respect to the ICC's procedures. It is improper to mix dollars of different value and relate them to output. To illustrate, in 1975 it might cost 50% more to add the same capacity as it did in 1970. Yet, by ignoring these price changes, the predictive equation is weighted with historical dollars. This leads to an understatement of investment needs occasioned by current and expected traffic volumes.

Even if the relationship between gross investment and output were restated in terms of constant dollars, the net investment relationship to output would still be obscured unless net investment were also restated. In addition, the introduction of technological improvements may distort current day reality of the net investment account amounts. For example, an investment in modern signaling may add the same capacity as a larger investment in additional mainline had previously added.

Appropriateness of Input Variables

Both the ICC and CTC costing methods employ two independent variables (the other two parameters under CTC procedures are constants). One of these variables, gross ton miles, is common to both methodologies. With regard to the second variable, the ICC uses carloads while the CTC employs train/yard hours.

The CTC use of train/yard hours presents a problem. It can be argued that plant configuration is a function of train/yard hours; however, it may also be argued that train/yard hours are a function of plant configuration. A heavy investment in long sidings or sophisticated signals and communcations or good surface and low grades will act to reduce train hours. A similar case can be made for yard hours. A large investment in a hump yard can easily reduce total switching hours needed for a high volume of business.

Investment Items: Fixed or Variable

There is no apparent justification for the treatment of track and grading as variable investment and structures as fixed investment. We understand, however, that this treatment is more the result of legislative fiat than special analysis.

Roadway Investment as a Continuous Function

The treatment of roadway investment as continuously variable is the result of applying regression techniques to the investment accounts. The use of regression analysis leads to an equation that purports to identify the change in roadway investment occasioned by added traffic within the relevant volume range. However, many of these investments would be required simply due to the passage of time; and as we shall discuss, the capital changes associated with others of these investments would actually be reduced were added traffic handled.

2. Calculations for Abandonment Studies

Treatment of roadway investment costs for branch line abandonments and subsidies by the CTC resembles that of the ICC. Costs are divided into on-branch and off-branch costs. On-branch costs are a function of the plant directly assignable to the branch in question. Off-branch costs are determined by the methodology described above for pricing purposes.

On-branch investment costs are equal to the cost of capital (expressed as a percentage) times the salvage value of all items in the plant accounts, in an amount not to exceed net book investment computed on system-wide depreciation basis. In other words, roadway investment in branch lines is considered by the CTC to be equal to the salvage value or depreciated ledger value, whichever is lower.

We fail to see any justification for this valuation procedure unless it is simply a means to arrive at the lowest possible number in order to reduce branch line subsidies. Inasmuch as the costing system was developed through an essentially political process whereby users of branch lines presented arguments for the preservation of their line, one may legitimately question whether such a definition of branch line investment bases has economic validity or is instead primarily the result of this political process.

From our point of view, however, it seems the choice of capital values ought to be the other way around, with the highest value being chosen. The value of capital is determined by the nature of the income it can produce. If some asset can produce more income when employed elsewhere than as a component of a branch line, then its value should be measured in that employment. Even if the asset were returning some income to the railroad as part of a marginal branch, it still would have an additional cost equal to the difference between what it is earning now and what it could be earning if utilized elsewhere. Therefore, the highest valuation, not the lowest, ought to be the one chosen.

## C. Conclusion as to Current Regulatory Procedures

Both the ICC Form and the CTC costing methodologies are deficient in their treatment of roadway investment costs. They assume the investment accounts properly reflect current prices, they assume investment is a function of one or two variables, and they assume a cost of capital equal to the average interest rate on all debt. The resulting treatment is both inaccurate and distorting. Thus, if costing, for pricing purposes, is to be improved, an alternative methodology must be employed.

## PROPOSED PROCEDURES FOR CALCULATING ROADWAY INVESTMENT COSTS FOR PRICING PURPOSES

Having considered current regulatory procedures, this section develops our proposed procedures for calculating roadway investment costs.

### A. Terminology Differences

To begin, certain terminology differences must be explained. The Interstate Commerce Commission defines roadway "investment" in terms of the road property asset accounts. In accordance with ICC accounting procedures, such assets are segregated into two groups: one group of accounts is designated as depreciable and the other as non-depreciable. The following assets are considered non-depreciable for ICC accounting purposes:

| ICC Account | Asset |
|---|---|
| 2 | Land |
| 8 | Ties |
| 9 | Rail |
| 10 | Other Track Material |
| 11 | Ballast |
| 12 | Track Laying and Surfacing |
| 38 | Roadway Small Tools |

Our approach to calculating the "wear-out rate" or "consumption" of the track structure as a function of certain traffic factors does not adhere to ICC accounting procedures. Thus, in a preceding section, we have provided a methodology for the calculation of traffic related consumption of track structure components. This procedure applies specifically to ties, rail, other track material, ballast, and track laying and surfacing, all of which are considered "non-depreciable" assets by the ICC. For example, we treat rail life as a function of:

(1) Annual tonnage density

(2) Composite of rail type, weight, metallurgy and condition

(3) Actual train speed

(4) Gradient

(5) Curvature and use of curve oilers

(6) Wheel loads and wheel diameter

(7) Train service type

In effect, then, we are treating all assets except land as "depreciable" or as being consumed as a function of specific traffic factors or time. As provided in our procedures, such consumption of the physical components according to their variability with traffic factors is then translated into a capital consumption allowance based on the current cost of replacing each track component in kind. This procedure provides for the inclusion of the recovery of capital expended for all roadway components except land which does not deteriorate with use.

Thus, our procedures for determining roadway investment costs address only the relevance of including the cost of capital as applied to roadway investment items in the long-run variable cost calculation.

B. Variability of the Cost of Roadway Capital

All capital outlays or investments in roadway incur a cost of financing that capital outlay. Whether the actual funds expended are provided from the issuance of debt, retained income, or some other source, a cost of the money used to finance the outlay is incurred. We will not develop a methodology for calculating a carrier's cost of capital. However, any cost of capital calculation should include an allowance for the cost of debt and the cost of equity capital, weighted according to these components' presence in a company's normal capital structure. The question is whether and to what extent this cost of capital should be included in the long-run variable cost calculation.

It is well established that variable costs properly describe the pricing floor below which no rate should be set. However, there is considerable debate surrounding the definition of variable roadway investment costs. What costs are variable? The answer to this question begs the issue of short-run versus long-run. Short-run variable costs are generally described as those costs which change when volume increases within a fixed productive capacity. Long-run applies to changes in operating costs and to investment decisions (broadly defined as "the acquisition of fixed factors of production") which give rise to costs that do not vary as the capacity thus created is more or less fully utilized. It is the application of these two cost levels that we shall discuss.

Economic theory is quite clear with respect to which costs are relevant for making pricing decisions. If the traffic in question can be served with existing "unused capacity," the pertinent costs are the short-run marginal costs (SRMC) which do not include any amount for the investment in plant capacity.

On the other hand, if the traffic in question cannot be handled efficiently with the existing capacity, and new capacity is demanded, the appropriate cost would be the long-run marginal cost (LRMC). LRMC differs from SRMC in that it includes the capital costs associated with making the investment in added capacity, as well as any cost savings resulting from the investment.

In discussing whether roadway investment costs at the LRMC or SRMC level are proper for inclusion in the long-run variable cost calculation for pricing decisions, let us consider a route. The route may be thought of as composing a number of separate, continuous segments, which may be infinitely small, if one prefers to view them as such. A route may be defined as the railroad facility between whose end-points all traffic will travel. Therefore A to B to C is only a route if all traffic from A to B travels also from B to C and *vice versa*. The route here is therefore A to C.

We assert that for any such route, there is a finite amount of traffic, of a given mix and using a given "above the rail" technology, that can be moved per unit of time. To assert the opposite is also to claim that traffic can move, infinitely fast, since throughput/unit time = velocity/unit time x K, so infinite throughput implies infinite velocity.

The limit of throughput for the route is given by the segment that has the smallest throughput; i.e., the capacity is determined by the worst "bottleneck". Therefore, unless all segments have an equal capacity, those segments with capacity greater than that with the smallest capacity will have capacity that is excess and unusable. The only route that can have no excess capacity is one whose segments all have equal capacity.

Consider such an ideally constructed route. The only way to change capacity without having unusable, excess capacity, is to change equally the capacity of all segments. 1/ The rational firm will endeavor to construct or modify routes so that these routes are ideal, ideal meaning no unusable, excess capacity, although this is usually impossible to accomplish in practice.

If the capacity of an ideal route can be changed in such a manner as to permit the addition of just one more unit of throughput, or of a very small percentage change in throughput, then we may conclude that roadway investment is at least partially variable. It must be emphasized, however, that even if it were physically possible to change capacity by one small unit at a time, it may also be very uneconomical to do so.

Consider that this route has no excess, unusable capacity, and is therefore operating at capacity. One additional bit of business appears. Examine how one can incrementally "vary" roadway plant to accommodate this additional increment of business. First, one could increase speed by just a small amount, say five percent. Or if it is a single track operation, sidings could be extended by a small amount, say one car length. If another bit of business appears, this incremental investment

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1/ Actually, one aspect of traffic carrying capacity can be varied without increasing the physical capacity of the entire route. This is throughput time. While total throughput cannot be increased, the time it takes for a unit to travel through can be improved.

In addition, if throughput time can be reduced, then meet/pass delays are also reduced, thereby increasing, although on a small scale, the capacity of a single track line (theoretically).

could be repeated, although possibly at a different rate.

While it is certainly possible to extend a siding by sixty or so feet at a time, and/or to increase speed by small amounts, it is not economical to do so. It is not economical (i.e., least costly) to add sixty feet to a siding every week for four months and then tear it up by these small increments when volume declines. It is not economical to raise speed by five percent at a time every month, say from 40 MPH to 42 to 44.1 to 46.3 and so on. Neither is it economical to let the speed deteriorate when volume drops off and then raise it again when volume picks up. It may well be very possible to vary these plant components, but it is clearly not economical.

Some other plant items, as mentioned, are completely fixed over wide ranges of output and are impossible to vary. These include such items as bridges and other structures, grading, and signalling. Changes in these items' ability to accommodate traffic typically involves a result suitable for a wide range of traffic volume.

One may be able to recall where small additions to the plant were made, and these additions made perfect economic sense. No doubt they did. However, such a project is invariably a step to bring a route into capacity balance. Small signalling projects for example, are often implemented to relieve bottlenecks. Bridge reconstruction is undertaken to remove a weight restriction. But no one would claim that it made economic sense to increase the axle loading of a <u>sound</u> structure from a Cooper's E-80 rating to E-130, if all the other structures on the route were still rated E-80 and would remain so for a very long time to come.

Based on this analysis, we conclude that roadway investment should be treated as fixed over ranges of traffic volume for which plant configuration is fixed. To do otherwise would prevent more complete utilization of the roadway investment and the resulting reduction in average costs which would flow from the contribution of added traffic.

As an illustration of this concept, assume a single track line equipped with CTC has a capacity of 30 trains per day, that current volume on the line is 15 trains per day, and that capacity will not be reached for several years into the future. Application of our thesis means that the capital costs associated with the investment in this line should be considered fixed until additional capacity is required, and that the capital costs should therefore be excluded from the long-run variable cost calculation for pricing purposes. Until 15 additional trains per day have been attracted to the route, the carrier's economic position would indeed be improved so long as the added traffic more than covered all long-run variable costs excluding the cost of capital associated with the roadway investments.

But we have advocated a "component-specific" approach to calculating roadway "consumption" costs because, as we have shown, the lives of roadway components differ significantly as a function both of the specific component and of the characteristics of the traffic moving over a particular line segment. Thus, the question should be raised as to whether dis-aggregation of the roadway into its individual components would provide a different conclusion as to the variability of roadway costs of capital. Such a question should assume location-specific investment costs would be developed in a manner similar to our proposed development of roadway maintenance costs.

Let us apply such an hypothesis to rail, which we have previously shown to be as much as 100% variable with traffic factors.

(1) <u>Assume</u>:

$60,000 = Current cost of replacing one mile of 136-lb. rail; all charged to expense

50% = Carrier's marginal tax rate (t)

10% - Carrier's cost of capital

10% = Investment Tax Credit (ITC)

99.6% = Variability of Rail with Traffic

300 Million Gross Tons Is Rail Life

(2) <u>After-tax Cost of Average Variable Investment</u>

$60,000 = Cost Per Mile

24,000 = After-tax Cost of Rail: ($60,000 x 50%) - ($6,000 for ITC)

24,000/2 x 99.6% = $11,952 = Average Variable Investment Over Life of Rail

(3) <u>Annual Variable Investment Cost (AVIC)</u>:

$$\text{AVIC} = \text{Average Variable Investment} \times \left(\frac{\text{Cost of Capital}}{1 - t}\right)$$

$$= \$11{,}952 \times \frac{0.10}{(1-0.50)}$$

$$= \$2{,}390$$

(4a) Case 1: <u>Low Volume Line</u>

@ 30 Million Gross Tons per year annual volume, Rail Life is 10 years

Capital Cost =($2,390 x 10)/300 = $79.7/Mil. G.T.

(4b) Case 2: <u>High Volume Line</u>

@ 60 Million Gross Tons per year annual volume, Rail Life is 5 years

Capital Cost = ($2,390 x 5)/300 = $39.8/Mil.G.T.

As shown, the investment cost of rail for the low volume line is double that of the high volume line per unit of traffic. Thus, we again conclude that roadway investment costs should be treated as fixed over a particular range of traffic because their unit cost declines as the asset becomes more fully utilized. And although this discussion has been in terms of rail, we believe all other roadway assets which we have identified as variable with traffic volume as well as those "fixed" will behave in a similar manner.

## C. Considering Roadway Capital Costs In Investment Decisions

Of course, there is a certain danger in excluding roadway capital costs from the long-run variable cost calculation. Even though such costs are fixed over ranges of traffic volume as we have shown, volume will reach the upper limit of capacity on certain routes in time. At that time, the investment required to increase route capacity is variable as is the associated cost of capital.

And it is at this time, therefore, that the cost of the proposed investment should be included in the long-run variable cost calculated for handling the required traffic volume. Of course, this projected long-run variable cost should also include any cost reductions from operating efficiencies which would be derived from the proposed capacity expansion.

All traffic then, which would utilize the expanded capacity should be tested for a positive contribution at the projected long-run variable cost level. If certain traffic segments produce a negative contribution, a determination should be made as to whether the added capacity would still be required if the negative contribution traffic were no longer handled. And, if the capacity expansion could be thus avoided, the negative contribution traffic should be eliminated. Given the slowness in rate-making procedures, this analysis and the upward rate proposed should probably be made about a year before the capacity limit will be reached in order that the capacity limit will not be exceeded.

On the other hand, if the capacity addition would still be required even were the negative contribution traffic not to move, that traffic should not be eliminated so long as it produces a positive contribution before considering the cost of the capital associated with the proposed addition to capacity. This is so because the capacity addition will have to be made anyway; the cost of capital to finance the outlay will be incurred anyway; and if the traffic makes a positive contribution to this sunk, cost of capital, the carrier's economic position will be improved.

In making the investment analysis described above, care should be taken that such an analysis avoids incremental reasoning. This can be accomplished by including all expected capacity additions which will be required to handle the marginal traffic over the planning horizon.

For example, if a short portion of a single track line is initially being proposed for expansion to double track over a heavy grade, but the remaining portion of the line will also require double track within a short period of time, then the marginal traffic analysis should cover both proposed capacity additions. Otherwise, each double tracking project may be separately determined to be desirable while in actuality, both are undesirable when the marginal traffic is eliminated.

The question of which traffic should be subjected to the marginal analysis is also important. We believe the appropriate traffic is that which will use the added capacity.

The creation of capacity gives rise to the phenomenon of joint supply. This phenomenon occurs when two services are created as the result of one indivisible process. In the case of an investment, the decision to add capacity to serve our July customers (service A) automatically results in the provision of the capacity to serve our January customers (service B). It is impossible to increase or decrease the amount of capacity available for sale in July without changing in the same proportion and in the same direction the capacity available for sale in January. When looking at the cost of this capacity alone, there is no objective way to attribute causal responsibility to any one group of customers. Without examining the demand side of the equation, we cannot determine who caused the investment, and any capital cost allocation would be entirely arbitrary.

Despite the many difficulties inherent to conditions of joint supply, the problem of determining cost responsibility is not impossible. Economic theory dictates that costs should be assigned on the basis of causal responsibility. Thus, to the extent that a given customer or a given service results in specific costs, that customer or service is directly responsible for those costs. When a group of shippers demands service that cannot be efficiently provided with the existing plant, an investment in new capacity must be made. At the time the investment is made, the investment costs are variable as we have stated, and they are then directly attributable to those customers requiring the investment. Therefore, the variable cost of serving these customers necessarily includes the capital costs associated with the added investment. It now remains only to identify these "responsible" customers.

If a plant were designed to carry exactly 20 carloads of traffic per month, it could handle more traffic but only at the expense of increasing the costs for all carloads handled. When the traffic volume grows to 21 carloads per month, the railroad may still operate with its original plant, but the cost per unit would be higher. The original plant is operated at an inefficient rate because investments are generally made in lump-sums for economic reasons. So, the plant capacity will not be expanded until the growth in traffic can cost justify the lump-sum investment.

If we assume the railroad will not make an investment in capacity until the volume grows to 26 carloads per month, who is responsible for the investment? Is it the shipper who adds the 26th car? Is it the group of shippers who add cars 21-26? Or, are all shippers responsible?

The test of "causal responsibility" is to ask the question, "Would the plant requirements be different if a given customer reduced or eliminated his demands on the system?" If the answer is yes, then the customer is causally responsible and his costs, when calculated, must reflect an appropriate portion of the capacity costs.

Continuing this example, if we assume:

(1) Plant capacity is equal to 20 carloads per month

(2) We have five customers who ship the following volumes: A = 5, B = 5, C = 4, D = 3 and E = 3.

(3) A uniform monthly volume of exactly 20 carloads

If customers A and B begin shipping at the rate of 8 carloads per month, our original plant will be over-taxed, and we may be able to justify an investment. Now let us assume the rail plant is expanded with an investment of $10,000 and the new plant is capab' of handling 30 cars per month. If the investment has a 30-yea' and the railroad's after-tax cost of capital is 10%, the annu capacity cost capital charge would be $500 ($10,000/2 x 10%) the life of the investment. This situation is illustrated ir grams I and II:

**DIAGRAM I**

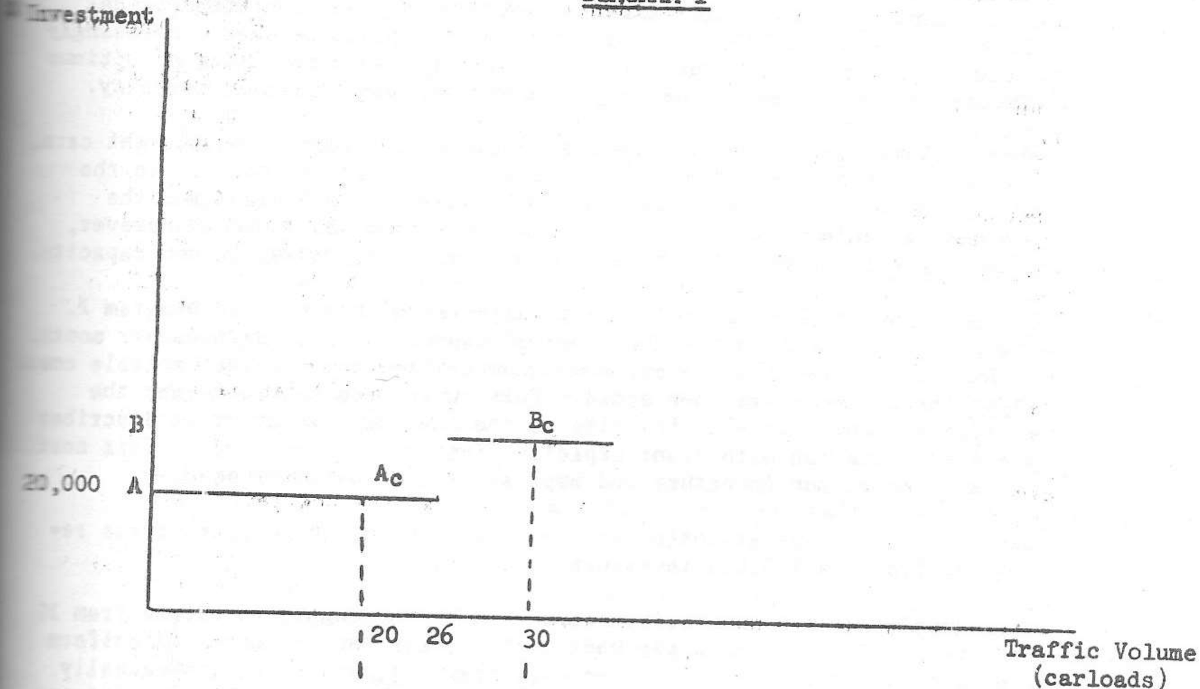
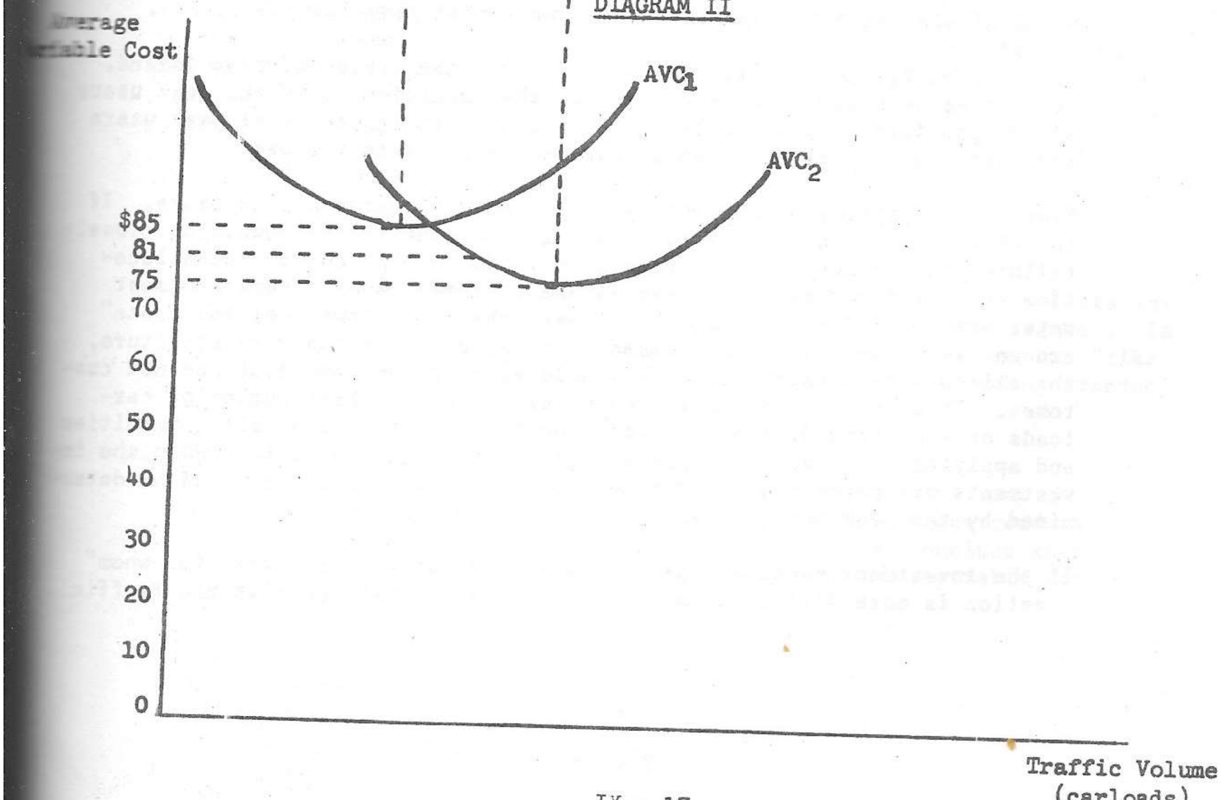



**DIAGRAM II**



In Diagram I, the horizontal line A describes the original plant investment of $20,000. The point $A_c$ identifies the point associated with the most efficient operation as 20 carloads per month. In Diagram II the curve AVC, describes the average variable costs associated with the original plant. As seen, the AVC curve declines as the plant becomes increasingly utilized, reaches a minimum point where the plant is operating at optimum efficiency, and rises as the output approaches the limits of capacity.

When customers A & B expand their shipping volume from five to eight cars, the total monthly volume changes from 20 to 26 cars per month. In the short run, we would meet this demand with the original plant and the average variable cost per car would increase from $85 to $87. However, if we expected to sustain the new volume, we would invest in new capacity.

The addition to plant capacity is illustrated with line B in Diagram I. The point $B_c$ describes the new level of capacity at 30 carloads per month. In Diagram II, we have the curve $AVC_2$ describing the average variable costs after the capacity has been added. This curve does not represent the average variable costs at the time of the investment; rather it describes a static situation with plant capacity fixed at the new level. This cost curve is short-run in nature and applies to all customers equally.

Let us now turn our attention to the assignment of the capital costs resulting from the $10,000 investment.

The investment in new capacity was caused by the change in volume from 20 cars per month to 26 cars per month. If we continue to assume a uniform flow for all customers for all months; then, all customers are causally responsible for the investment. Even though customers C, D and E did not increase their demands on the system, they still must be held accountable for the plant addition. If they had reduced their monthly demand by a total of six carloads, the investment would not have been necessary.

In most cases, capacity is expanded to serve the period of peak demand. As long as peak demand is the cause of the expansion, only the peak users are responsible, and capacity costs should be assigned to all peak users according to the degree to which each contributes to the peak.

Every cost system should be designed to meet the needs of its users. If the costs will be used as a rate-making tool, the system should be closely tailored to the needs of the rate maker. Up to this point, the allocation of capacity costs have been at the customer level. However, most rates are applied at the commodity level where "customer-related costs" are not very useful. Since commodity rates dominate the rate structure, the allocation of capacity costs should be based on commodity and not customer. This would be accomplished by dividing the total number of carloads of each commodity by the total number of carloads of all commodities and applying the respective percentages to the capital costs. When the investments are peak-related, the numerators and denominators would be determined by the peak month only.

If the investment expands capacity to meet a future need, the "for whom" question is more difficult to answer. We cannot rely on historic traffic data to identify the responsible customers; instead, we must project the volume for each customer and assign the capacity costs accordingly. Since the investment was justified on the basis of future growth, the projected volume should be available from our forecast.

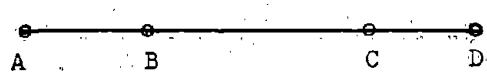
In our experience, the usual peak period is a month. That is to say, most capacity expansions are proposed in order to meet the traffic demands of a peak month. However, the selection of an appropriate peak period should reflect each carrier's own policy.

Since variable costs identify the pricing floor, it is important for these costs to be as precise as possible. If roadway investment costs were lumped together and allocated on the basis of "system" service units, we would fail to meet this objective. Traffic moves over specific routes and not average routes. If we assume the latter, we overstate some costs and understate others. The only remedy is to identify investment by route and location and determine the causal factors. Since it is virtually impossible to examine each investment individually, we must do some aggregation.

All investments should be classified into linehaul, yard, or terminal investments. The terminal classification might be further segregated into TOFC/COFC and regular carload.

In the interest of practicality, the linehaul investment data would have to be aggregated. The most useful form of aggregation would identify specific route segments. While it would be advantageous to make these segments as large as possible, their length would be dictated by traffic flows. Some segments might be as short as 20 miles while others are as long as 300 miles.

If a route segment represents the distance between two points, the majority of traffic should flow through the end-points of the segment. For example, it would be improper to define a route as all points from "A to D" if a substantial volume of traffic terminated at points B or C. One consequence




of the "A to D" definition would be the allocation of capacity costs incurred on the B to D portion to traffic not even using this segment. In other words, a route must be defined narrowly enough to encompass "like traffic," yet broad enough to be manageable from the accounting standpoint.

## D. Conclusion

We have shown that the cost of capital incurred to finance roadway investments is fixed over ranges of volume. Therefore, we conclude such costs should not be included in the calculation of long-run variable costs for the pricing floor.

However, when capacity additions are required, a contribution analysis of traffic causing the additions should be made. At this point, the entire cost of proposed capacity is variable, including the associated cost of capital. Thus, if specific traffic segments cannot generate a positive contribution and the proposed capacity would not otherwise be required, then these negative contribution segments should be eliminated. As we have stated, the relevant traffic to subject to this marginal analysis is that which causes the requirement for added capacity. Finally, capacity replacements affecting the continuity of a network should be viewed as abandonment decisions which are discussed below.

## PROPOSED PROCEDURES FOR CALCULATING ROADWAY INVESTMENT COSTS FOR ABANDONMENT DECISIONS

In an abandonment analysis, all roadway investment costs which will occur if the line is removed should be considered variable. Thus, the translation of the total value of the investment in the line into realizable, current dollars is the principal analytic task.

In addition, if the line were continued in operation, any required rehabilitation of the line would require the expenditure of capital. Any such rehabilitation must be recovered over the expected future life of a line, and must include an allowance for the cost of capital incurred to fund such a rehabilitation expenditure.

If abandonment occurs, land will be released for other use (i.e., sale or lease) whose after-tax value can be determined by land appraisals with adjustment for taxes. However, if the line were continued in operation, receipt of this value would be deferred over the expected future life of the branch line. The cost of this foregone value can be obtained by comparing the difference in net present value at time zero to the net present value at the end of the branch's expected future life, using the carrier's cost of capital as a discount factor.

Salvage value, after the cost of removing the track structure components, should be calculated. If the line were continued in operation, these net salvage benefits would be foregone over the expected life of the line. Again, the cost of foregoing these net salvage benefits can be calculated by comparing net present values.

Finally, abandonment of a line usually results in a tax reduction because net salvage receipts are less than the book value of the line. Again continued operation of the line will cause this benefit to be foregone. This opportunity cost also should be calculated by comparing net present values.

Taken together, these investment costs should be annualized and compared to the net contribution of revenues (less operating expenses) generated by traffic which would be lost if the line were abandoned.

# X - COMPARISON OF COSTING PROCEDURES AND COST RESULTS

## Introduction

The extent of departure from "conventional" roadway costing procedures evident in the procedures developed in this study necessarily makes any comparison of resulting costs extremely difficult and thus essentially prevents significant conclusions from being drawn. Several rough cost comparisons were made however, and are presented here together with comparisons of several other aspects of the procedures themselves.

## Cost Levels

Only two comparisons were made between costs calculated from the procedures developed herein and those resulting from other procedures.

Linehaul unit (GTM) cost for only the major program elements of the study area track structure were calculated as described in Section VII . Resulting costs (considering all ranges of track and traffic conditions) ranged from $0.10 to $1.31 per 1000 GTM. The roughly comparable system average variable unit cost, based on 1974 running track expenses of the Southern Pacific Transportation Company as reported to the Interstate Commerce Commission and calculated using the Commission assumption of 57% average variability, was $0.25 per 1000 GTM. Previously utilized Southern Pacific total variable maintenance of way unit costs, as calculated using the procedures described in Section V, resulted in a system average unit cost of $0.45 per 1000 GTM.

Obviously, the only significant conclusion which can be drawn from these comparisons is not that resultant cost levels are similar or dissimilar, but that system average costs cannot begin to describe the "variability" of "variable" roadway costs at the operating district level.

## Relative Cost Behavior for High Density Vs. Low Density Lines

A comparison of Figures 27 and 31 indicates that the cost per gross ton mile for program maintenance items (rail, ties, surfacing, ballasting, turnouts, and track crossings) is lower for high density lines than for low density lines. The explanation for this can be drawn from Figures 7, 9, 12, and 13. As annual tonnage on a given line increases, the lives of the respective track components decrease in terms of years but increase in terms of gross tonnage.

Decreases in available on-track time for maintenance forces, which generally occur with increases in annual tonnage clearly increase the cost of performing program track renewal work. However, as long as the percentage increase in these costs is less than the percentage increase in tonnage which moves over the track during the respective component lives, the cost per gross ton mile will be less.

## Accounting Systems

Here also, there can be no comparisons between accounting structures inherent in the type of system utilized in these procedures and those of either the Interstate Commerce Commission or the Canadian Transport Commission. These latter systems are simply not designed or intended to provide the degree of management control and cost analysis capability inherent in the more extensive and complex accounting systems in use in the industry today.

## Uses for Internal Costing

There is no question that costing procedures developed here provide the capability to refine roadway cost analysis to a route and service-specific basis. The advantages of such a system, given the pervasive competition faced by the railroad industry in marketing its transportation services, can be substantial. The qualifier is needed to reflect the continuing requirement to improve the quality of data relating to the physical and economic behavior of railroad roadway and to recognize that added complexity and cost are associated with the procedures developed here. Recognizing these factors, internal carload/train load costing can, utilizing these or similar procedures, distinguish the varying roadway costs associated with specific rail services. These procedures also have application to the economic evaluation of specific proposed trackage rehabilitation projects.

## Uses for Regulatory Costing

Costing procedures described here and the resultant roadway costs will have application to regulatory proceedings when such proceedings are conducted in recognition of probable distinctions between economic and incurred costs. The use of predictive methodologies for analyzing roadway economic costs must be brought to bear on proceedings relating to specific types of rail service. Such methodologies will almost certainly find increasing acceptance as the body of relevant knowledge of the behavior of railroad track structure increases and specific relationships between the roadway and its service environment become more clearly defined and universally accepted. The influence of such data and similar costing procedures upon the determination of relevant roadway costs in proceedings related to cost sharing between different rail services is already apparent.[1]

Finally, these procedures, and particularly the accounting structure implied, will almost certainly also find application in actual loss calculations in abandonment or subsidy proceedings.

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1. "A Methodology for Service Cost Sharing," Report of a Study for the Trustees of the Penn-Central Transportation Company, DeLeuw, Cather and Company, (ICC Finance Docket 27353) December 1972.

# XI - GUIDELINES FOR IMPLEMENTATION OF ROADWAY COSTING PROCEDURES

## Introduction

This section describes the decisions, considerations and requirements for the implementation of roadway costing procedures akin to those developed in this study. It is intended to be a general statement of the implications surrounding the attainment of refined roadway costs to an extent, and with techniques and procedures proposed and utilized throughout this effort. The material in this section presupposes that committments exist to develop railroad roadway costs which are service-specific in nature and which reflect the economic roadway costs of providing railroad service.

## Organizational Requirements

Costing procedures as described in this study will most assuredly require the assemblance of a project team or special study group. While the size and composition of such a staff will depend to some extent on the relative size and complexity of the roadway network being analyzed as well as upon the current level of cost finding capability, as a minimum, such a staff should include the following:

1 Engineering Department Representative - This individual would ideally be possessed of substantial engineering field experience, perhaps as Division Engineer, Assistant Division Engineer or General Track Supervisor. In addition, this team member should have substantial knowledge of current procedures relative to the reporting and control of engineering expenditures.

1 Cost Analyst - This team member should be thoroughly familiar with procedures currently used by the railroad for analyzing railroad costs for pricing purposes, including existing data sources such as accounting reports and traffic statistics as well as data handling systems.

1 Intermediate Level Programmer - This individual should be proficient in both COBOL and FORTRAN language and should be thoroughly familiar with existing management information systems, including individual data files and reporting capabilities.

2 Clerical Personnel - These individuals must be capable of interpreting both Engineering Department and Accounting Department records and reports including engineering track charts, line profile drawings, periodic budget reports, etc.

In addition it will be most important to assign specific liason personnel in both the Accounting and Management Systems organizations of the railroad.

Significant Considerations

Of utmost importance to the scope and level of effort entailed in developing roadway costing procedures of the type described herein is the nature of existing data. Specifically, the following areas will be paramount.

1. Engineering Data

   The existing amount, format, timeliness and integrity of track physical characteristics data will be a significant determinant of the level of project effort. In addition, the extent of existing information (either internally developed or accumulated from other sources) relevant to the prediction of the physical behavior of roadway track structure of the type existing on the specific railroad under study will be of prime importance in determining the level of additional effort required in this area. It is likely that at least some railroads possess substantial amounts of internal data for estimating the performance of various types of their specific roadway track structure under varying traffic conditions and would be able to substantially reduce the level of field investigation effort reported herein.

2. Accounting System Data

   The nature and sophistication of existing accounting and expenditure control systems will also play a significant role in the development of roadway costs on a basis similar to that described here. To the extent that decentralized service-related responsibility accounting is not in use or under development, substantial effort must be directed toward structurally altering existing systems to provide data of the type proposed for use in roadway cost analysis.

3. Traffic Characteristics Data

   Development of service-specific traffic data at the level demonstrated in this work represents a sizeable undertaking. As described previously, such data may either be manually developed from sample train movement reports or extracted from the several types of computerized traffic/operations control and information systems existing in the industry. Once formulated however, procedures for acquiring such traffic data can result in the routine periodic accumulation and analysis of data vitally important to performance requirements attendant to the roadway track structure. Such data is a prime requisite for eventual development of service-specific or product line-based roadway costs.

Perhaps more basic to the successful development of refined roadway costs than any of the data or systems constraints outlined above is the necessity for coordination and communication of the far reaching impacts of specific marketing, operating and engineering decisions as they affect the eventual economic behavior of the roadway system. When the need to recognize the interrelationships and common data requirements of the various railroad departmental functions has been firmly established, the necessary infrastructure for refined cost analysis will have been developed. Cost analysis and costing procedures of the type proposed and demonstrated here cannot be successfully undertaken without this basic infrastructure.

# XII - CONCLUSIONS AND RECOMMENDATIONS

While individual railroads must each determine their specific needs for refined roadway costs, the procedures developed in this study provide a basis for the determination and allocation of variable roadway costs incurred in providing specific rail services on specific portions of a railroad roadway network. To imply, however, that sufficient information currently exists, or has been developed in this study for the exact assessment of the direct or relative roadway costs associated with rail service provided under varying track/traffic conditions would be seriously remiss.

## Track Structure Research

While the body of relevant, well-documented track research data is expanding, it is still insufficient to provide railroad management with adequate decision-making capability, not only for the establishment of rail service prices but also for effective operations and maintenance planning and control.

Although this study has made use of much of the existing data purporting to describe the physical behavior of the primary elements of the roadway track structure, the areas still open to subjective evaluation, i.e., engineering judgment, are numerous. In fact, the performance capability of every element in the subgrade-ballast-track system warrants further study and probable revision. For example, much more study should be devoted to the entire subject of rail life and the development of procedures to evaluate it, including methods which take into account specific removal criteria and reuse policies as well as the identification of the effects of all significant physical and traffic characteristics.

Track geometry performance represents another major area where much additional research is warranted. Perhaps required here is the development of a serviceability index based on the amount of wear and deterioration to be permitted in track before surfacing and lining or reconstruction must be performed. Condemning limits for rail wear should be a part of such an index. This index would likely be a function of long-term dynamic response to physical change rather than to traffic volume alone. That is, the way tonnage is applied in terms of wheel loads, frequency of load application, train service type, and speed may be just as significant as the actual number of tons carried. Various attributes might be attached to the track index levels including permissable track deflections and specific moduli of track elasticity. Bearing capacity of subgrades and depths of ballast would be additional factors. The relation of subgrade and ballast to track modulus and to deflection should also be included. These factors and related indices could be further related to speeds, wheel loads, or other train service effects.

In summary, the problem with practically all current engineering data of the type required for use in roadway economic cost analyses is the almost complete lack of control and comparability with which it was derived. No two sets of data are obtained under exactly the same set of conditions. Thus, it is extremely difficult to isolate the effects of any one element or factor. The solution, then, and the recommended nature of future research, is to analyze each of the primary track structure elements, item by item, determining their physical and resultant economic behavior under a series of carefully controlled conditions and environments.

The costing procedures developed here, then, are seen as both a means to begin to utilize presently available types of roadway performance information in the costing of rail services for pricing purposes, and as an infrastructure capable of incorporating future, more relevant roadway research data to help insure that adequate consideration of all the economic consequences of rail service and operating decisions upon the railroad fixed plant is undertaken.

Significant Aspects of Roadway Costs

Results of the study have indicated the potentially widely variant nature of roadway costs, particularly unit (GTM) variable costs as determined by the type and volume of traffic carried on a specific route or line segment. The nature of variable and total unit cost behavior, particularly as affected by route traffic density, is obviously vital to an accurate assessment of overall product-line or route-specific profitability and the establishment of optimum pricing and service planning policies. Unit variable linehaul roadway costs developed in the study ranged from less than 20¢/1000 GTM to well over $3/1000 GTM, depending on route and service conditions. Given variations of this magnitude in unit variable cost, and recognizing the impact upon associated (route-specific or allocated) unit fixed costs occasioned by structural changes in traffic volume, the importance of refined fixed plant costing capability becomes clearly evident. The implications of such cost behavior indeed go far beyond the issue of improved cost information for internal pricing decisions.

Significant refinements in railroad cost-finding capability and particularly those in the area of railroad roadway costs will not be achieved without commitment of substantial resources. Whether in the area of expenditure reporting and control or in the area of scientific research into the nature of the track-train environment, meaningful improvements in roadway costing capability will result only when the significant variants of this complex and vital aspect of railroad service are much more thoroughly understood and evaluated.

While the potential costs and benefits of such refinements must enter into any decision to more thoroughly investigate the economic behavior of specific railroad roadway "service," it should be recognized that the consequences of incorrect or inadequate information become more and more severe as the financial resources of individual railroads or the industry become more scarce. The potential cost-effectiveness of refined roadway cost analysis procedures must be viewed in light of just such conditions.

## APPENDIX A

TRACK INVENTORY FILE CREATION
DOCUMENTS

# RAIL FILE INPUT

| COMND CODE 1-3 | 4 | LINE CODE 5-8 | SEQ. NO. 9-11 | 12 | HISI FH 13-14 | 15 | JT WR CWR 16-18 | 19 | NEW SH 20-21 | 22 | M. P. FROM 23-30 | M. P. TO 31-38 | E W S 39 | 40 | L E F T 41 | R / G H T 42 | WGT 43-45 | MANF 46-49 | YEAR ROLLED 50-53 | YEAR LAID 54-57 | 58 | YEAR TRANSP 59-62 | 63 | TONNAGE PER YEAR 64-69 | TOTAL TONNAGE 70-75 | 76-80 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

FIGURE A-1

# TIE CHARACTERISTICS FILE

| CMD CODE | LINE CODE | SEQ. NO. | MILEPOST FROM | MILEPOST TO | TIE MAT. | TIE SP. | Treat. | Tie Type | TIE SIZE | PROG. RENEW. | TIES RENEWED | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|

FIGURE A-2

## CURVE CHARACTERISTICS FILE

| CMD NO. | LINE NO. | SEQ. NO. | CURVE NO. | CMPD | MILEPOST FROM | MILEPOST TO | DEGREE CURVATURE | CLASS | SUPEREL (IN) | SPIRAL WEST | SPIRAL EAST | CURVE LENGTH (FT) | OILED | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

FIGURE A-3

GRADIENT CHARACTERISTICS FILE

| CMD. CD | LINE CODE | SEQ. NO. | MILE POST FROM | MILE POST TO | Direction | ELEV. AT MP. FROM | ELEV. AT MP. TO | % GRADE | CLASS | |
|---|---|---|---|---|---|---|---|---|---|---|

FIGURE A-4

## TRACK SUPPORT CHARACTERISTICS FILE

| CMD CD. | LINE CODE | SEQ. NO. | MILEPOST FROM | MILEPOST TO | CLASS | MODULUS | |
|---|---|---|---|---|---|---|---|
| | | | | | | | |

FIGURE A-5

MISCELLANEOUS OBJECT & NOTATION FILE INPUT

| COMMD CODE 1-3 | 4 | LINE NO. 5-8 | SEG. NO. 9-11 | TYPE CODE 12-15 | M. P. FROM 16-23 | POS. FROM 24-26 | POS. TO 27-29 | ARGUMENT 30-32 | M. P. TO 33-40 | OFFSET 41-46 | ADJUST 47 | ANGLE 48-50 | ALPHANUMERIC NOTATION 51-80 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | A | 1 3 | T.O. | 136.416 | +1 | +2 | 14 | 136,416 | | | | No. 14 T. O. EB MAIN-TRK TO RT. |

FIGURE A-6

## SUB-DIRECTORY FILE INPUT

| COMND CODE 1-3 | 4 | LINE CODE 5-8 | SEG. NO. 9-11 | M. P. FROM 12-19 | STATION FROM 20-31 | M. P. TO 32-39 | STATION TO 40-51 | TRK CODE 52 | STATE 53-54 | DIV 55-57 | OWNERSHIP 58-60 | TEMP MAX 61-63 | TEMP MIN 64-66 | TEMP MEAN 67-69 | PRECIPITA-TION RAIN 70-72 | PRECIPITA-TION SNOW 73-75 | U. R. OR S 76 | CORROSION 77 | ICE 78 | HURRICANE 79 | FLOOD 80 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
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FIGURE A-7

# BALLAST SUBGRADE & VEGETATION FILE INPUT

| COMND CODE | | LINE CODE | SEQ. NO. | M. P. FROM | M. P. TO | FIRST LAYER BALLAST | | SECOND LAYER BALLAST | | YEAR SURFCD | YEAR TIED | SUBGRADE PARAMETER | VEG. CODE | CONTRL CODE | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | TYPE | DEPTH | TYPE | DEPTH | | | | | | |
| 1-3 | 4 | 5-6 | 9-11 | 12-19 | 20-27 | 28-31 | 32-35 | 36-39 | 40-43 | 44-48 | 49-53 | 54-61 | 62-65 | 66-69 | 70-80 |

FIGURE A-8

## - M of W Economic Analysis Project -
## Field Survey

The purpose of this survey is to obtain the benefit of field engineering experience and judgment regarding both program and ordinary M of W activity requirements for providing and properly maintaining various types of trackage under varying traffic conditions. The survey is neither a test of knowledge nor an attempt to evaluate performance in any way.

The survey consists of five sections. Section I should be completed by Roadmasters. This section deals with providing estimates as to program and other major trackwork requirements for specific track segments in each Roadmaster's district (although some districts may not be represented, as a result of the track segment selection procedure employed). This section should be fairly self-explanatory as to instructions for completion.

Section II should be completed by both Roadmaster and Division Office personnel. This section deals in more general terms with the effects of various track and traffic characteristics on track maintenance and renewal requirements and also seeks to identify potential impacts resulting from a number of possible changes in reporting requirements.

Section III should be completed by the Division Engineer's Office. This section relates to force level and equipment requirements for ordinary track and other maintenance requirements, assuming adequate level of program maintenance.

Section IV should be completed by the Division B & B Supervisor and deals with the potential establishment of relationships between structures maintenance efforts and different levels/types of traffic.

Section V can be completed by either the Division Office, Roadmasters, or both. This section deals with estimates of available on-track time for rail laying, tie, and surfacing operations in main track territory.

- M of W Economic Analysis Project -
Field Survey

## Section I

### Program/Major Trackwork Requirements
### Sample Track Segments

General:

This section of the survey involves completing FORM RECM-1 for the track segments specified. Responses should reflect each Roadmaster's judgment as to adequate and economic track maintenance and renewal for each segment. The following general guidelines apply:

1) The "line" code in columns 5-8 is the Circular 4 line designation.

2) The "track" code in column 32 (E,W,or S) indicates whether eastbound, westbound, or single track.

3) If the weight of rail in track does not match that indicated in columns 39-41 or if the condition (New or Secondhand) does not match that shown in column 43, ignore this track segment and go on to the next line.

Please follow the instructions given below in completing the form. In responding to the items requested, assume that current traffic conditions (annual tonnage, amount of unit train traffic, amount of traffic moving in jumbo cars, Amtrak, etc.) will remain unchanged, and also that current speed limits will stay the same (unless track is temporarily slow ordered). If current traffic levels are substantially less than normal, assume what you would consider to be a more typical tonnage density.

1) Columns 45-48: "YEAR RAIL REPL."

Based on the current age and condition of the rail, what year do you estimate that relay should be accomplished? e.g. 1978, etc.

2) Columns 50-52: "EST. TIE LIFE".

IF POSSIBLE, estimate the average life (in years) which you feel could be obtained from cross ties in the track segment. If you feel no estimate is possible, leave blank.

3) Columns 54-56: "MAJ. SURF. CYCLE".

What major surfacing cycle, in years, (tie renewal and at least a 3" raise) would you establish for the track segment? e.g. 6, etc.

4) Columns 58-60: "NO. INT. SURF.".

Considering the major surfacing cycle previously specified, how many (if any) intermediate surfacings would you specify between major lifts? Put the number of intermediate surfacings in column 60.

5) Columns 62-64" "TYPE INT. SURFACING".

IF intermediate surfacings are called for, how extensive should they be? Indicate by putting one of the following codes in column 64:

A = minor (1") lift

B = major (3") lift

6) Columns 66-68: "% TIE MAJ. SURF."

What % of cross ties should be renewed at each major surfacing?

7) Columns 70-72: "BAL. TYPE".

What type of ballast is used? Indicate by putting one of the following codes in column 72.

A = crushed rock

B = Slag

C = Cinders

d = Other

8) Columns 74-80: "CUMULATIVE TONNAGE".

Leave Blank.

District Roadmaster ____________

Use Pencil

# FIELD SURVEY
## PROGRAM/MAJOR TRACKWORK REQUIREMENTS

Use Pencil

DOT-FR-30028
Date:

| CMD CODE | LINE CODE | SEQ. NO. | MILEPOST FROM | MILEPOST TO | TRACK | CLASS | WGT | N S | YEAR RAIL REPL. | EST. TIE LIFE | MAJ. SURF. CYCLE | NO. INT. SURF. | TYPE INT. SURF. | % TIE MAJ. SURF. | BAL. TYPE | CUMULATIVE TONNAGE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | |

FORM RECM-1

- M of W Economic Analysis Project -
Field Survey

## Section II
## Effects of Track and Traffic Characteristics on M of W Requirements

This section of the survey will require that District/Division personnel, based on their experience and judgment, supply answers to a number of questions relating to the physical behavior of track as affected by traffic conditions. Some of these questions are admittedly very generalized, however, responses should be as brief as possible.

1) Considering only the factors of rail weight and annual tonnage, (assuming all other factors affecting rail life are constant), if we assign a life of 1.0 to 132 lb. rail, what is your estimate of the relative lives of the other weights of rail for the annual tonnage densities shown.

| Annual Tonnage | Rail Wt. 136# | 132# | 119# | 112# | 90# |
|---|---|---|---|---|---|
| 10 MGT | 1.14 | 1.0 | .91 | .84 | .65 |
| 20 MGT | 1.13 | 1.0 | .87 | .80 | .60 |
| 30 MGT | 1.12 | 1.0 | .83 | .74 | .54 |
| 40 MGT | 1.10 | 1.0 | .78 | .68 | .46 |
| 50 MGT | 1.07 | 1.0 | .73 | .63 | .39 |

2) Considering only jointed track vs. CWR, and assigning a life of 1.0 to CWR, what is your estimate of the relative life of jointed rail?

Would this depend also on the annual tonnage?
If so, what is your estimate of the relative life of jointed for the tonnage densities shown below?

| | 10 MGT | 20 MGT | 30 MGT | 40 MGT | 50 MGT |
|---|---|---|---|---|---|
| JT | .857 | .807 | .752 | .695 | .629 |
| CWR | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |

3) Considering only the effects of freight train speeds, (all other factors being constant), and assigning a life of 1.0 to rail in 50 MPH territory, what is your estimate of relative rail life for the speeds shown below?

| 10 | 20 | 30 | 40 | 50 | 60 | 70 |
|---|---|---|---|---|---|---|
| 2.55 | 2.04 | 1.65 | 1.25 | 1.0 | .88 | .77 |

B-5

4) Considering only tangent track, have you experienced cases where rail life was foreshortened on steep grades?

If so, and assigning a life of 1.0 to rail in level territory, what is your estimate of the relative life of rail for the grades shown below?

| LEVEL TRACK | +1% | +1.5% | +2% | +2.5% | -1% | -1.5% | -2% | -2.5% |
|---|---|---|---|---|---|---|---|---|
| 1.0 | .94 | .86 | .76 | .65 | .96 | .90 | .81 | .71 |

5) Considering only the effects of track curvature, and assigning a life of 1.0 to rail in tangent track, what is your estimate of the relative life of rail in the curvature ranges shown below?

| | TANGENT TRACK | $1^o$-$3^o$ | $3^o$-$6^o$ | $6^o$-$10^o$ |
|---|---|---|---|---|
| without rail lubricators | 1.0 | .80 | .59 | .35 |
| with rail lubricators | 1.0 | .89 | .72 | .51 |

6) Considering only the effects of special metallurgy or heat treatment, and assigning a life of 1.0 to ordinary carbon, control-cooled curve rail, what is your estimate of the relative lives of these different type rails?

| | |
|---|---|
| carbon rail | 1.0 |
| High Silicon Rail | 1.47 |
| Heat treated | 1.37 |

7) If the life of rail in tangent main tracks (in terms of total millions of gross tons) is expressed as 'X', what is your general estimate of the remaining life of that rail in relay applications? e.g. .5X, etc. Briefly explain.

8) If the life of rail in tangent main track (MGT) is expressed as 'X', what is your estimate of the lives of associated other track materials listed below? (e.g. .5X etc.).

Open Track OTM

| | |
|---|---|
| Joint Bars | 1.07 |
| Track Bolts | .70 |
| Tie Plates | 1.73 |
| Spikes | .88 |
| Tie Plugs | .90 |
| Rail Anchors | 1.17 |
| Nut Locks | 1.09 |

Turnouts/Track Crossings

| | |
|---|---|
| Frogs | .71 |
| Switch points | .76 |
| Guard Rails | 1.20 |
| Stock rails | .70 |
| Switch Plates | 1.35 |
| Closure Rail | 1.11 |
| Other Turnout OTM | 1.43 |

9) Have you encountered specific cases where you felt that the incidence of traffic hauled in heavier cars (say 90-ton cars or heavier), with the associated increases in wheel/rail contact pressure, has shortened rail life over what you have been experiencing in territories without much heavy-car traffic? Briefly explain.

If you have had such experience with heavy-car territory, try to estimate the effects of heavy cars on rail life as follows: If the total life of rail in territory where only 50-ton cars operate was assigned a value of 1.0, what is your estimate of the relative rail life if the same traffic were hauled only in the car sizes shown?

| 50-Ton Cars | 70-Ton Cars | 100-Ton Cars | 125-Ton Cars |
|---|---|---|---|
| 1.0 | .87 | .74 | .61 |

10) If you have experience maintaining track in territory where unit trains operate, do you feel that such traffic has any separate or unique effect on rail life? Briefly explain.

If so, and assigning a value of 1.0 to the life of rail in territory where only mixed consist trains operate, what is your estimate of the relative rail life in the same territory if the same traffic were moved only in unit trains?

| | |
|---|---|
| mixed consist trains | 1.0 |
| unit trains | .91 |

Do you feel that operation of 6-axle locomotives is having any appreciable effect on rail life? ☐

Briefly explain. Try to estimate the relative effect, if any.

11) Considering only the effect of annual tonnage, estimate the service life (years) of standard treated crossties in tangent track territories having the annual tonnages shown.

| 10 MGT | 20 MGT | 30 MGT | 40 MGT | 50 MGT |
|---|---|---|---|---|
| 37.47 | 32.53 | 27.69 | 23.72 | 19.33 |

12) Considering only the effects of track curvature, and assigning a life of 1.0 to crossties in tangent track, what is your estimate of the relative tie life for the curvature ranges shown below?

| Tangent Track | 1°-3° | 3°-6° | 6°-10° |
|---|---|---|---|
| 1.0 | .88 | .71 | .52 |

13) If the life of crossties in CWR territory or in mid-rail positions in jointed territory is assigned a value of 1.0, what is your estimate of the relative life of joint ties?

| CWR or Mid-Rail | 1.0 |
|---|---|
| Joint Ties | .557 |

14) Considering tangent track, have you experienced cases where tie life was foreshortened on steep grades?

If so, and assigning a life of 1.0 to ties in level territory, what is your estimate of the relative life of tie for the grades shown below?

| LEVEL TRACK | +1% | +1.5% | +2% | +2.5% | -1% | -1.5% | -2% | -2.5% |
|---|---|---|---|---|---|---|---|---|
| 1.0 | .92 | .83 | .74 | .70 | .94 | .88 | .80 | .74 |

15) Considering only the effects of freight train speeds, (all other factors being constant), and assigning a life of 1.0 to ties in 50 MPH territory, what is your estimate of relative tie life for the speeds shown below?

| 10 | 20 | 30 | 40 | 50 | 60 | 70 |
|---|---|---|---|---|---|---|
| 2.09 | 1.90 | 1.39 | 1.0 | 1.0 | .999 | .899 |

16) Have you encountered specific cases where you felt that the incidence of traffic hauled in heavier cars (say 90-ton cars or heavier), with the associated increase in track deflection, has shortened tie life over what you have been experiencing in territories without much heavy-car traffic? Briefly explain.

16) cont.

If you have had such experience with heavy-car territory, try to estimate the effects of heavy cars on tie life as follows: If the total life of ties in territory where only 50-ton cars operate was assigned a value of 1.0, what is your estimate of the relative tie life if the same traffic were hauled only in the car sizes shown?

| 50-Ton Cars | 70-Ton Cars | 100-Ton Cars | 125-Ton Cars |
|---|---|---|---|
| 1.0 | .89 | .76 | .64 |

17) Do you feel that operation of 6-axle locomotives is having any appreciable effect on tie life? ☐

Briefly explain. Try to estimate the relative effect, if any.

18) For the six categories of track support listed below, and assigning a value of 1.0 to the life of crossties in the territory described by the first category, estimate the relative life of crossties in the remaining categories.

| Class | | Life |
|---|---|---|
| 1 | Good Ballast, Good Drainage, Stable Subgrade | 1.0 |
| 2 | Good Ballast, Good Drainage, Unstable Subgrade | .82 |
| 3 | Good Ballast, Poor Drainage, Stable Subgrade | .74 |
| 4 | Foul Ballast, Poor Drainage, Fair Subgrade | .60 |
| 5 | Foul Ballast, Poor Drainage, Poor/Unstable Subgrade | .46 |
| 6 | Foul Ballast (due to sand), Good Drainage, Stable Subgrade | .69 |

19) Considering only the effects of annual tonnage, estimate the major surfacing cycle (in years) required in territories with the ranges of annual tonnage shown below.

| | 5-10 MGT | 10-20 MGT | 20-30 MGT | 30-40 MGT | 40-50 MGT | 50-60 MGT |
|---|---|---|---|---|---|---|
| Cycle Length | 13.05 | 11.58 | 9.69 | 8.13 | 6.72 | 5.36 |
| Number of intermediate surfacings | 1.87 | 1.90 | 2.0 | 1.93 | 1.91 | 1.81 |
| Type of intermediate surfacings | B | B | B | B | B | B |

19) cont.

If you feel that intermediate surfacings are required, indicate the number of such surfacings between each major surfacing and the type of intermediate surfacing.

Type A = full (3") lift

Type B = minor (1") lift

20) Considering only the effects of rail weight (all other factors being constant) and assigning a surfacing cycle length of 1.0 to 132 LB territory, estimate the relative surfacing cycle lengths for the rail weights shown below.

| | Rail Wt. | | | | |
|---|---|---|---|---|---|
| | 136# | 132# | 119# | 112# | 90# |
| Cycle length | 1.03 | 1.0 | .89 | .79 | .58 |

21) IF the major surfacing cycle in jointed rail territory is expressed as 'X' years, what is your estimate of cycle length in CWR territory, e.g. 1.25 X, etc. Briefly explain.

1.70

22) Considering tangent track, have you experienced cases where surfacing cycle length life was foreshortened on steep grades?

If so, and assigning a life of 1.0 to surfacing cycle length in level territory, what is your estimate of the relative surfacing cycle length for the grades shown below?

| LEVEL TRACK | +1% | +1.5% | +2% | +2.5% | -1% | -1.5% | -2% | -2.5% |
|---|---|---|---|---|---|---|---|---|
| 1.0 | .94 | .85 | .74 | .67 | .96 | .89 | .77 | .72 |

23) Have you encountered specific cases where you felt that the incidence of traffic hauled in heavier cars (say 90-ton cars or heavier), with the associated increase in track deflection, has shortened surfacing cycles over what you have been experiencing in territories without much heavy-car traffic? Briefly explain.

24) For the six categories of track support listed on the next page, and assigning a value of 1.0 to the major surfacing cycle length in the territory described by the first category, estimate the relative

24) cont.

major surfacing cycle length in the remaining categories.

| Class | | Life |
|---|---|---|
| 1 | Good Ballast, Good Drainage, Stable Subgrade | 1.0 |
| 2 | Good Ballast, Good Drainage, Unstable Subgrade | .70 |
| 3 | Good Ballast, Poor Drainage, Stable Subgrade | .73 |
| 4 | Foul Ballast, Poor Drainage, Fair Subgrade | .59 |
| 5 | Foul Ballast, Poor Drainage, Poor/Unstable Subgrade | .40 |
| 6 | Foul Ballast (due to sand), Good Drainage, Stable Subgrade | .68 |

25) Considering only the effects of freight train speeds, (all other factors being constant), and assigning a surfacing cycle length of 1.0 in 50 MPH territory, what is your estimate of relative surfacing. cycle length for the speeds shown below?

| 10 | 20 | 30 | 40 | 50 | 60 | 70 |
|---|---|---|---|---|---|---|
| 2.17 | 1.75 | 1.40 | 1.14 | 1.0 | .88 | .74 |

26) If you have experience maintaining track in territory where unit trains operate, do you feel that such traffic has any separate or unique effect on surfacing cycle length? Briefly explain.

If so, and assigning a value of 1.0 to cycle length in territory where <u>only</u> mixed consist trains operate, what is your estimate of the relative surfacing cycle length in the same territory if the same traffic were moved only in unit trains?

| | |
|---|---|
| mixed consist trains | 1.0 |
| unit trains | .90 |

Do you feel that operation of 6-axle locomotives is having any appreciable effect on surfacing cycle length?

Briefly explain. Try to estimate the relative effect, if any.

27) In territory where passenger trains operate, are surfacing cycles different than if no passenger trains were present? YES

If so, do you feel this is because of higher passenger speeds (if any)? YES Briefly explain.

If passenger and freight speeds are the same, would there still be a difference in surfacing requirements? YES Briefly explain.

RIDE QUALITY

28) Are there main track territories in your district where undercutting or plowing/sledding should be accomplished (along with ballast cleaning/replacement) on a relatively definite cycle? [ ]

If so, please indicate below.

| MP FROM - MP TO | FREQUENCY OF UNDERCUT AND SURFACE | PLOWING/SLEDDING & SURFACING |
|---|---|---|
| | | |

Division ________________ Date ________________

M of W Economic Analysis Project
Field Survey

Section III

- Ordinary Track Maintenance and Other Requirements -

## General

Ordinary or Routine maintenance may generally be divided into two categories: Track maintenance and non-track maintenance. Non-track costs would include items such as clearing ditches and culverts, fence repairs, weed control, removal of snow, ice, and sand, and various other routine (housekeeping) activities.

Track-related routine maintenance would include the items listed below.

- spot tamping and lining
- spot tie replacement
- gauging & adjusting anchors
- reparing insulated joints
- weld grinding
- driving down spikes
- joint lubrication
- install new or reformed joint bar
- renew/tighten track bolts
- repair wheel burns
- ultrasonic inspection
- replace defective/failed rails
- rail end welding
- rail surface grinding

## Questions

1) Approximately how many track miles in each of the following categories exist on your division?

A. Primary main

B. Secondary main

C. Branch tracks

D. Yard tracks (see Section II responses)

E. Remaining "siding" trackage

2) Considering the mileage and traffic conditions currently existing on your division, and assuming that adequate "program" track maintenance (rail relay, tie renewal, major and intermediate surfacing and ballasting) is being carried out. What is your estimate of the labor force required to handle only the routine track maintenance activities described above. You may present this in the best way you see fit, however, your response should describe the organization and levels of necessary manpower. You should also, if possible, state these requirements on a man hr. per track mile basis (for each labor category) for the track categories above.

3) The concept of so-called "fixed" costs has presented some difficult problems in M of W cost analysis over the years. Cost analysts seek to identify these costs (those which are essentially independent of changes in traffic volume) in order to provide rate makers with information about the degree of profitability of a particular service at a particular price. Theoretically, if we would incur these "fixed" costs whether we hauled an additional carload of traffic or not, we would be better off taking the traffic even if it contributed only marginally to covering its portion of fixed costs. Many other factors of course enter into such a decision, however, the concept of "fixed" and "variable" costs nevertheless plays an important part in railroad pricing decisions. Some obvious examples of essentially fixed costs might be: property taxes, some types of interest charges, some portion of depreciation expenses, some inspection costs incurred as a result of legal requirements, etc.

In the M of W area, there would seem to be two definitions of fixed cost which might apply (with perhaps very different implications). We would like you to attempt to specify which costs you would consider as fixed using both definitions. To describe cost areas, you should use PACE EIN'S (just the number will do), or if you feel that perhaps only some <u>portion</u> of costs covered by a particular EIN are fixed, please give a short explanation.

Defintion I: "Fixed M of W costs are those which would have to be incurred if <u>any</u> traffic is to be moved".

3) cont.

Definition II: "If there were no traffic today, but we must be prepared to support our typical volume of traffic at any time, the M of W costs incurred would be considered our "fixed" costs".

Division ____________ Date: ____________

B & B Supervisor ____________

- M of W Economic Analysis Project -
Field Survey

Section IV

- Structures Costs -

General:

Cost analysts have traditionally treated structures maintenance costs as "fixed" with respect to volume and type of traffic. The general rationale has always been that unless the design limits of the structure are exceeded, most annual maintenance would be attributable to the elements, accidents, etc. While it is recognized that structures or their specific components do wear out, the service lives involved are long enough to have precluded quantifying any specific effects which, for instance, annual tonnage may have on structure life/cost. This section of the survey is an attempt to draw upon the experience and judgment of the B & B Supervisor to help determine if refinements in structures costing can be made and, if so, what procedures would be required.

Questions:

1) Have you been able to observe changes in wear and stress patterns on structures which you believe can be attributed to heavier wheel loads? ☐

If so, please explain. Consider concrete, steel, and timber structures.

2) In the same way, has the operation of 6-axle locomotives materially changed structural wear? ☐

If so, please explain. Consider concrete, steel, and timber structures.

3) Do you feel that maintenance of structures is materially affected by the presence of passenger train traffic? ☐

If so, please explain.

4) For structures of the same type, size, condition, and climatic environment, do you believe there is a relationship between annual maintenance and annual tonnage?

If so, describe which areas of structures maintenance you believe to be affected by annual tonnage volume.

5) If you feel that, all other factors being equal, annual tonnage does have an effect on annual maintenance or on actual life and if we assign a value of 1.0 to the maintenance requirements or life of structures in territory with 20-30 million gross tons of traffic annually, can you estimate how the specific areas of maintenance which you described in (4) above would be relatively affected by the different tonnage volumes shown below.

| | Concrete | | | | | Timber | | | | | Steel | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Specific Maintenance Area | 5-10 MGT | 10-20 MGT | 20-30 MGT | 30-40 MGT | 40-50 MGT | 5-10 MGT | 10-20 MGT | 20-30 MGT | 30-40 MGT | 40-50 MGT | 5-10 MGT | 10-20 MGT | 20-30 MGT | 30-40 MGT | 40-50 MGT |
| | | | 1.0 | | | | | 1.0 | | | | | 1.0 | | |
| | | | 1.0 | | | | | 1.0 | | | | | 1.0 | | |
| | | | 1.0 | | | | | 1.0 | | | | | 1.0 | | |
| | | | 1.0 | | | | | 1.0 | | | | | 1.0 | | |
| | | | 1.0 | | | | | 1.0 | | | | | 1.0 | | |

6) For structures of the same type, size, condition, and climatic environment, do you believe there is a relationship between annual maintenance and train speed?

If so, describe which areas of structures maintenance you believe to be affected by annual tonnage volume.

7) If you feel that all other factors being equal, train speed does have an effect on annual maintenance or on actual life, and if we assign a value of 1.0 to the maintenance requirements or life of structures in territory with 50 mph train speeds can you estimate how the specific areas of maintenance which you described in (4) above would be relatively affected by the different speeds shown below.

7) cont.

| Specific Maintenance Area | Concrete | | | | | | | Timber | | | | | | | Steel | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 10 MPH | 20 MPH | 30 MPH | 40 MPH | 50 MPH | 60 MPH | 70 MPH | 10 MPH | 20 MPH | 30 MPH | 40 MPH | 50 MPH | 60 MPH | 70 MPH | 10 MPH | 20 MPH | 30 MPH | 40 MPH | 50 MPH | 60 MPH | 70 MPH |
| | | | | | 1.0 | | | | | | | 1.0 | | | | | | | 1.0 | | |
| | | | | | 1.0 | | | | | | | 1.0 | | | | | | | 1.0 | | |
| | | | | | 1.0 | | | | | | | 1.0 | | | | | | | 1.0 | | |
| | | | | | 1.0 | | | | | | | 1.0 | | | | | | | 1.0 | | |
| | | | | | 1.0 | | | | | | | 1.0 | | | | | | | 1.0 | | |

8) Do you feel that traffic conditions (speed, tonnage, wheel loads) materially affect maintenance of any of the following:

Tunnels ☐ If so, explain briefly.

Culverts ☐ If so, explain briefly.

Fences, snowsheds, signs ☐ If so, explain briefly.

Stations, office buildings ☐ If so, explain briefly.

## Section V

### - Available On-Track Time Estimates -

On the attached Division Map, indicate general variations in available on-track time for main line rail laying, surfacing, and tie renewal operations as follows:

1) For surfacing and tie renewal operations, indicate approximate changes in available on-track time with a solid line using:

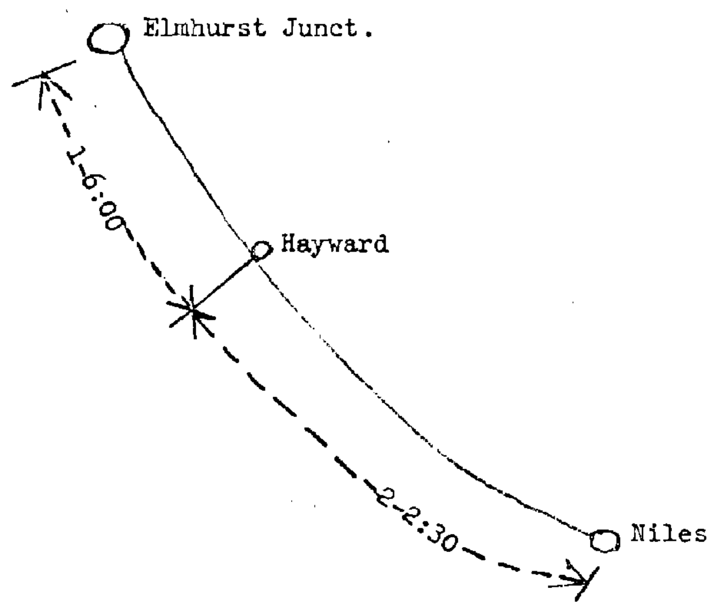
   Red pencil for territory where available on track time is approximately 6 hrs. per day.

   Yellow pencil for territory where available on track time is approximately 5 hrs. per day.

   Blue pencil for territory where available on-track time is approximately 4 hrs. per day.

   Green pencil for territory where available on-track time is approximately 3 hrs. per day.

2) For rail laying operations, indicate approximate changes in available on-track time with a dashed line using: Black pencil and indicating variations as shown in the example below.




In the example 1-6:00 would mean that approximately one continuous 6-hour period of on-track time was generally available for rail laying operations between Elmhurst Jct. and Hayward, and that two separate 2-hr. 30 minute periods of on-track time were available for operations between Hayward and Niles. Of course other variations may apply in any particular territory.

# APPENDIX C

TRACK COMPONENT LIFE REPORTS

| LN CD | SEG | MP FR | MP TO | WGT | TYP | CD | MT | CURVE | O | GRADE | BLLST TS | UC | PS | M | CN TRK RAIL | TIME | TIE | T C | LNKE | LNKW | ANNUAL MGT | EST RAIL LIFE-MGT | EST TIE LIFE-YRS | EST SURF LIFE-YRS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C | 27 | 539.090 | 539.115 | 112 | JT | SH | | 060000 | | -2 | 3B | 5 | | X | 1.5 | 2.5 | 4.0 | 0 | 0344 | 0343 | 5.007 | 112 | 34 | 12 |
| C | 27 | 539.119 | 539.220 | 112 | JT | SH | | 000000 | | -2 | 3B | 5 | | X | 1.5 | 2.5 | 4.0 | 0 | 0344 | 0343 | 5.007 | 282 | 48 | 12 |
| C | 27 | 539.220 | 539.230 | 112 | JT | SH | | 100000 | | -2 | 3B | 5 | | X | 1.5 | 2.5 | 4.0 | 0 | 0344 | 0343 | 5.007 | 37 | 27 | 12 |
| C | 27 | 539.230 | 539.295 | 112 | WR | SH | | 100000 | | -2 | 3B | 5 | | X | 1.5 | 2.5 | 4.0 | 0 | 0344 | 0343 | 5.007 | 37 | 27 | 12 |
| C | 27 | 539.295 | 539.300 | 112 | WR | SH | | 000000 | | -2 | 3B | 5 | | X | 1.5 | 2.5 | 4.0 | 0 | 0344 | 0343 | 5.007 | 262 | 50 | 12 |
| C | 27 | 539.300 | 539.398 | 110 | JT | SH | | 042000 | | -2 | 3B | 5 | | X | 1.5 | 2.5 | 4.0 | 0 | 0344 | 0343 | 5.007 | 176 | 38 | 11 |
| C | 27 | 539.398 | 539.410 | 110 | JT | SH | | 060000 | | -2 | 3B | 5 | | X | 1.5 | 2.5 | 4.0 | 0 | 0344 | 0343 | 5.007 | 269 | 48 | 11 |
| C | 27 | 539.410 | 540.070 | 112 | WR | SH | | 000000 | | -2 | 3B | 5 | | X | 1.5 | 2.5 | 4.0 | 0 | 0344 | 0343 | 5.007 | 282 | 50 | 12 |
| C | 27 | 540.070 | 540.080 | 119 | JT | N | | 000000 | | -2 | 3B | 5 | | X | 1.5 | 2.5 | 4.0 | 0 | 0344 | 0343 | 5.007 | 291 | 48 | 12 |
| C | 27 | 540.080 | 540.300 | 112 | WR | SH | | 000000 | | -2 | 3B | 5 | | X | 1.5 | 2.5 | 4.0 | 0 | 0344 | 0343 | 5.007 | 282 | 50 | 12 |
| C | 27 | 540.300 | 540.440 | 112 | WR | SH | | 000000 | | -2 | 3B | 5 | | X | 1.5 | 2.5 | 4.0 | 0 | 0342 | 0341 | 5.007 | 252 | 44 | 10 |
| C | 27 | 540.440 | 540.450 | 119 | JT | N | | 000000 | | -2 | 3B | 5 | | X | 1.5 | 2.5 | 4.0 | 0 | 0342 | 0341 | 5.007 | 261 | 44 | 10 |
| C | 27 | 540.450 | 540.670 | 112 | WR | SH | | 000000 | | -2 | 3B | 5 | | X | 1.5 | 2.5 | 4.0 | 0 | 0342 | 0341 | 5.007 | 252 | 44 | 10 |
| C | 27 | 540.670 | 541.003 | 112 | JT | SH | | 040000 | | -2 | 3B | 5 | | X | 1.5 | 2.5 | 4.0 | 0 | 0342 | 0341 | 5.007 | 164 | 34 | 10 |
| C | 27 | 541.003 | 541.010 | 112 | JT | SH | | 000000 | | -2 | 3B | 5 | | X | 1.5 | 2.5 | 4.0 | 0 | 0342 | 0341 | 5.007 | 252 | 44 | 10 |
| C | 27 | 541.010 | 541.020 | 112 | WR | SH | | 000000 | | -2 | 3B | 5 | | X | 1.5 | 2.5 | 4.0 | 0 | 0342 | 0341 | 5.007 | 252 | 44 | 10 |
| C | 27 | 541.020 | 541.210 | 112 | JT | SH | | 000000 | | -2 | 3B | 5 | | X | 1.5 | 2.5 | 4.0 | 0 | 0342 | 0341 | 5.007 | 252 | 44 | 10 |
| C | 27 | 541.210 | 541.405 | 112 | JT | SH | | 040000 | | -2 | 3B | 5 | | X | 1.5 | 2.5 | 4.0 | 0 | 0342 | 0341 | 5.007 | 164 | 34 | 10 |
| C | 27 | 541.405 | 541.410 | 112 | JT | SH | | 000000 | | -2 | 3B | 5 | | X | 1.5 | 2.5 | 4.0 | 0 | 0342 | 0341 | 5.007 | 252 | 44 | 10 |
| C | 27 | 541.410 | 543.070 | 112 | WR | SH | | 000000 | | -2 | 3B | 5 | | X | 1.5 | 2.5 | 4.0 | 0 | 0342 | 0341 | 5.007 | 252 | 44 | 10 |
| C | 27 | 543.070 | 543.080 | 112 | WR | SH | | 040000 | | -2 | 3B | 5 | | X | 1.5 | 2.5 | 4.0 | 0 | 0342 | 0341 | 5.007 | 164 | 34 | 10 |
| C | 27 | 543.080 | 543.185 | 112 | JT | SH | | 040000 | | -2 | 3B | 5 | | X | 1.5 | 2.5 | 4.0 | 0 | 0342 | 0341 | 5.007 | 164 | 34 | 10 |
| C | 27 | 543.185 | 543.260 | 112 | JT | SH | | 000000 | | -2 | 3B | 5 | | X | 1.5 | 2.5 | 4.0 | 0 | 0342 | 0341 | 5.007 | 252 | 44 | 10 |
| C | 27 | 543.260 | 543.360 | 112 | JT | SH | | 040000 | | -2 | 3B | 5 | | X | 1.5 | 2.5 | 4.0 | 0 | 0342 | 0341 | 5.007 | 164 | 34 | 10 |
| C | 27 | 543.360 | 543.366 | 112 | WR | SH | | 040000 | | -2 | 3B | 5 | | X | 1.5 | 2.5 | 4.0 | 0 | 0342 | 0341 | 5.007 | 164 | 34 | 10 |
| C | 27 | 543.366 | 543.650 | 112 | WR | SH | | 000000 | | -2 | 3B | 5 | | X | 1.5 | 2.5 | 4.0 | 0 | 0342 | 0341 | 5.007 | 252 | 44 | 10 |
| C | 27 | 543.650 | 543.690 | 112 | JT | SH | | 000000 | | -2 | 3B | 5 | | X | 1.5 | 2.5 | 4.0 | 0 | 0342 | 0341 | 5.007 | 252 | 44 | 10 |
| C | 27 | 543.690 | 543.700 | 119 | JT | N | | 000000 | | -2 | 3B | 5 | | X | 1.5 | 2.5 | 4.0 | 0 | 0342 | 0341 | 5.007 | 261 | 44 | 10 |
| C | 27 | 543.700 | 543.770 | 112 | JT | SH | | 000000 | | -2 | 3B | 5 | | X | 1.5 | 2.5 | 4.0 | 0 | 0342 | 0341 | 5.007 | 252 | 44 | 10 |
| C | 27 | 543.770 | 543.790 | 119 | JT | N | | 000000 | | -2 | 3B | 5 | | X | 1.5 | 2.5 | 4.0 | 0 | 0342 | 0341 | 5.007 | 261 | 44 | 10 |
| C | 27 | 543.790 | 543.800 | 112 | JT | SH | | 000000 | | -2 | 3B | 5 | | X | 1.5 | 2.5 | 4.0 | 0 | 0342 | 0341 | 5.007 | 252 | 44 | 10 |
| C | 27 | 543.800 | 543.906 | 112 | JT | SH | | 050000 | | -2 | 3B | 5 | | X | 1.5 | 2.5 | 4.0 | 0 | 0342 | 0341 | 5.007 | 127 | 32 | 10 |
| C | 27 | 543.906 | 543.940 | 117 | JT | SH | | 000000 | | -2 | 3B | 5 | | X | 1.5 | 2.5 | 4.0 | 0 | 0342 | 0341 | 5.007 | 252 | 44 | 10 |
| C | 27 | 543.940 | 544.200 | 90 | JT | N | | 000000 | | -2 | 3B | 5 | | X | 1.5 | 2.5 | 4.0 | 0 | 0342 | 0341 | 5.007 | 241 | 44 | 10 |
| C | 27 | 544.200 | 544.710 | 90 | JT | N | | 000000 | | -2 | 3B | 5 | | X | 2.5 | 2.5 | 5.0 | 0 | 0340 | 0339 | 5.007 | 257 | 46 | 10 |
| C | 27 | 544.710 | 544.805 | 90 | JT | N | | 020000 | | -2 | 3B | 5 | | X | 2.5 | 2.5 | 5.0 | 0 | 0340 | 0339 | 5.007 | 190 | 40 | 10 |
| C | 27 | 544.805 | 545.030 | 90 | JT | N | | 000000 | | -2 | 3B | 5 | | X | 2.5 | 2.5 | 5.0 | 0 | 0340 | 0339 | 5.007 | 257 | 46 | 10 |
| C | 27 | 545.030 | 545.050 | 112 | JT | SH | | 000000 | | -2 | 3B | 5 | | X | 2.5 | 2.5 | 5.0 | 0 | 0340 | 0339 | 5.007 | 269 | 46 | 11 |
| C | 27 | 545.050 | 545.140 | 112 | JT | SH | | 050000 | | -2 | 3B | 5 | | X | 2.5 | 2.5 | 5.0 | 0 | 0340 | 0339 | 5.007 | 136 | 34 | 11 |
| C | 27 | 545.140 | 545.150 | 112 | JT | SH | | 060000 | | -2 | 3B | 5 | | X | 2.5 | 2.5 | 5.0 | 0 | 0340 | 0339 | 5.007 | 107 | 32 | 11 |
| C | 27 | 545.150 | 545.201 | 90 | JT | N | | 060000 | | -2 | 3B | 5 | | X | 2.5 | 2.5 | 5.0 | 0 | 0340 | 0339 | 5.007 | 103 | 32 | 10 |
| C | 27 | 545.201 | 545.540 | 90 | JT | N | | 000000 | | -2 | 3B | 5 | | X | 2.5 | 2.5 | 5.0 | 0 | 0340 | 0339 | 5.007 | 257 | 46 | 10 |
| C | 27 | 545.540 | 545.550 | 117 | JT | SH | | 000000 | | -2 | 3B | 5 | | X | 2.5 | 2.5 | 5.0 | 0 | 0340 | 0339 | 5.007 | 269 | 46 | 11 |
| C | 27 | 545.550 | 545.763 | 112 | JT | SH | | 040000 | | -2 | 3B | 5 | | X | 2.5 | 2.5 | 5.0 | 0 | 0340 | 0339 | 5.007 | 175 | 37 | 11 |
| C | 27 | 545.763 | 545.840 | 112 | JT | SH | | 000000 | | -2 | 3B | 5 | | X | 2.5 | 2.5 | 5.0 | 0 | 0340 | 0339 | 5.007 | 269 | 46 | 11 |
| C | 27 | 545.840 | 545.986 | 112 | JT | SH | | 040000 | | -2 | 3B | 5 | | X | 2.5 | 2.5 | 5.0 | 0 | 0340 | 0339 | 5.007 | 175 | 37 | 11 |
| C | 27 | 545.986 | 546.000 | 112 | JT | SH | | 000000 | | -2 | 3B | 5 | | X | 2.5 | 2.5 | 5.0 | 0 | 0340 | 0339 | 5.007 | 269 | 46 | 11 |
| C | 27 | 546.000 | 546.130 | 90 | JT | N | | 000000 | | -2 | 3B | 5 | | X | 2.5 | 2.5 | 5.0 | 0 | 0340 | 0339 | 5.007 | 257 | 46 | 10 |
| C | 27 | 546.130 | 546.250 | 113 | CWR | N | | 000000 | | -2 | 3B | 5 | | X | 2.5 | 2.5 | 5.0 | 0 | 0340 | 0339 | 5.007 | 382 | 47 | 13 |
| C | 27 | 546.250 | 546.331 | 113 | JT | SH | | 060000 | | -2 | 3B | 5 | | X | 2.5 | 2.5 | 5.0 | 0 | 0340 | 0339 | 5.007 | 107 | 32 | 11 |
| C | 27 | 546.331 | 546.350 | 113 | JT | SH | | 000000 | | -2 | 3B | 5 | | X | 2.5 | 2.5 | 5.0 | 0 | 0340 | 0339 | 5.007 | 269 | 46 | 11 |
| C | 27 | 546.350 | 546.429 | 90 | JT | N | | 020000 | | -2 | 3B | 5 | | X | 2.5 | 2.5 | 5.0 | 0 | 0340 | 0339 | 5.007 | 190 | 40 | 10 |
| C | 27 | 546.429 | 546.550 | 90 | JT | N | | 000000 | | -2 | 3B | 5 | | X | 2.5 | 2.5 | 5.0 | 0 | 0340 | 0339 | 5.007 | 257 | 46 | 10 |
| C | 27 | 546.550 | 546.560 | 112 | JT | SH | | 000000 | | -2 | 3B | 5 | | X | 2.5 | 2.5 | 5.0 | 0 | 0340 | 0339 | 5.007 | 269 | 46 | 11 |
| C | 27 | 546.560 | 546.659 | 112 | JT | SH | | 060000 | | -2 | 3B | 5 | | X | 2.5 | 2.5 | 5.0 | 0 | 0340 | 0339 | 5.007 | 107 | 32 | 11 |
| C | 27 | 546.659 | 546.660 | 112 | JT | SH | | 000000 | | -2 | 3B | 5 | | X | 2.5 | 2.5 | 5.0 | 0 | 0340 | 0339 | 5.007 | 269 | 46 | 11 |

FIGURE C-1

TRACK STRUCTURE COMPONENT LIFE REPORT

FIGURE C-2

TRACK STRUCTURE COMPONENT LIFE REPORT

| LN CD | SEQ | MP FR | MP TO | WGT | TYP | CD | MT | CURVE | O | GRADE | TS | BLLST UC | PS | M | ON TRK TIME RAIL | | TIE | T C | LNKE | LNKW | ANNUAL MGT | EST RAIL LIFE-MGT | EST TIE LIFE-YRS | EST SURF LIFE-YRS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 1 | 4.693 | 4.757 | 132 | WR | SH | | 000000 | | +2 | 3C | | | | 6.0 | .0 | 6.0 | 0 | 0435 | 0436 | 34.414 | 937 | 20 | 5 |
| A | 2 | 4.757 | 4.910 | 132 | WR | SH | | 000000 | | +1 | 3C | | | | 6.0 | .0 | 6.0 | 1 | 0435 | 0000 | 16.148 | 650 | 28 | 7 |
| A | 2 | 4.910 | 4.970 | 132 | JT | SH | | 000000 | | +1 | 3C | | | | 6.0 | .0 | 6.0 | 1 | 0435 | 0000 | 16.148 | 650 | 28 | 7 |
| A | 2 | 4.970 | 5.320 | 132 | JT | N | | 000000 | | +1 | 3C | | | | 6.0 | .0 | 6.0 | 1 | 0435 | 0000 | 16.148 | 650 | 28 | 7 |
| A | 2 | 5.320 | 5.386 | 132 | JT | N | | 013730 | | +1 | 3C | | | | 6.0 | .0 | 6.0 | 1 | 0435 | 0000 | 16.148 | 481 | 25 | 7 |
| A | 2 | 5.386 | 5.560 | 132 | JT | N | | 000000 | | +1 | 3C | | | | 6.0 | .0 | 6.0 | 1 | 0435 | 0000 | 16.148 | 650 | 28 | 7 |
| A | 2 | 5.560 | 5.600 | 132 | JT | N | | 013000 | | +1 | 3C | | | | 6.0 | .0 | 6.0 | 1 | 0435 | 0000 | 16.148 | 565 | 27 | 7 |
| A | 2 | 5.600 | 5.630 | 132 | JT | N | | 013000 | | +1 | 4C | | | | 6.0 | .0 | 6.0 | 1 | 0435 | 0000 | 16.148 | 565 | 24 | 6 |
| A | 2 | 5.630 | 5.700 | 132 | JT | N | | 005500 | | +1 | 4C | | | | 6.0 | .0 | 6.0 | 1 | 0435 | 0000 | 16.148 | 565 | 24 | 6 |
| A | 2 | 5.700 | 6.220 | 132 | JT | SH | | 005500 | | +1 | 4C | | | | 6.0 | .0 | 6.0 | 1 | 0435 | 0000 | 16.148 | 565 | 24 | 6 |
| A | 2 | 6.220 | 6.269 | 132 | JT | SH | | 010000 | | +1 | 4C | | | | 6.0 | .0 | 6.0 | 1 | 0435 | 0000 | 16.148 | 565 | 24 | 6 |
| A | 2 | 6.269 | 6.600 | 132 | JT | SH | | 002000 | | +1 | 4C | | | | 6.0 | .0 | 6.0 | 1 | 0435 | 0000 | 16.148 | 650 | 25 | 6 |
| A | 2 | 6.600 | 6.970 | 132 | JT | SH | | 002300 | | +1 | 4C | | | | 6.0 | .0 | 6.0 | 1 | 0437 | 0000 | 16.148 | 523 | 20 | 5 |
| A | 2 | 6.970 | 7.220 | 132 | JT | N | | 000000 | | +1 | 4C | | | | 6.0 | .0 | 6.0 | 1 | 0437 | 0000 | 16.148 | 523 | 20 | 5 |
| A | 2 | 7.220 | 7.240 | 136 | WR | N | | 000000 | | +1 | 4C | | | | 6.0 | .0 | 6.0 | 1 | 0437 | 0000 | 16.148 | 539 | 21 | 5 |
| A | 2 | 7.240 | 7.350 | 132 | JT | N | | 000000 | | +1 | 4C | | | | 6.0 | .0 | 6.0 | 1 | 0437 | 0000 | 16.148 | 523 | 20 | 5 |
| A | 2 | 7.350 | 7.419 | 132 | JT | N | | 010000 | | +1 | 4C | | | | 6.0 | .0 | 6.0 | 1 | 0437 | 0000 | 16.148 | 455 | 19 | 5 |
| A | 2 | 7.419 | 7.730 | 132 | JT | N | | 000000 | | +1 | 4C | | | | 6.0 | .0 | 6.0 | 1 | 0437 | 0000 | 16.148 | 523 | 20 | 5 |
| A | 2 | 7.730 | 7.770 | 132 | WR | SH | | 000000 | | +1 | 4C | | | | 6.0 | .0 | 6.0 | 1 | 0437 | 0000 | 16.148 | 523 | 20 | 5 |
| A | 2 | 7.770 | 7.810 | 132 | JT | N | | 000000 | | +1 | 4C | | | | 6.0 | .0 | 6.0 | 1 | 0437 | 0000 | 16.148 | 523 | 20 | 5 |
| A | 2 | 7.810 | 7.840 | 136 | WR | N | | 000000 | | +1 | 4C | | | | 6.0 | .0 | 6.0 | 1 | 0437 | 0000 | 16.148 | 539 | 21 | 5 |
| A | 2 | 7.140 | 7.990 | 132 | JT | N | | 000000 | | +1 | 4C | | | | 6.0 | .0 | 6.0 | 1 | 0437 | 0000 | 16.148 | 523 | 20 | 5 |
| A | 2 | 7.990 | 8.910 | 112 | JT | N | | 000000 | | +1 | 4C | | | | 6.0 | .0 | 6.0 | 1 | 0437 | 0000 | 16.148 | 469 | 20 | 4 |
| A | 2 | 8.910 | 8.940 | 136 | CWR | N | | 000000 | | +1 | 4C | | | | 6.0 | .0 | 6.0 | 1 | 0437 | 0000 | 16.148 | 766 | 21 | 6 |
| A | 2 | 8.940 | 9.330 | 132 | JT | N | | 000000 | | +1 | 4C | | | | 6.0 | .0 | 6.0 | 1 | 0437 | 0000 | 16.148 | 523 | 20 | 5 |
| A | 2 | 9.330 | 9.360 | 136 | CWR | N | | 000000 | | +1 | 4C | | | | 6.0 | .0 | 6.0 | 1 | 0437 | 0000 | 16.148 | 766 | 21 | 6 |
| A | 2 | 9.360 | 9.550 | 132 | JT | N | | 000000 | | +1 | 4C | | | | 6.0 | .0 | 6.0 | 1 | 0437 | 0000 | 16.148 | 523 | 20 | 5 |
| A | 2 | 9.550 | 9.580 | 136 | CWR | N | | 000000 | | +1 | 4C | | | | 6.0 | .0 | 6.0 | 1 | 0437 | 0000 | 16.148 | 766 | 21 | 6 |
| A | 2 | 9.580 | 10.000 | 132 | JT | N | | 000000 | | +1 | 4C | | | | 6.0 | .0 | 6.0 | 1 | 0437 | 0000 | 16.148 | 523 | 20 | 5 |
| A | 2 | 10.000 | 10.040 | 132 | JT | N | | 000000 | | +1 | 1C | | | | 6.0 | .0 | 6.0 | 1 | 0437 | 0000 | 16.148 | 523 | 30 | 8 |
| A | 2 | 10.040 | 10.070 | 136 | CWR | N | | 000000 | | +1 | 1C | | | | 6.0 | .0 | 6.0 | 1 | 0437 | 0000 | 16.148 | 766 | 33 | 9 |
| A | 2 | 10.070 | 10.660 | 132 | JT | N | | 000000 | | +1 | 1C | | | | 6.0 | .0 | 6.0 | 1 | 0437 | 0000 | 16.148 | 523 | 30 | 8 |
| A | 2 | 10.660 | 10.690 | 136 | WR | N | | 000000 | | +1 | 1C | | | | 6.0 | .0 | 6.0 | 1 | 0437 | 0000 | 16.148 | 539 | 32 | 8 |
| A | 2 | 10.690 | 11.030 | 132 | JT | N | | 000000 | | +1 | 1C | | | | 6.0 | .0 | 6.0 | 1 | 0437 | 0000 | 16.148 | 523 | 30 | 8 |
| A | 2 | 11.030 | 11.230 | 132 | JT | N | | 014000 | | +1 | 1C | | | | 6.0 | .0 | 6.0 | 1 | 0437 | 0000 | 16.148 | 455 | 28 | 8 |
| A | 2 | 11.230 | 11.310 | 132 | JT | N | | 000000 | | +1 | 1C | | | | 6.0 | .0 | 6.0 | 1 | 0437 | 0000 | 16.148 | 523 | 30 | 8 |
| A | 2 | 11.310 | 11.650 | 136 | CWR | N | | 000000 | | +1 | 1C | | | | 6.0 | .0 | 6.0 | 1 | 0437 | 0000 | 16.148 | 766 | 33 | 9 |
| A | 2 | 11.650 | 11.670 | 132 | JT | N | | 000000 | | +1 | 1C | | | | 6.0 | .0 | 6.0 | 1 | 0437 | 0000 | 16.148 | 523 | 30 | 8 |
| A | 2 | 11.670 | 12.270 | 136 | CWR | N | | 000000 | | +1 | 1C | | | | 6.0 | .0 | 6.0 | 1 | 0437 | 0000 | 16.148 | 766 | 33 | 9 |
| A | 2 | 12.270 | 12.290 | 136 | JT | N | | 000000 | | +1 | 1C | | | | 6.0 | .0 | 6.0 | 1 | 0437 | 0000 | 16.148 | 539 | 32 | 8 |
| A | 2 | 12.290 | 13.060 | 136 | CWR | N | | 000000 | | +1 | 1C | | | | 6.0 | .0 | 6.0 | 1 | 0437 | 0000 | 16.148 | 766 | 33 | 9 |
| A | 2 | 13.060 | 13.090 | 136 | JT | N | | 003600 | | +1 | 1C | | | | 6.0 | .0 | 6.0 | 1 | 0437 | 0000 | 16.148 | 469 | 31 | 8 |
| A | 2 | 13.090 | 13.630 | 136 | CWR | N | | 003600 | | +1 | 1C | | | | 6.0 | .0 | 6.0 | 1 | 0437 | 0000 | 16.148 | 666 | 32 | 9 |
| A | 2 | 13.630 | 13.670 | 136 | JT | N | | 000000 | | +1 | 1C | | | | 6.0 | .0 | 6.0 | 1 | 0437 | 0000 | 16.148 | 539 | 32 | 8 |
| A | 2 | 13.670 | 14.510 | 132 | JT | N | | 000000 | | +1 | 1C | | | | 6.0 | .0 | 6.0 | 1 | 0437 | 0000 | 16.148 | 523 | 30 | 8 |
| A | 2 | 14.510 | 14.550 | 136 | JT | N | | 000000 | | +1 | 1C | | | | 6.0 | .0 | 6.0 | 1 | 0437 | 0000 | 16.148 | 539 | 32 | 8 |
| A | 2 | 14.550 | 14.820 | 132 | JT | N | | 000000 | | +1 | 1C | | | | 6.0 | .0 | 6.0 | 1 | 0437 | 0000 | 16.148 | 523 | 30 | 8 |
| A | 2 | 14.820 | 14.890 | 136 | WR | N | HS | 003600 | | +1 | 1C | | | | 6.0 | .0 | 6.0 | 1 | 0437 | 0000 | 16.148 | 699 | 31 | 8 |
| A | 2 | 14.890 | 15.000 | 132 | JT | N | | 003600 | | +1 | 1C | | | | 6.0 | .0 | 6.0 | 1 | 0437 | 0000 | 16.148 | 455 | 28 | 8 |
| A | 2 | 15.000 | 15.240 | 132 | JT | N | | 003600 | | +1 | 1C | | | | 6.0 | .0 | 6.0 | 1 | 0439 | 0000 | 16.148 | 418 | 26 | 7 |
| A | 2 | 15.240 | 15.260 | 136 | JT | SH | | 003600 | | +1 | 1C | | | | 6.0 | .0 | 6.0 | 1 | 0439 | 0000 | 16.148 | 430 | 28 | 7 |
| A | 2 | 15.260 | 15.270 | 136 | JT | N | | 003600 | | +1 | 1C | | | | 6.0 | .0 | 6.0 | 1 | 0439 | 0000 | 16.148 | 430 | 28 | 7 |
| A | 2 | 15.270 | 16.070 | 132 | JT | N | | 003600 | | +1 | 1C | | | | 6.0 | .0 | 6.0 | 1 | 0439 | 0000 | 16.148 | 418 | 26 | 7 |
| A | 2 | 16.070 | 16.600 | 136 | JT | N | | 003600 | | +1 | 1C | | | | 6.0 | .0 | 6.0 | 1 | 0439 | 0000 | 16.148 | 430 | 28 | 7 |
| A | 2 | 16.600 | 17.040 | 136 | JT | N | | 000000 | | +1 | 1C | | | | 6.0 | .0 | 6.0 | 1 | 0441 | 0000 | 16.148 | 478 | 28 | 7 |
| A | 2 | 17.040 | 17.060 | 136 | WR | N | | 000000 | | +1 | 1C | | | | 6.0 | .0 | 6.0 | 1 | 0441 | 0000 | 16.148 | 478 | 30 | 7 |

FIGURE C-3

TRACK STRUCTURE COMPONENT LIFE REPORT

| LN CD | SEG | MP FR | MP TO | WGT | TYP | CD | MT | CURVE | O | GRADE | TS | BLLST UC | PS | M | ON TRK TIME RAIL | | TIE | T C | LNKE | LNKW | ANNUAL MGT | EST RAIL LIFE-MGT | EST TIE LIFE-YRS | EST SURF LIFE-YRS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 57 | 428.370 | 428.560 | 136 | CWR | N | | 000000 | | +2 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 840 | 27 | 8 |
| A | 57 | 428.560 | 428.600 | 136 | CWR | N | | 020200 | | +2 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 622 | 25 | 8 |
| A | 57 | 428.600 | 428.630 | 136 | CWR | N | | 020200 | | +2 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 622 | 25 | 6 |
| A | 57 | 428.630 | 428.826 | 132 | JT | N | | 020200 | | +2 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 425 | 22 | 7 |
| A | 57 | 428.826 | 430.610 | 132 | JT | N | | 000000 | | +2 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 574 | 25 | 7 |
| A | 57 | 430.610 | 431.840 | 132 | JT | N | | 000000 | | +2 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 574 | 25 | 7 |
| A | 57 | 431.840 | 433.020 | 132 | JT | N | | 000000 | | +3 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 555 | 24 | 6 |
| A | 57 | 433.020 | 433.040 | 132 | JT | N | | 002300 | | +2 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 574 | 25 | 7 |
| A | 57 | 433.040 | 433.420 | 136 | CWR | N | | 002300 | | +2 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 840 | 27 | 8 |
| A | 57 | 433.420 | 433.440 | 132 | JT | N | | 002300 | | +2 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 592 | 27 | 7 |
| A | 57 | 433.440 | 433.800 | 136 | CWR | N | | 002300 | | +2 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 840 | 27 | 8 |
| A | 57 | 433.800 | 433.820 | 132 | JT | N | | 002300 | | +2 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 574 | 25 | 7 |
| A | 57 | 433.820 | 433.855 | 136 | CWR | N | | 002300 | | +2 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 840 | 27 | 8 |
| A | 57 | 433.855 | 434.175 | 136 | CWR | N | | 020000 | | +2 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 622 | 25 | 8 |
| A | 57 | 434.175 | 434.280 | 136 | CWR | N | | 000000 | | +2 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 840 | 27 | 8 |
| A | 57 | 434.280 | 436.250 | 136 | CWR | N | | 000000 | | -2 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 840 | 27 | 6 |
| A | 57 | 436.250 | 436.150 | 136 | CWR | N | | 003000 | | +1 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 731 | 26 | 8 |
| A | 57 | 436.850 | 437.530 | 136 | CWR | N | | 000000 | | +2 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 840 | 27 | 8 |
| A | 57 | 437.530 | 437.900 | 136 | CWR | N | | 000000 | | +2 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 840 | 27 | 8 |
| A | 57 | 437.900 | 438.100 | 136 | CWR | N | | 004500 | | +1 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 731 | 26 | 6 |
| A | 57 | 438.100 | 438.180 | 136 | CWR | N | | 010000 | | +1 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 731 | 26 | 8 |
| A | 57 | 438.180 | 438.259 | 132 | JT | N | | 010000 | | +1 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 500 | 24 | 7 |
| A | 57 | 438.259 | 438.890 | 132 | JT | N | | 000000 | | +1 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 574 | 25 | 7 |
| A | 57 | 438.890 | 439.020 | 113 | JT | N | | 000000 | | +1 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 515 | 25 | 6 |
| A | 57 | 439.020 | 439.030 | 113 | JT | N | | 010000 | | +1 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 448 | 24 | 6 |
| A | 57 | 439.030 | 439.040 | 132 | JT | N | | 010000 | | +1 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 500 | 24 | 7 |
| A | 57 | 439.040 | 439.210 | 136 | CWR | N | | 010000 | | +1 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 731 | 26 | 6 |
| A | 57 | 439.210 | 439.310 | 132 | JT | N | | 010000 | | +1 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 500 | 24 | 7 |
| A | 57 | 439.310 | 439.853 | 136 | CWR | N | | 010000 | | +1 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 731 | 26 | 8 |
| A | 57 | 439.853 | 439.890 | 136 | CWR | N | | 000000 | | +1 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 840 | 27 | 6 |
| A | 57 | 439.890 | 440.060 | 113 | JT | N | | 000000 | | +1 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 515 | 25 | 6 |
| A | 57 | 440.060 | 440.350 | 113 | JT | N | | 000000 | | +2 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 515 | 25 | 6 |
| A | 57 | 440.350 | 440.470 | 113 | JT | SH | | 000000 | | +2 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 515 | 25 | 6 |
| A | 57 | 440.470 | 440.500 | 119 | JT | N | | 000000 | | +2 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 533 | 25 | 6 |
| A | 57 | 440.500 | 440.520 | 119 | JT | N | | 010000 | | +2 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 463 | 24 | 6 |
| A | 57 | 440.520 | 440.540 | 136 | JT | N | | 010000 | | +2 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 515 | 25 | 7 |
| A | 57 | 440.540 | 440.690 | 136 | CWR | N | | 010000 | | +2 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 731 | 26 | 8 |
| A | 57 | 440.690 | 441.279 | 136 | CWR | N | | 010000 | | +1 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 731 | 26 | 8 |
| A | 57 | 441.279 | 441.300 | 136 | CWR | N | | 000000 | | +1 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 840 | 27 | 8 |
| A | 57 | 441.300 | 441.510 | 119 | CWR | N | | 000000 | | +1 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 756 | 26 | 8 |
| A | 57 | 441.510 | 441.590 | 136 | CWR | N | | 000000 | | +1 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 840 | 27 | 8 |
| A | 57 | 441.590 | 442.290 | 119 | CWR | N | | 000000 | | +1 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 756 | 26 | 8 |
| A | 57 | 442.290 | 442.480 | 119 | CWR | N | | 000000 | | +2 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 756 | 26 | 6 |
| A | 57 | 442.480 | 442.500 | 136 | CWR | N | | 000000 | | +2 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 840 | 27 | 8 |
| A | 57 | 442.500 | 442.600 | 136 | CWR | N | | 000000 | | +1 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 840 | 27 | 8 |
| A | 57 | 442.600 | 443.461 | 136 | CWR | N | | 020000 | | +1 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 622 | 25 | 8 |
| A | 57 | 443.461 | 443.560 | 136 | CWR | N | | 000000 | | +1 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 840 | 27 | 8 |
| A | 57 | 443.560 | 443.840 | 136 | CWR | N | | 013500 | | +1 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 622 | 25 | 8 |
| A | 57 | 443.840 | 443.880 | 136 | CWR | N | | 000000 | | +1 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 840 | 27 | 8 |
| A | 57 | 443.880 | 445.010 | 119 | CWR | N | | 000000 | | +1 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 756 | 26 | 8 |
| A | 57 | 445.010 | 445.360 | 136 | CWR | N | | 000000 | | +1 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 840 | 27 | 8 |
| A | 57 | 445.360 | 446.970 | 136 | CWR | N | | 000000 | | +2 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 840 | 27 | 6 |
| A | 57 | 446.970 | 447.600 | 119 | CWR | N | | 000000 | | +2 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 756 | 26 | 8 |
| A | 57 | 447.600 | 447.620 | 113 | JT | N | | 000000 | | +2 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 515 | 25 | 6 |
| A | 57 | 447.620 | 448.100 | 119 | CWR | N | | 000000 | | +2 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2510 | 28.895 | 756 | 26 | 8 |
| A | 57 | 448.100 | 448.830 | 119 | CWR | N | | 000000 | | +2 | 1A | | | | 6.0 | .0 | 6.0 | 4 | .0000 | 2512 | 28.895 | 756 | 26 | 8 |

FIGURE C-4

TRACK STRUCTURE COMPONENT LIFE REPORT

| LN CD | SEG | MP FR | MP TO | WGT | TYP | CD | MT | CURVE | O | GRADE | TS | BLLST UC | PS | M | ON TRK TIME RAIL | | TIE | T C | LNKE | LNKW | ANNUAL MGT | EST RAIL LIFE-MGT | EST TIE LIFE-YRS | EST SURF LIFE-YRS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B | 92 | 1142.270 | 1142.310 | 136 | JT | N | | 000000 | | +3 | 1B | | | | 1.5 | 2.5 | 4.0 | 0 | 1057 | 1058 | 53.970 | 939 | 21 | 5 |
| B | 92 | 1142.310 | 1142.510 | 136 | CWR | N | | 000000 | | +3 | 1B | | | | 1.5 | 2.5 | 4.0 | 0 | 1057 | 1058 | 53.970 | 1334 | 21 | 6 |
| B | 92 | 1142.510 | 1143.000 | 136 | CWR | N | | 000000 | | -2 | 1B | | | | 1.5 | 2.5 | 4.0 | 0 | 1057 | 1058 | 53.970 | 1381 | 22 | 7 |
| B | 92 | 1143.000 | 1143.540 | 136 | CWR | N | | 000000 | | +2 | 1B | | | | 1.5 | 2.5 | 4.0 | 0 | 1057 | 1058 | 53.970 | 1381 | 22 | 7 |
| B | 92 | 1143.540 | 1143.970 | 136 | CWR | N | | 000000 | | +3 | 1B | | | | 1.5 | 2.5 | 4.0 | 0 | 1057 | 1058 | 53.970 | 1334 | 21 | 6 |
| B | 92 | 1143.970 | 1144.670 | 136 | CWR | N | | 000000 | | -3 | 1B | | | | 1.5 | 2.5 | 4.0 | 0 | 1057 | 1058 | 53.970 | 1334 | 21 | 6 |
| B | 92 | 1144.670 | 1145.002 | 136 | CWR | N | | 013300 | | -3 | 1B | | | | 1.5 | 2.5 | 4.0 | 0 | 1057 | 1058 | 53.970 | 987 | 19 | 6 |
| B | 92 | 1145.002 | 1145.160 | 136 | CWR | N | | 000000 | | -3 | 1B | | | | 1.5 | 2.5 | 4.0 | 0 | 1057 | 1058 | 53.970 | 1334 | 21 | 6 |
| B | 92 | 1145.160 | 1145.200 | 136 | CWR | N | | 000000 | | +1 | 1B | | | | 1.5 | 2.5 | 4.0 | 0 | 1057 | 1058 | 53.970 | 1381 | 22 | 7 |
| B | 92 | 1145.200 | 1145.625 | 136 | CWR | N | | 010000 | | +1 | 1B | | | | 1.5 | 2.5 | 4.0 | 0 | 1057 | 1058 | 53.970 | 1202 | 21 | 7 |
| B | 92 | 1145.625 | 1145.810 | 136 | CWR | N | | 000000 | | +1 | 1B | | | | 1.5 | 2.5 | 4.0 | 0 | 1057 | 1058 | 53.970 | 1361 | 22 | 7 |
| B | 92 | 1145.810 | 1146.150 | 136 | CWR | N | | 000000 | | -2 | 1B | | | | 1.5 | 2.5 | 4.0 | 0 | 1057 | 1058 | 53.970 | 1381 | 22 | 7 |
| B | 92 | 1146.150 | 1146.570 | 136 | CWR | N | | 000000 | | +2 | 1B | | | | 1.5 | 2.5 | 4.0 | 0 | 1057 | 1058 | 53.970 | 1381 | 22 | 7 |
| B | 92 | 1146.570 | 1147.250 | 136 | CWR | N | | 000000 | | +1 | 1B | | | | 1.5 | 2.5 | 4.0 | 0 | 1057 | 1058 | 53.970 | 1381 | 22 | 7 |
| B | 92 | 1147.250 | 1147.540 | 136 | CWR | SH | | 003000 | | +1 | 1B | | | | 1.5 | 2.5 | 4.0 | 0 | 1057 | 1058 | 53.970 | 1202 | 21 | 7 |
| B | 92 | 1147.540 | 1147.577 | 136 | CWR | SH | | 010720 | | +1 | 1B | | | | 1.5 | 2.5 | 4.0 | 0 | 1057 | 1058 | 53.970 | 1202 | 21 | 7 |
| B | 92 | 1147.577 | 1147.610 | 136 | CWR | SH | | 000000 | | +1 | 1B | | | | 1.5 | 2.5 | 4.0 | 0 | 1057 | 1058 | 53.970 | 1381 | 22 | 7 |
| B | 92 | 1147.610 | 1147.656 | 136 | CWR | SH | | 010400 | | +1 | 1B | | | | 1.5 | 2.5 | 4.0 | 0 | 1057 | 1058 | 53.970 | 1202 | 21 | 7 |
| B | 92 | 1147.656 | 1147.690 | 136 | CWR | SH | | 000000 | | +1 | 1B | | | | 1.5 | 2.5 | 4.0 | 0 | 1057 | 1058 | 53.970 | 1381 | 22 | 7 |
| B | 92 | 1147.690 | 1147.950 | 113 | CWR | SH | | 000000 | | +1 | 1B | | | | 1.5 | 2.5 | 4.0 | 0 | 1057 | 1058 | 53.970 | 1201 | 21 | 6 |
| B | 92 | 1147.950 | 1148.000 | 113 | CWR | SH | | 000000 | | -3 | 1B | | | | 1.5 | 2.5 | 4.0 | 0 | 1057 | 1058 | 53.970 | 1160 | 20 | 6 |
| B | 92 | 1148.000 | 1148.100 | 113 | CWR | SH | | 000000 | | -2 | 3C | | | | 1.5 | 2.5 | 4.0 | 0 | 1057 | 1058 | 53.970 | 1201 | 14 | 4 |
| B | 92 | 1148.100 | 1148.130 | 113 | CWR | SH | | 000000 | | +1 | 3C | | | | 1.5 | 2.5 | 4.0 | 0 | 1057 | 1058 | 53.970 | 1201 | 14 | 4 |
| B | 93 | 1148.300 | 1148.630 | 113 | CWR | SH | | 000000 | | -2 | 3C | | | | 1.5 | 1.5 | 3.0 | 0 | 1059 | 1060 | 54.600 | 1080 | 12 | 4 |
| B | 93 | 1148.630 | 1149.000 | 113 | CWR | SH | | 000000 | | -2 | 3C | | | | 1.5 | 1.5 | 3.0 | 0 | 1059 | 1060 | 54.600 | 1080 | 12 | 4 |
| B | 93 | 1149.000 | 1149.410 | 113 | CWR | SH | | 000000 | | -2 | 1B | | | | 1.5 | 2.0 | 3.0 | 0 | 1059 | 1060 | 54.600 | 1080 | 19 | 5 |
| B | 93 | 1149.410 | 1149.470 | 113 | CWR | SH | | 000000 | | +1 | 1B | | | | 1.5 | 1.5 | 3.0 | 0 | 1059 | 1060 | 54.600 | 1080 | 19 | 5 |
| B | 93 | 1149.470 | 1149.510 | 113 | JT | N | | 000000 | | +1 | 1B | | | | 1.5 | 1.5 | 3.0 | 0 | 1059 | 1060 | 54.600 | 760 | 18 | 5 |
| B | 93 | 1149.510 | 1151.150 | 113 | CWR | SH | | 000000 | | +1 | 1B | | | | 1.5 | 1.5 | 3.0 | 0 | 1059 | 1060 | 54.600 | 1080 | 19 | 5 |
| B | 93 | 1151.150 | 1151.700 | 113 | CWR | SH | | 000000 | | -2 | 1B | | | | 1.5 | 1.5 | 3.0 | 0 | 1059 | 1060 | 54.600 | 1080 | 19 | 5 |
| B | 93 | 1151.700 | 1152.130 | 113 | CWR | SH | | 000000 | | +1 | 1B | | | | 1.5 | 1.5 | 3.0 | 0 | 1059 | 1060 | 54.600 | 1080 | 19 | 5 |
| B | 93 | 1152.130 | 1152.630 | 113 | CWR | N | | 000000 | | +1 | 1B | | | | 1.5 | 1.5 | 3.0 | 0 | 1059 | 1060 | 54.600 | 1080 | 19 | 5 |
| B | 93 | 1152.630 | 1152.900 | 113 | CWR | N | | 003000 | | +2 | 1B | | | | 1.5 | 1.5 | 3.0 | 0 | 1059 | 1060 | 54.600 | 939 | 18 | 5 |
| B | 93 | 1152.900 | 1153.375 | 113 | CWR | N | | 003000 | | +2 | 1B | | | | 1.5 | 1.5 | 3.0 | 0 | 1059 | 1060 | 54.600 | 939 | 18 | 5 |
| B | 93 | 1153.375 | 1153.670 | 113 | CWR | N | | 000000 | | +3 | 1B | | | | 1.5 | 1.5 | 3.0 | 0 | 1059 | 1060 | 54.600 | 1043 | 18 | 5 |
| B | 93 | 1153.670 | 1153.870 | 113 | CWR | N | | 000000 | | +2 | 1B | | | | 1.5 | 1.5 | 3.0 | 0 | 1059 | 1060 | 54.600 | 1080 | 19 | 5 |
| B | 93 | 1153.870 | 1153.890 | 113 | JT | N | | 000000 | | +2 | 1B | | | | 1.5 | 1.5 | 3.0 | 0 | 1059 | 1060 | 54.600 | 760 | 18 | 5 |
| B | 93 | 1153.890 | 1154.550 | 113 | CWR | N | | 000000 | | +2 | 1B | | | | 1.5 | 1.5 | 3.0 | 0 | 1059 | 1060 | 54.600 | 1080 | 19 | 5 |
| B | 93 | 1154.550 | 1158.050 | 113 | CWR | N | | 000000 | | +2 | 1B | | | | 1.5 | 1.5 | 3.0 | 0 | 1059 | 1060 | 54.600 | 1080 | 19 | 5 |
| B | 93 | 1158.050 | 1159.180 | 113 | CWR | N | | 000000 | | +2 | 1B | | | | 1.5 | 1.5 | 3.0 | 0 | 1059 | 1060 | 54.600 | 1080 | 19 | 5 |
| B | 93 | 1159.180 | 1163.440 | 113 | CWR | N | | 000000 | | +3 | 1B | | | | 1.5 | 1.5 | 3.0 | 0 | 1059 | 1060 | 54.600 | 1043 | 18 | 5 |
| B | 93 | 1163.440 | 1164.460 | 113 | CWR | N | | 000000 | | +3 | 1B | | | | 1.5 | 1.5 | 3.0 | 0 | 1059 | 1060 | 54.600 | 1043 | 18 | 5 |
| B | 93 | 1164.460 | 1165.020 | 113 | CWR | N | | 000000 | | +2 | 1B | | | | 1.5 | 1.5 | 3.0 | 0 | 1059 | 1060 | 54.600 | 1080 | 19 | 5 |
| B | 93 | 1165.020 | 1165.040 | 132 | JT | N | | 000000 | | +2 | 1B | | | | 1.5 | 1.5 | 3.0 | 0 | 1059 | 1060 | 54.600 | 849 | 18 | 5 |
| B | 93 | 1165.040 | 1165.100 | 136 | CWR | N | | 000000 | | +2 | 1B | | | | 1.5 | 1.5 | 3.0 | 0 | 1059 | 1060 | 54.600 | 1241 | 20 | 6 |
| B | 93 | 1165.100 | 1165.980 | 136 | CWR | N | | 000000 | | +3 | 1B | | | | 1.5 | 1.5 | 3.0 | 0 | 1059 | 1060 | 54.600 | 1199 | 19 | 6 |
| B | 93 | 1165.980 | 1166.280 | 136 | CWR | N | | 000000 | | +2 | 1B | | | | 1.5 | 1.5 | 3.0 | 0 | 1059 | 1060 | 54.600 | 1241 | 20 | 6 |
| B | 93 | 1166.280 | 1166.300 | 132 | JT | N | | 000000 | | +2 | 1B | | | | 1.5 | 1.5 | 3.0 | 0 | 1059 | 1060 | 54.600 | 849 | 18 | 5 |
| B | 93 | 1166.300 | 1166.800 | 136 | CWR | N | | 000000 | | +3 | 1B | | | | 1.5 | 1.5 | 3.0 | 0 | 1059 | 1060 | 54.600 | 1199 | 19 | 6 |
| B | 93 | 1166.800 | 1169.350 | 136 | CWR | N | | 000000 | | +2 | 1B | | | | 1.5 | 1.5 | 3.0 | 0 | 1059 | 1060 | 54.600 | 1241 | 20 | 6 |
| B | 93 | 1169.350 | 1169.800 | 136 | CWR | N | | 000000 | | -2 | 1B | | | | 1.5 | 1.5 | 3.0 | 0 | 1059 | 1060 | 54.600 | 1241 | 20 | 6 |
| B | 93 | 1169.800 | 1170.310 | 136 | JT | N | | 000000 | | -2 | 1B | | | | 1.5 | 1.5 | 3.0 | 0 | 1059 | 1060 | 54.600 | 874 | 19 | 5 |
| B | 93 | 1170.310 | 1170.320 | 136 | CWR | N | | 000000 | | -2 | 1B | | | | 1.5 | 1.5 | 3.0 | 0 | 1059 | 1060 | 54.600 | 1241 | 20 | 6 |
| B | 93 | 1170.320 | 1170.800 | 136 | CWR | N | | 010000 | | -2 | 1B | | | | 1.5 | 1.5 | 3.0 | 0 | 1059 | 1060 | 54.600 | 1080 | 19 | 6 |
| B | 93 | 1170.800 | 1171.288 | 136 | CWR | N | | 010000 | | +3 | 1B | | | | 1.5 | 1.5 | 3.0 | 0 | 1059 | 1060 | 54.600 | 1043 | 18 | 6 |
| B | 93 | 1171.288 | 1171.870 | 136 | CWR | N | | 000000 | | +3 | 1B | | | | 1.5 | 1.5 | 3.0 | 0 | 1059 | 1060 | 54.600 | 1199 | 19 | 6 |

FIGURE C-5

TRACK STRUCTURE COMPONENT LIFE REPORT

| LN CD | SEG | MP FR | MP TO | WGT | TYP | CD | MT | CURVE | O | GRADE | BLLST TS UC | PS | M | ON TRK TIME RAIL | | TIE | T C | LNKE | LNKW | ANNUAL MGT | EST RAIL LIFE-MGT | EST TIE LIFE-YRS | EST SURF LIFE-YRS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B | 27 | 346.800 | 346.820 | 136 | JT | N | | 000000 | | +6 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 999 | 15 | 4 |
| B | 27 | 346.820 | 347.000 | 136 | CWR | N | HS | 000000 | | +6 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 999 | 15 | 5 |
| B | 27 | 347.000 | 347.020 | 136 | CWR | N | | 000000 | | +6 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 1418 | 15 | 5 |
| B | 27 | 347.020 | 347.040 | 136 | CWR | N | | 054000 | | +6 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 566 | 11 | 5 |
| B | 27 | 347.040 | 347.250 | 136 | CWR | N | | 054000 | | +6 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 566 | 11 | 5 |
| B | 27 | 347.250 | 347.270 | 136 | WR | N | HS | 054000 | | +6 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 594 | 11 | 4 |
| B | 27 | 347.270 | 347.630 | 136 | WR | N | HS | 100000 | X | +6 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 732 | 8 | 4 |
| B | 27 | 347.630 | 347.644 | 136 | WR | N | HS | 100000 | X | +7 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 682 | 8 | 4 |
| B | 27 | 347.644 | 347.650 | 136 | WR | N | HS | 000000 | | +7 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 1385 | 14 | 4 |
| B | 27 | 347.650 | 347.670 | 136 | JT | N | HS | 000000 | | +7 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 1385 | 14 | 4 |
| B | 27 | 347.670 | 347.690 | 136 | JT | N | HS | 063000 | X | +7 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 1013 | 9 | 4 |
| B | 27 | 347.690 | 347.850 | 136 | JT | N | HS | 063000 | X | +6 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 1088 | 11 | 4 |
| B | 27 | 347.850 | 347.859 | 136 | JT | N | | 063000 | X | +6 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 730 | 11 | 4 |
| B | 27 | 347.859 | 347.870 | 136 | JT | N | | 000000 | | +6 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 999 | 15 | 4 |
| B | 27 | 347.870 | 347.967 | 136 | CWR | N | | 030600 | | +6 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 865 | 13 | 5 |
| B | 27 | 347.967 | 347.980 | 136 | CWR | N | | 000000 | | +6 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 1418 | 15 | 5 |
| B | 27 | 347.980 | 348.103 | 136 | JT | N | | 102000 | | +6 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 133 | 8 | 4 |
| B | 27 | 348.103 | 348.110 | 136 | JT | N | | 000000 | | +6 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 999 | 15 | 4 |
| B | 27 | 348.110 | 348.260 | 136 | WR | N | HS | 102000 | | +6 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 198 | 8 | 4 |
| B | 27 | 348.260 | 348.279 | 136 | WR | N | HS | 102000 | | +6 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 198 | 8 | 4 |
| B | 27 | 348.279 | 348.280 | 136 | WR | N | HS | 000000 | | +6 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 1488 | 15 | 4 |
| B | 27 | 348.280 | 348.290 | 136 | JT | N | | 000000 | | +6 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 999 | 15 | 4 |
| B | 27 | 348.290 | 348.320 | 136 | WR | N | HS | 000000 | | +6 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 1468 | 15 | 4 |
| B | 27 | 348.320 | 348.350 | 136 | JT | N | | 000000 | | +6 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 999 | 15 | 4 |
| B | 27 | 348.350 | 348.370 | 136 | JT | N | | 101000 | | +6 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 133 | 8 | 4 |
| B | 27 | 348.370 | 348.520 | 136 | JT | N | | 101000 | | +5 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 145 | 9 | 4 |
| B | 27 | 348.520 | 348.620 | 136 | WR | N | HS | 060300 | | +5 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 649 | 12 | 4 |
| B | 27 | 348.620 | 348.635 | 136 | WR | N | HS | 060300 | | +6 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 594 | 11 | 4 |
| B | 27 | 348.635 | 348.640 | 136 | WR | N | HS | 000000 | | +6 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 1488 | 15 | 4 |
| B | 27 | 348.640 | 349.040 | 136 | CWR | N | | 000000 | | +6 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 1418 | 15 | 5 |
| B | 27 | 349.040 | 349.060 | 136 | JT | N | | 000000 | | +6 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 999 | 15 | 4 |
| B | 27 | 349.060 | 349.100 | 136 | JT | SH | | 000000 | | +6 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 999 | 15 | 4 |
| B | 27 | 349.100 | 349.120 | 136 | JT | N | | 000000 | | +6 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 999 | 15 | 4 |
| B | 27 | 349.120 | 349.402 | 136 | WR | N | HS | 040000 | | +6 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 969 | 12 | 4 |
| B | 27 | 349.402 | 349.420 | 136 | WR | N | HS | 000000 | | +6 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 1488 | 15 | 4 |
| B | 27 | 349.420 | 349.670 | 136 | CWR | N | | 000000 | | +6 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 1418 | 15 | 5 |
| B | 27 | 349.670 | 349.700 | 136 | WR | N | HS | 100000 | X | +6 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 732 | 8 | 4 |
| B | 27 | 349.700 | 349.730 | 136 | WR | N | HS | 100000 | X | +5 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 801 | 9 | 4 |
| B | 27 | 349.730 | 349.743 | 136 | WR | N | HS | 100000 | X | +6 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 732 | 8 | 4 |
| B | 27 | 349.743 | 349.760 | 136 | WR | N | HS | 000000 | | +6 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 1488 | 15 | 4 |
| B | 27 | 349.760 | 349.820 | 136 | CWR | N | | 000000 | | +6 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 1418 | 15 | 5 |
| B | 27 | 349.820 | 349.850 | 136 | CWR | N | | 045800 | | +6 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 717 | 12 | 5 |
| B | 27 | 349.850 | 349.960 | 136 | CWR | N | | 045800 | | +6 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 717 | 12 | 5 |
| B | 27 | 349.960 | 350.009 | 136 | CWR | N | | 045800 | | +6 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 717 | 12 | 5 |
| B | 27 | 350.009 | 350.070 | 136 | CWR | N | | 000000 | | +6 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 56.171 | 1418 | 15 | 5 |
| B | 27 | 350.070 | 350.080 | 136 | JT | N | | 000000 | | +6 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 999 | 15 | 4 |
| B | 27 | 350.080 | 350.100 | 136 | JT | N | | 100500 | X | +6 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 491 | 8 | 4 |
| B | 27 | 350.100 | 350.119 | 136 | JT | N | | 100500 | X | +6 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 491 | 8 | 4 |
| B | 27 | 350.119 | 350.179 | 136 | JT | N | | 095700 | | +6 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 133 | 8 | 4 |
| B | 27 | 350.179 | 350.437 | 136 | JT | N | | 100000 | | +6 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 133 | 8 | 4 |
| B | 27 | 350.437 | 350.450 | 136 | JT | N | | 000000 | | +6 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 999 | 15 | 4 |
| B | 27 | 350.450 | 350.510 | 136 | WR | N | HS | 100000 | | +6 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 198 | 8 | 4 |
| B | 27 | 350.510 | 350.550 | 140 | JT | N | | 100000 | | +6 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 146 | 8 | 4 |
| B | 27 | 350.550 | 350.574 | 140 | JT | N | | 100000 | | +5 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 160 | 9 | 4 |
| B | 27 | 350.574 | 350.580 | 140 | JT | N | | 000000 | | +5 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 1204 | 17 | 4 |
| B | 27 | 350.580 | 350.640 | 136 | CWR | N | | 000000 | | +5 | 38 | 6 | X | 2.0 | .0 | 3.0 | 0 | 0931 | 0932 | 58.171 | 1550 | 18 | 5 |

# UNIT PRODUCTION COSTS.

## A. General Material Cost Assumptions

The following assumptions have been applied to calculate material costs in the study trackage area:

(1) For material costing purposes, rail will be considered as being one of only three types: New, relay or scrap. This is of course a simplification in the valuation of second-hand rail given that such rail may have a variety of uses (values), depending on its type, weight, condition, etc. However, given the inability to accurately predict the end use of specific rail suitable for relay, this broad categorization is necessary.

(2) All rail to be laid in the main line trackage under study will be new rail.

(3) On picking up jointed rail which was laid new, 75% will be credited as relay rail and 25% (includes a cropping allowance) will be credited as scrap. For CWR laid new, 95% will be credited as relay and 5% as scrap.

(4) On picking up rail which was laid second hand, 50% will be credited as relay rail and 50% will be credited as scrap.

## B. Valuation of Salvageable Rail

The value of rail at any time is a function of its remaining life (in terms of million gross tons), and the value of new as well as scrap rail. New rail and scrap rail have values (dollars per ton based on "pattern weight") determined by prices on their respective markets. However, the value of relay rail is not easily determined because there is not a large market for it. This is due primarily to the fact that each railroad tends to generate enough relay rail to satisfy its own requirements.

New rail is laid in main line service. Its life under these conditions is a function of many factors including the rail section, annual tonnage operated over it, physical conditions such as curvature, gradient, and rail metallurgy, and traffic conditions such as wheel loads and speeds. When rail wear deteriorates the quality of rail sufficiently, it is removed from high speed, heavy annual tonnage main line service and relaid in low speed, low annual tonnage branch line service. The Southern Pacific decision to remove rail from main line service is based primarily upon the probability of a rail failure. This generally occurs when about 30% to 50% of the rail life is remaining (i.e. 50% to 70% of the life of the rail is used up in main line service).

Not all rail removed from main line service is usable as relay rail. The portion which can be relaid is ordinarily cropped and welded either into welded or continuous welded rail (72-1440'). Cropping results in about 10% of the rail being scrap. Rail defects result in another 5% of the rail being scrap. Due to excessive wear (curve rail), about 10% of the rail is suitable for use only in yard and industry tracks ("back track"). The result is that of a mile of rail removed from main line service about 75% is usable in branch line service. These estimates are based upon the judgment of Southern Pacific engineering personnel.

With this information it is possible to estimate a value for rail laid in branch lines based upon its expected remaining life. The value of rail suitable for use in branch line service is given by equation (1).

(1) $B = (X)(N - 0.9S) + 0.9S$

where B = value of rail usable for branch line service ($ per ton, based on pattern weight")

X = fraction of total rail life remaining when rail is laid in branch lines

N = price of new rail ($ per ton, based on "pattern weight")

S = price of scrap rail ($ per ton, based on "pattern weight")

The "0.9" factor applied to the scrap price is to account for the difference between the "pattern weight" and actual weight of the scrap rail. Based on the judgment that X has a value between 0.3 and 0.5, it seems reasonable to assign it a value of 0.4 for this analysis. This is done in equation (2).

(2) $B = 0.4 (N - 0.9S) + 0.9S$

When rail is removed from branch line service, about 50% is usable in "back tracks". The remaining 50% is scrap. The value of rail suitable for use in "back tracks" is given by equation (3).

(3) $C = Y (N = 0.9S) + 0.9S$

where C = value of rail usable for "back tracks" ($ per ton, based on "pattern weight")

Y = fraction of total rail life remaining when rail is laid in "back tracks"

N,S = are defined the same as in equation (1)

The nature of rail laid in "back tracks" makes determination of the value of Y difficult. During times when there is a large need for this class of rail, some rail which may be sold for scrap during periods of less demand may be used in "back tracks". However, under most circumstances it is unlikely that the fraction of life remaining in this rail would exceed 10% of the total life of the rail (in terms of tonnage). Based on this, equation (3) becomes:

(4) $C = 0.1\ (N - 0.9S) + 0.9S$

The class of rail called "relay rail" is composed of both rail laid in branch lines and rail laid in "back tracks". The value of relay rail must be based on the value of these two classes of rail (i.e. usable in branch lines, and usable in "back tracks") and the proportion of total relay rail each constitutes. When one mile of rail is taken up from main line service, 0.75 mile is usable in branch lines, and 0.10 mile is usable in "back tracks". Of the 0.75 mile of branch line rail released, 50% or 0.375 mile is usable in "back tracks". In other words, when one mile of rail is taken out of main line service, an eventual 1.225 miles of relay rail is released. This 1.225 miles is composed of 0.75 mile for use in branch lines, and 0.475 mile for use in "back tracks" (0.100 mile released from main line service plus 0.375 mile released from branch line service). Based on this, the value of relay rail can be determined from equation (5).

(5) $V = \frac{0.75}{1.225} B + \frac{0.475}{1.225} C = 0.61B + 0.39C$

When the values for B and C [from equations (2) and (4) respectively] are substituted into equation (5), the result is:

(6) $V = 0.61\ [0.4\ (N - 0.9S) + 0.9S] + 0.39\ [0.1\ (N - 0.9S) + 0.9S]$

$= 0.2830\ (N - 0.9S) + 0.9S$

Current (July 1, 1975) prices for new and scrap rail are substituted into equation (1) to determine an average economic value for salvageable rail in the study. This value is $144.50/ton.

## C. Price Levels

All costs (labor, material, equipment rentals) reflect prices/rates at the July 1, 1975 level.

## D. Basis of Estimated Costs

### 1. Maintenance of Equipment

The cost of in-field and shop repairs of automotive, work and boarding equipment is included in the daily rental rate of that equipment. The rental rates include expense of traveling mechanics that may be assigned to specific work forces.

### 2. Handling Cost of Materials And Supplies

Purchase expense, foreign line freight included. Transportation and handling from nearest Terminal to/at work site included. Handling and Transportation on S.P. Lines to Terminal nearest work site not included.

3. Move Work Force And Equipment

From On-duty point to on-duty point (end of one project to start of new project) not included.
From on-duty point to work site (on current project) **included**.

4. Rail Relay Labor

Labor applied to relay vs. rail is performed by a 50-man System Rail Gang using its assigned roadway machines, tools, automotive and boarding equipment. Labor applied to welding is performed by a 7-man system Welding Gang that accompanies the System Rail Gang. Welding Gang uses its own assigned tools and equipment.

All other labor and equipment, except CWR train cars are drawn from local assignments.

5. Rail Relay Costs

Costs for rail relay include the following:

a. Unloading rail (14 men, train crew, equipment rental CWR train)
b. Unloading OTM (6 men, train crew, equipment rental, work train)
c. Relaying rail (50 men, equipment rental)
d. Sorting OTM released (8 men, equipment rental)
e. Loading Rail [OTM released (7 men, train crew, equipment rental, work train)]
f. Field Weld Rail (7 men, equipment rental)
g. Repair Track Circuits (signalmen, equipment rental)
h. Electrical/Sanitary/Water service (labor, equipment rental)

6. Estimated Work Equipment Rental-Rail Relay

| Type of Equipment | Life Exp. (Years) | Estimated Cost To Replace | Estimated Daily Maint. | Deprn. Interest Prop. Tax | Daily 8-Hr. Rate |
|---|---|---|---|---|---|
| Speed swings (2) | 12 | $80,000 | $76.92 | $72.12 | $149.04 |
| Camp Car Electric Generators (2) | 10 | 10,070 | 9.67 | 9.84 | 19.51 |
| Track Work Machines: Spike Puller, Power Wrench, Vibrator, Anchor Applicators, Rail Gager | 8 | 63,215 | 40.76 | 68.96 | 109.72 |
| Air Compressor | 8 | 8,500 | 8.17 | 9.27 | 17.44 |
| Track Work Machines: Adzer, Crib Reducer, Tie Sprayer, Track Drills, Rail Saw, Spike Driver | 6 | 58,040 | 55.85 | 74.31 | 130.16 |
| Rail Welding Equipment: Rail Heater, Pre-heaters, Rail Pullers, Utility Grinder, Surface Grinder, Rail Saw | 6 | 25,950 | 24.80 | 33.22 | 58.02 * |
| Automotive Equipment: | | | | | |
| Truck (Trackmen) | 8 | 8,000 | 7.69 | 8.73 | 16.42 |
| Bus (Trackmen) | 6 | 16,000 | 15.38 | 20.48 | 35.86 |
| Pick-up Truck (Trackmen) | 6 | 4,000 | 3.84 | 5.12 | 8.96 |
| Truck (welding force) | 8 | 10,000 | 9.61 | 10.91 | 20.52 * |
| | | Total Daily Rate | | | $565.65 |
| | | Hourly Rate | | | 70.71 |

| | |
|---|---|
| * Welding force equipment hourly rate | 9.82 |
| Track force equipment hourly rate | 60.89 |

Deprn. rate = replace cost ÷ life exp. ÷ 220 work days.

Interest rate 10% + prop. tax rate 1.5% x replace cost ÷ 220 work days.

7. Estimated Work Equipment Rental-Tie Renewals-Surfacing

| Type of Equipment | Estimated Cost To Replace | Estimated Service Life | Estimated Daily Maint. Cost | Deprn., Interest, Prop. Tax | Daily Rental Rate | Hourly Rental Rate |
|---|---|---|---|---|---|---|
| 1 2½-Truck | $15,000 | 8 | $ 9.67 | $16.36 | $26.00 | $ 5.25 |
| 1 Passenger Van | 15,400 | 6 | 11.65 | 19.72 | 31.37 | 3.92 |
| 2 Tie Cranes | 38,430 | 10 | 22.20 | 37.56 | 59.76 | 7.47 |
| 2 Spike Pullers | 7,694 | 8 | 4.96 | 8.39 | 13.35 | 1.67 |
| 2 Tie Removers | 20,064 | 8 | 16.46 | 21.89 | 38.35 | 4.79 |
| 1 Tie Scarafier-Remover | 25,420 | 12 | 17.23 | 22.92 | 40.14 | 5.01 |
| 2 Rail Lifters | 7,840 | 6 | 5.94 | 10.04 | 15.93 | 2.00 |
| 2 Spike Drivers | 12,780 | 8 | 8.25 | 13.95 | 22.20 | 2.78 |
| 1 Ballast Regulator | 40,010 | 12 | 38.47 | 36.07 | 74.54 | 9.32 |
| 1 Spot Tamper | 53,780 | 12 | 29.98 | 28.11 | 58.09 | 7.26 |
| 2 Forman Trailers | 12,000 | 8 | 3.60 | 13.09 | 16.69 | 2.09 |
| 5 4-man Trailers | 27,500 | 6 | 6.00 | 35.21 | 41.21 | 5.15 |
| | Equipment Rental-Replace Cross Ties | | | | $437.68 | $54.71 |
| 1 Burro Crane | | | | | 84.16 | 10.52 |
| Diesel Locomotive | | | | | 315.00 | 39.33 |
| 3 Flatcars | | | | | 12.00 | 1.50 |
| | Equipment Rental-Unload Cross Ties | | | | $411.16 | $51.40 |
| Tamper/Jack/Leveler | 60,035 | 6 | 33.46 | | | |

8. Estimated Rental Rates Of House Trailers And Rolling Equipment

| Type of Equipment | Daily Rate | Hourly Rate |
|---|---|---|
| House Trailers (3) | $ 20.82 * | $ 2.60 * |
| Roadway Boarding Cars (11) | 174.79 | 21.85 |
| Roadway Tank, Tool, Flatcars (13) | 8.84 | 1.11 |
| Totals | $204.45 | $25.56 |
| * Total Welding Force Equipment | $ 20.82 | $ 2.60 |
| Total Track Force Equipment | $183.63 | $22.95 |

Estimated Cost Of Hand Tool Rental

| | Daily Rate | Hourly Rate |
|---|---|---|
| Welders Hand Tools | $ 15.00 | $ 1.88 |
| Trackmens Hand Tools | 85.00 | 10.62 |

Summary Of Work/Camp Equipment & Hand Tool Rental

| | Daily Rate | Hourly Rate |
|---|---|---|
| Welding Forces | $114.36 | $14.30 |
| Track Forces | 755.74 | 94.46 |
| Total | $870.10 | $108.76 |

# TABLE D-1 RAIL LABOR, EQUIPMENT RENTAL AND WORK TRAIN COSTS
(July 1, 1975 Level)

WORK SHEET CS 9805

OPERATING EXPENSE OF LABOR, EQUIPMENT RENTAL AND WORK TRAIN TO RELAY ONE TRACK MILE OF RAIL AT VARIOUS WORK PERIODS ON TRACK

| WORK HRS. ON TRACK | 6 HRS. | 5 HRS | 3 HRS | 2 HRS | 4:10/1:40 | 2:30/2:30 | 1:40/2:30 | 1:40/1:40 |
|---|---|---|---|---|---|---|---|---|
| TYPE LABOR & ACCT. | | | | | | | | |
| TRACK 220 | $36.00 | 42.95 | 94.95 | 179.25 | 41.35 | 52.60 | 66.05 | 95.30 |
| SIGNAL 249 | 3.05 | 3.15 | 4.20 | 5.90 | 3.15 | 3.35 | 3.60 | 4.20 |
| ELECTRIC/WATER 229 | .90 | 1.15 | 2.80 | 5.55 | 1.30 | 1.40 | 1.85 | 2.80 |
| TOTAL M OF W. LABOR | 39.95 | 47.25 | 101.95 | 190.70 | 45.80 | 57.35 | 71.50 | 102.30 |
| | | | | | | | | |
| M. OF W. EQUIPMENT RENTAL & ACCOUNT | | | | | | | | |
| TRACK 220 | 12.30 | 14.25 | 33.20 | 63.55 | 14.35 | 17.65 | 29.30 | 33.75 |
| SIGNAL 249 | .30 | .35 | .55 | .90 | .35 | .35 | .40 | .55 |
| ELECTRIC/WATER 229 | .15 | .15 | .45 | .90 | .15 | .20 | .30 | .45 |
| TOTAL M. OF W. EQUIP. | 12.75 | 14.75 | 34.20 | 65.35 | 14.85 | 18.20 | 30.00 | 34.75 |
| | | | | | | | | |
| WORK TRAIN & ACCOUNT | | | | | | | | |
| TRAIN CREW 220 | 15.95 | 18.45 | 28.00 | 41.55 | 16.50 | 19.10 | 23.55 | 30.30 |
| EQUIP. RENTAL [illegible] | 9.25 | 10.65 | 16.45 | 24.90 | 9.50 | 11.05 | 13.75 | 17.75 |
| TOTAL WORK TRAIN | 25.20 | 29.10 | 44.45 | 66.45 | 26.00 | 30.15 | 37.30 | 48.05 |

M OF W FORCES RATE OF PAY INCREASE [illegible] 1975 [illegible] 7.5% TRAIN CREW OVER SAME PERIOD RATE INCREASE 5%

## TABLE D-2 RAIL MATERIAL COSTS
(July 1, 1975 Level)

WORK SHEET C S 9809 | SHEET C S 9801

OPERATING EXPENSE OF MATERIAL AND RETIREMENT ACCOUNTS TO RELAY ONE MAIN LINE TRACK MILE WITH NEW RAIL OF SAME WEIGHT AND WELDED LENGTHS OF RAIL REPLACED

| RAIL INSTALLED | 136# CWR | 136# 78' | 136# 39' | 132# CWR | 132# 78' | 132# 39' | 115# CWR | 115# 78' | 115# 39' | 112# CWR | 112# 78' | 112# 39' | 90# CWR | 90# 78' | 90# 39' |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MATERIAL COST | | | | | | | | | | | | | | | |
| RAIL | 622.35 | 622.35 | 622.35 | 604.05 | 604.05 | 604.05 | 544.55 | 544.55 | 544.55 | 517.10 | 517.10 | 517.10 | 411.85 | 411.85 | 411.85 |
| PLATES, 50% RENEWAL | 137.05 | 137.05 | 137.05 | 137.05 | 137.05 | 137.05 | 125.25 | 125.25 | 125.25 | 125.25 | 125.25 | 125.25 | 74.60 | 74.60 | 74.60 |
| PLATES, % RENEWAL | | | | | | | | | | | | | | | |
| PLATES, % RENEWAL | | | | | | | | | | | | | | | |
| 6 HOLE ANGLE BARS | 4.40 | | | 4.40 | | | 3.75 | | | 3.60 | | | 2.25 | | |
| 4 HOLE ANGLE BARS | | 46.35 | 92.10 | | 46.35 | 92.10 | | 40.45 | 80.90 | | 34.35 | 68.70 | | 23.80 | 47.60 |
| NUTS/BOLTS/LOCKS | .85 | 7.70 | 15.40 | .85 | 7.70 | 15.40 | .85 | 7.70 | 15.40 | .85 | 7.70 | 15.40 | .45 | 4.10 | 8.20 |
| COMP. JOINTS (2 EA) | 4.55 | 4.55 | 4.55 | 4.55 | 4.55 | 4.55 | 4.40 | 4.40 | 4.40 | 4.40 | 4.40 | 4.40 | 4.30 | 4.30 | 4.30 |
| 6 HOLE INSUL. JOINTS | 5.00 | | | 5.00 | | | 4.45 | | | 4.20 | | | 3.40 | | |
| 4 HOLE INSUL. JOINTS | | 3.20 | 3.20 | | 3.20 | 3.20 | | 2.85 | 2.85 | | 2.70 | 2.70 | | 2.20 | 2.20 |
| RAIL ANCHORS | 20.10 | 15.70 | 11.80 | 20.10 | 15.70 | 11.80 | 20.10 | 15.70 | 11.80 | 20.10 | 15.70 | 11.80 | 20.10 | 15.70 | 11.80 |
| TRACK SPIKES | 23.15 | 23.15 | 23.15 | 23.15 | 23.15 | 23.15 | 23.15 | 23.15 | 23.15 | 23.15 | 23.15 | 23.15 | 23.15 | 23.15 | 23.15 |
| TIE PLUGS | 2.35 | 2.35 | 2.35 | 2.35 | 2.35 | 2.35 | 2.35 | 2.35 | 2.35 | 2.35 | 2.35 | 2.35 | 2.35 | 2.35 | 2.35 |
| GAGE PLUGS | 1.05 | | | 1.05 | | | 1.05 | | | 1.05 | | | 1.05 | | |
| TIE COATING | 1.35 | 1.35 | 1.35 | 1.35 | 1.35 | 1.35 | 1.35 | 1.35 | 1.35 | 1.35 | 1.35 | 1.35 | 1.35 | 1.35 | 1.35 |
| TRK CIRCUITS/BONDING | 1.80 | 3.10 | 4.45 | 1.80 | 3.10 | 4.45 | 1.80 | 3.10 | 4.45 | 1.80 | 3.10 | 4.45 | 1.80 | 3.10 | 4.45 |
| WATER/SANITARY SERV | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 |
| DR. ACCT. 214 (RAIL) | 622.35 | 622.35 | 622.35 | 604.05 | 604.05 | 604.05 | 544.55 | 544.55 | 544.55 | 517.10 | 517.10 | 517.10 | 411.85 | 411.85 | 411.65 |
| DR. ACCT. 216 (OTM) | 199.85 | 241.40 | 291.55 | 199.85 | 241.40 | 291.55 | 186.70 | 223.20 | 267.45 | 186.30 | 216.75 | 255.10 | 133.00 | 151.55 | 175.55 |
| DR. ACCT 249 (SIGNAL) | 1.80 | 3.10 | 4.45 | 1.80 | 3.10 | 4.45 | 1.60 | 3.10 | 4.45 | 1.80 | 3.10 | 4.45 | 1.80 | 3.10 | 4.45 |
| DR. ACCT. 229 (ROADWAY BLDGS) | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 |
| TOTAL DR. OPTG. (MATL.) | 825.10 | 867.95 | 919.45 | 806.80 | 849.65 | 901.15 | 734.15 | 771.95 | 817.55 | 706.35 | 738.05 | 777.75 | 547.75 | 567.60 | 592.95 |
| | | | | | | | | | | | | | | | |
| SALVAGE | | | | | | | | | | | | | | | |
| SH RAIL @ 55.577% NEW | 328.60 | 276.70 | 259.40 | 318.90 | 268.55 | 251.75 | 287.50 | 242.10 | 227.00 | 273.00 | 229.90 | 215.55 | 217.45 | 183.10 | 171.65 |
| SCRAP RAIL @ $75.00 NT | 8.95 | 35.90 | 44.88 | 8.70 | 34.85 | 43.55 | 7.85 | 31.40 | 39.25 | 7.45 | 29.85 | 37.30 | 5.95 | 23.75 | 29.70 |
| SH OTM @ 55.577% NEW | 77.10 | 85.00 | 99.00 | 77.10 | 85.00 | 99.00 | 72.75 | 76.90 | 88.95 | 72.55 | 74.10 | 83.80 | 44.65 | 46.65 | 53.65 |
| SCRAP OTM @ $50.00 NT | 5.05 | 8.75 | 10.95 | 5.05 | 8.75 | 10.95 | 4.95 | 8.30 | 10.30 | 4.95 | 8.30 | 10.30 | 4.40 | 6.35 | 7.45 |
| CR. ACCT. 214 (RAIL) | 337.55 | 312.60 | 304.28 | 327.60 | 303.40 | 295.30 | 295.35 | 273.50 | 266.25 | 280.45 | 259.75 | 252.85 | 223.40 | 206.85 | 201.35 |
| CR. ACCT. 216 (OTM) | 82.15 | 93.75 | 109.95 | 82.15 | 93.75 | 109.95 | 77.70 | 85.20 | 99.25 | 77.50 | 82.40 | 94.10 | 49.05 | 53.00 | 61.10 |
| TOTAL CR. OPTG-DR. 712 | 419.70 | 406.35 | 414.23 | 409.75 | 397.15 | 405.25 | 373.05 | 358.70 | 365.50 | 357.95 | 342.15 | 346.95 | 272.45 | 259.85 | 262.45 |

# TABLE D-3 TIE RENEWAL COSTS
## (July 1, 1975 Level)

WORK SHEET C.S. 6005

| MAIN LINE TIE RENEWALS | | | 20% TIE RENEWAL = 650 TIES PER TRK. MILE | | | | | | | | 25% TIE RENEWAL = 812 TIES PER TRK. MILE | | | | | | | | 30% TIE RENEWAL = 975 TIES PER TRK. MILE | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ONE TRACK MILE | UNIT COST | | ASSIGNED HOURS ON-TRACK TIME | | | | | | | | ASSIGNED HOURS ON-TRACK TIME | | | | | | | | ASSIGNED HOURS ON-TRACK TIME | | | | | | | |
| | | | 6.0 | | 5.0 | | 4.0 | | 3.0 | | 6.0 | | 5.0 | | 4.0 | | 3.0 | | 6.0 | | 5.0 | | 4.0 | | 3.0 | |
| Unload Cross Ties | | | HRS | COST | HRS | COST | HRS | COST | HRS | COST | HRS | COST | HRS | COST | HRS | COST | HRS | COST | HRS | COST | HRS | COST | HRS | COST | HRS | COST |
| TRACK FORCES, 4 MEN | HR | $15.01 | 3.26 | $60. | 3.65 | $65. | 4.18 | $75. | 4.60 | $85. | 3.91 | $70. | 4.40 | $80. | 4.89 | $90. | 5.53 | $100. | 4.57 | $80. | [illegible] | $95. | 5.72 | $105. | 6.43 | $115. |
| TRAIN CREW | HR | 80.70 | | 2.65 | | 2.95 | | 3.30 | | 3.70 | | 3.15 | | 3.55 | | 3.95 | | 4.45 | | 3.70 | | 4.20 | | 4.60 | | 5.20 |
| EQUIPMENT RENTAL | HR | [illegible] | | .35 | | .40 | | .45 | | .50 | | .45 | | .50 | | .55 | | .60 | | .50 | | .55 | | .65 | | .70 |
| WORK TRAIN RENTAL | HR | 41.70 | | 1.35 | | 1.55 | | 1.70 | | 1.90 | | 1.65 | | 1.85 | | 2.05 | | 2.30 | | 1.90 | | 2.15 | | 2.40 | | 2.70 |
| REPLACE CROSS TIES | | | 11.82 | | 14.45 | | 18.57 | | 26.0 | | 13.14 | | 18.05 | | [illegible] | | 32.48 | | 17.73 | | [illegible] | | 22.86 | | [illegible] | |
| CROSS TIES 7"x9" | EA | 13.08 | | 85.00 | | 85.00 | | 85.00 | | 85.00 | | 106.20 | | 106.20 | | 106.20 | | 106.20 | | 127.55 | | 127.55 | | 127.55 | | 127.55 |
| TRACK SPIKES (% OF KEGS) | KEG | [illegible] | | 4.65 | | 4.65 | | 4.65 | | 4.65 | | 5.80 | | 5.80 | | 5.80 | | 5.80 | | 6.95 | | 6.95 | | 6.95 | | 6.95 |
| TRACK FORCE, 22 MEN | HR | 106.44 | | 12.60 | | 15.40 | | 19.75 | | 27.70 | | 15.70 | | 19.20 | | 24.70 | | 34.60 | | 18.90 | | 23.05 | | 29.65 | | 41.55 |
| EQUIPMENT RENTAL | HR | 57.45 | | 6.80 | | 8.30 | | 10.65 | | 14.95 | | 8.50 | | 10.35 | | 13.35 | | 18.65 | | 10.20 | | 12.45 | | 16.00 | | 22.45 |
| GROSS COST PER TRACK MILE | | | | 114.00 | | 118.90 | | 126.25 | | 139.25 | | 142.15 | | 148.25 | | 157.50 | | 173.60 | | 170.50 | | 177.85 | | 188.85 | | 208.25 |
| LESS SALVAGE - SPIKES | KEG | 5.00 | | .40 | | .40 | | .40 | | .40 | | .50 | | .50 | | .50 | | .50 | | .60 | | .60 | | .60 | | .60 |
| LESS SALVAGE - TIES | EA | .40 | | 2.60 | | 2.60 | | 2.60 | | 2.60 | | 3.25 | | 3.25 | | 3.25 | | 3.25 | | 3.90 | | 3.90 | | 3.90 | | 3.90 |
| NET COST PER TRACK MILE | | | | 117.00 | | 121.90 | | 129.25 | | 142.25 | | 145.90 | | 152.00 | | 161.25 | | 177.35 | | 175.00 | | 182.55 | | 193.35 | | 212.75 |
| SUMMARY OF UNIT COSTS | ACCOUNT | | | | | | | | | | | | | | | | | | | | | | | | | |
| TRACK LABOR | 220 | | | 13.20 | | 16.05 | | 20.50 | | 28.55 | | 16.40 | | 20.00 | | 25.60 | | 35.60 | | 19.70 | | 24.00 | | 30.70 | | 42.70 |
| CROSS TIES | 212 | | | 85.00 | | 85.00 | | 85.00 | | 85.00 | | 106.20 | | 106.20 | | 106.20 | | 106.20 | | 127.55 | | 127.55 | | 127.55 | | 127.55 |
| OTM | 216 | | | 4.65 | | 4.65 | | 4.65 | | 4.65 | | 5.80 | | 5.80 | | 5.80 | | 5.80 | | 6.95 | | 6.95 | | 6.95 | | 6.95 |
| M OF W EQUIP. RENTAL | 220 | | | 7.15 | | 8.70 | | 11.10 | | 15.45 | | 8.95 | | 10.85 | | 13.90 | | 19.25 | | 10.70 | | 13.00 | | 16.65 | | 23.15 |
| TRAIN CREW | 220 | | | 2.65 | | 2.95 | | 3.30 | | 3.70 | | 3.15 | | 3.55 | | 3.95 | | 4.45 | | 3.70 | | 4.20 | | 4.60 | | 5.20 |
| TRAIN EQUIP. RENTAL | 220 | | | 1.35 | | 1.55 | | 1.70 | | 1.90 | | 1.65 | | 1.85 | | 2.05 | | 2.30 | | 1.90 | | 2.15 | | 2.40 | | 2.70 |
| DR. OPTG. (CASH) | | | | 114.00 | | 118.90 | | 126.25 | | 139.25 | | 142.15 | | 148.25 | | 157.50 | | 173.60 | | 170.50 | | 177.85 | | 188.85 | | 208.25 |
| SALVAGE | | | | | | | | | | | | | | | | | | | | | | | | | | |
| CROSS TIES (SCRAP) | 212 | | | <2.60> | | <2.60> | | <2.60> | | <2.60> | | <3.25> | | <3.25> | | <3.25> | | <3.25> | | <3.90> | | <3.90> | | <3.90> | | <3.90> |
| TRACK SPIKES (SCRAP) | 216 | | | <.40> | | <.40> | | <.40> | | <.40> | | <.50> | | <.50> | | <.50> | | <.50> | | <.60> | | <.60> | | <.60> | | <.60> |
| CR. OPTG | | | | 3.00 | | 3.00 | | 3.00 | | 3.00 | | 3.75 | | 3.75 | | 3.75 | | 3.75 | | 4.50 | | 4.50 | | 4.50 | | 4.50 |
| M.O.H. TIES/SPIKES | 712 | | | 3.00 | | 3.00 | | 3.00 | | 3.00 | | 3.75 | | 3.75 | | 3.75 | | 3.75 | | 4.50 | | 4.50 | | 4.50 | | 4.50 |
| CR. MOH | | | | 3.00 | | 3.00 | | 3.00 | | 3.00 | | 3.75 | | 3.75 | | 3.75 | | 3.75 | | 4.50 | | 4.50 | | 4.50 | | 4.50 |

TABLE D-4 TRACK SURFACING COSTS
(July 1, 1975 Level)

WORK SHEET C S 9805

| RESURFACE TRACK | 3" BALLAST REPLACED - SINGLE TRACK TERRITORY | | | | | | | | | | 3" BALLAST REPLACED - DOUBLE TRACK TERRITORY * | | | | | | | | | | I.C.C. ACCT. | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HRS. ON-TRACK TIME | | | 3.0 | | 5.0 | | 4.0 | | 3.0 | | | | 6.0 | | 5.0 | | 4.0 | | 3.0 | | NUMBER | REV TO [illegible] |
| ONE TRACK MILE | UNIT | COST | HRS | COST | HRS | COST | HRS | COST | HRS | COST | UNIT | COST | HRS | COST | HRS | COST | HRS | COST | HRS | COST | | * COST IS FOR ONE |
| UNLOAD BALLAST | | | 1.37 | | 2.13 | | 2.5 | | 2.34 | | | | 2.06 | | 2.21 | | 2.37 | | 2.53 | | | TRK. MILE ON ONE |
| TRACK FORCE-5 MEN | HR. | 15.76 | | 35 | | 40 | | 40 | | 45 | HR | 18.16 | | 40 | | 40 | | 45 | | 45 | 213 | MAIN TRACK ONLY. |
| TRAIN CREW | HR. | 80.70 | | 155 | | 165 | | 175 | | 185 | HR | 80.70 | | 145 | | 180 | | 190 | | 205 | 216 | |
| EQUIPMENT RENTAL | HR. | [illegible] | | 5 | | 5 | | 5 | | 5 | HR | [illegible] | | 5 | | 5 | | 5 | | 5 | 218 | |
| WORK TRAIN | HR | 62.10 | | 115 | | 125 | | 135 | | 145 | HR. | 67.10 | | 130 | | 135 | | 145 | | 155 | 218 | ESTIMATE DOES NOT |
| RESURFACE/RE-ALIGN | | | 13.8 | | 15.6 | | 18.59 | | 26.0 | | | | 12.41 | | 15.67 | | 20.25 | | 28.34 | | | INCLUDE REPAIRS OR |
| TRACK FORCE-[illegible] MEN | HR. | [illegible] | | 385 | | 470 | | 605 | | 850 | HR. | 32.68 | | 420 | | 515 | | 660 | | 925 | 220 | PROTECTION OF BRIDGE |
| EQUIPMENT RENTAL | HR. | 67.15 | | 560 | | 680 | | 875 | | 1140 | HR. | 47.15 | | 610 | | 740 | | 955 | | 1335 | 220 | SURFACING THROUGH |
| SIGNAL WORK | | | 13.8 | | 15.4 | | 18.59 | | 26.0 | | | | 12.41 | | 15.67 | | 20.25 | | 28.34 | | | TURNOUTS, TRACK |
| SIGNALMAN (1) | HR. | 5.17 | | 75 | | 90 | | 115 | | 160 | HR. | 6.17 | | 80 | | 95 | | 125 | | 175 | 249 | CROSSINGS OR GRADE |
| SIGNAL MATERIAL | T.M. | 110.50 | | 110 | | 110 | | 110 | | 110 | TM | [illegible] | | 110 | | 110 | | 110 | | 110 | 249 | CROSSINGS. |
| PERSONAL EXPENSES | HR. | 2.57 | | 30 | | 35 | | 50 | | 65 | HR | 2.57 | | 35 | | 40 | | 50 | | 75 | 249 | |
| EQUIPMENT RENTAL | HR. | 1.18 | | 15 | | 15 | | 20 | | 30 | HR. | 1.18 | | 15 | | 20 | | 25 | | 35 | 249 | |
| SUB TOTAL (A) | | | | 1495 | | 1735 | | 2190 | | 2735 | | | | 1610 | | 1890 | | 2310 | | 3065 | | |
| WESTERN DIVN. | 5.80 | | | | | | | | | | 6.20 | | | | | | | | | | | |
| BALLAST | C.Y. | 3.19 | | 1850 | | 1850 | | 1850 | | 1850 | C.Y. | 3.19 | | 2020 | | 2020 | | 2020 | | 2020 | 218 | |
| SUB TOTALS (A) | | | | 1485 | | 1735 | | 2130 | | 2735 | | | | 1610 | | 1850 | | 2310 | | 3065 | | |
| TOTAL COSTS | | | | 3335 | | 3585 | | 3980 | | 4585 | | | | 3630 | | 3900 | | 4330 | | 5085 | | |
| SACRAMENTO DIVN. | | | | | | | | | | | | | | | | | | | | | | |
| BALLAST | C.Y. | 2.05 | | 1190 | | 1190 | | 1190 | | 1190 | C.Y. | 2.05 | | 1300 | | 1300 | | 1300 | | 1300 | 218 | |
| SUB TOTALS (A) | | | | 1485 | | 1735 | | 2130 | | 2735 | | | | 1610 | | 1880 | | 2310 | | 3065 | | |
| TOTAL COSTS | | | | 2675 | | 2925 | | 3320 | | 3925 | | | | 2910 | | 3180 | | 3610 | | 4365 | | |
| OREGON DIVN. | | | | | | | | | | | | | | | | | | | | | | |
| BALLAST | C.Y. | 2.14 | | 1240 | | 1240 | | 1240 | | 1240 | C.Y. | 2.14 | | 1355 | | 1355 | | 1355 | | 1355 | 218 | |
| SUB TOTALS (A) | | | | 1485 | | 1735 | | 2130 | | 2735 | | | | 1610 | | 1880 | | 2310 | | 3065 | | |
| TOTAL COSTS | | | | 2725 | | 2975 | | 3370 | | 3975 | | | | 2965 | | 3235 | | 3665 | | 4420 | | |
| SAN JOAQUIN/L.A. DIVN. | | | | | | | | | | | | | | | | | | | | | | |
| BALLAST | C.Y. | 3.08 | | 1785 | | 1785 | | 1785 | | 1785 | C.Y. | 3.08 | | 1950 | | 1950 | | 1950 | | 1950 | 218 | |
| SUB TOTALS (A) | | | | 1485 | | 1735 | | 2130 | | 2735 | | | | 1610 | | 1880 | | 2310 | | 3065 | | |
| TOTAL COSTS | | | | 3270 | | 3520 | | 3915 | | 4520 | | | | 3560 | | 3830 | | 4260 | | 5015 | | |
| TUCSON DIVN. | | | | | | | | | | | | | | | | | | | | | | |
| BALLAST | C.Y. | [illegible] | | 855 | | 855 | | 855 | | 855 | C.Y. | 1.47 | | 930 | | 930 | | 930 | | 930 | 218 | |
| SUB TOTALS (A) | | | | 1485 | | 1735 | | 2130 | | 2735 | | | | 1610 | | 1850 | | 2310 | | 3065 | | |
| TOTAL COSTS | | | | 2340 | | 2590 | | 2985 | | 3590 | | | | 2540 | | 2810 | | 3240 | | 3995 | | |
| PACIFIC LINES AVG. | C.Y. | 2.29 | | 1330 | | 1330 | | 1330 | | 1330 | C.Y. | 2.41 | | 1545 | | 1545 | | 1545 | | 1545 | 218 | |
| SUB TOTALS (A) | | | | 1495 | | 1735 | | 2130 | | 2735 | | | | 1610 | | 1850 | | 2310 | | 3065 | | |
| TOTAL COSTS | | | | 2815 | | 3065 | | 3460 | | 4065 | | | | 3155 | | 3155 | | 3855 | | 4610 | | |

TABLE D-5. TURNOUT RENEWAL COSTS
(July 1, 1975 Level)

MAIN LINE SWITCH & FROG RENEWAL
REPLACE 136# SWITCH POINTS, #14 FROG, STOCKRAILS

| | HRS. | RATE | I.C.C. ACCT. NO. | COST LABOR | COST MATL. | COST OTHER | |
|---|---|---|---|---|---|---|---|
| TRACK FORCE ( 5 MEN) | | | | | | | |
| TRAVEL TIME | 1.5 | 17.45 | 220 | 26. | | | |
| REMOVE/REPLACE SW. POINTS, FROG, STK. RAILS | 4.5 | 17.45 | 220 | 79. | | | |
| SWITCH POINTS (2), NEW | | | 216 | | 780. | | |
| FROG #14 RS,NEW | | | 216 | | 2609. | | |
| STOCKRAILS (2),NEW | | | 214 | | 847. | | |
| SPIKES/OTM, NEW | | | 216 | | 49. | | |
| EQUIPMENT RENTAL | | | | | | 30. | |
| SIGNAL FORCE ( 2 MEN) | | | | | | | |
| TRAVEL TIME | 1.5 | 11.43 | 249 | 17. | | | |
| REBOND RAIL, REMOVE/REPLACE SW.ROD & ADJUST | 6.5 | | 249 | 75. | | | |
| MISCL. MATL. | | | 249 | | 15. | | |
| EQUIPMENT RENTAL | | | 249 | | | 30. | |
| | | | | 197. | 4300. | 60. | |
| TOTAL- PERFORM WORK | | | | | | | 4557 |
| SALVAGE | | | | | | | |
| SCRAP RAIL | | | 214 | | 161. | | |
| SCRAP OTM | | | 216 | | 274. | | |
| SALVAGE CREDIT | | | | | | | ( 455 ) |
| NET COST | | | | | | | 4122 |

## TRACK COMPONENT LIFE AND COST EQUATIONS

### I. Rail

Life: $G = \frac{KWD^{1.565}}{F_r}$

Unit Cost: $U_r = \frac{(C)\left[1 - (0.004)\left(\frac{G}{D}\right)\right](1 + T)}{(1000)(KWD^{.565})}$

Annual Cost: $A_r = \frac{(Y)(F_r)(U_r)(1000)}{(1 + T)}$

Where - G = Rail life in million gross tons.

K = Composite relative physical wear factor (rail) for specific track segment.

W = Weight of rail (lbs./yd.)

D = Annual tonnage in million gross tons

$F_r$ = Composite relative traffic wear factor (rail) $\left(\sum\sum\sum\frac{D_{ijk}}{F_{ijk}}\right)$ for specific track segment.

$U_r$ = Cost in dollars per thousand gross ton miles.

C = Appropriate rail cost (dollars per mile)

T = Fraction (decimal) of total tonnage carried in locomotives.

$A_r$ = Annual cost in dollars per year.

Y = Length of specific track segment.

### II. Ties

Life: $H = \frac{(1.181)(L)(D^{0.60875})\left(e^{\left[4.5881 - 0.06077(\alpha)\right]}\right)}{F_t}$

Unit Cost: $U_t = \frac{(C)\left[1 - (0.02)(H)\right](1 + T)}{(1.181)(1000)(L)(D^{.60825})\left(e^{\left[4.5881 - .06077(\alpha)\right]}\right)}$

Annual Cost: $A_t = \frac{(Y)(F_t)(U_t)(1000)}{(1 + T)}$

Where - H = Tie life in years.

L = Composite physical wear factor (ties) for specific track segment.

D = Annual tonnage in million gross tons.

$\alpha$ = Degree of curvature.

$F_t$ = Composite relative traffic wear factor (ties) $(\sum\sum\sum \frac{D_{ijk}}{F_{ijk}})$ for specific track segment.

$U_t$ = Cost in dollars per thousand gross ton miles.

C = Appropriate tie cost (dollars per mile).

T = Fraction (decimal) of total tonnage carried in locomotives.

$A_t$ = Annual cost in dollars per year.

Y = Length of specific track segment.

III. Surfacing

Life: $J = \frac{(M)\ (D^{0.63698})\ (e^{3.2451})}{F_s}$

Unit Cost: $U_s = \frac{(3)\ (C)\ [1 - (0.039)\ (J)]\ (1 + T)}{(1000)\ (M)\ (D^{0.63698})\ (e^{3.2451})}$

Annual Cost: $A_s = \frac{(Y)\ (F_s)\ (U_s)\ (1000)}{(1 + T)}$

Where - J = Major surfacing cycle in years.

M = Composite relative physical wear factor (surfacing) for specific track segment.

D = Annual tonnage in million gross tons.

$F_s$ = Composite relative traffic wear factor (surfacing).

$U_s$ = Cost in dollars per thousand gross ton miles.

C = Appropriate surfacing cost (dollars per mile)

T = Fraction (decimal) of total tonnage carried in locomotives.

$A_s$ = Annual cost in dollars per year.

Y = Length of specific track segment.

IV. Undercutting, and Plowing/Sledding

Unit Cost: $U_b = \frac{(C)\ (1 + T)}{(1000)\ (D)\ (P)}$

Annual Cost: $A_b = \frac{(Y)\ (F_b)\ U_b)\ (1000)}{(1 + T)}$

Where - $U_b$ = Unit cost in dollars per thousand gross ton miles.

C = Appropriate undercutting or plowing/sledding cost (dollars per mile).

T = Fraction (decimal) of total tonnage carried in locomotives.

D = Annual tonnage in million gross tons.

P = Undercutting or plowing/sledding cycle.

$A_b$ = Annual cost in dollars per year.

Y = Length of specific track segment (miles).

$F_b$ = Composite traffic wear factor (ballasting) for specific track segment.

V. Turnouts and Track Crossings

Unit Cost: $U_o = \frac{(C)\ (1 + T)\ (N)}{(KWD^{.565})\ (1000)}$

Annual Cost: $A_o = \frac{(Y)\ (F_r)\ (U_o)\ (1000)}{(1 + T)}$

Where - $U_o$ = Cost in dollars per thousand gross ton miles.

C = Appropriate turnout/track crossing cost in dollars per turnout/track crossing.

T = Fraction (decimal) of total tonnage carried in locomotives.

N = Number of turnouts/track crossings in track segment.

K = Composite relative physical wear factor (rail) for specific track segment.

W = Weight of rail (lbs./yd.) in track segment.

D = Annual tonnage in million gross tons.

$A_o$ = Annual turnout/track crossing cost in dollars per year.

Y = Length of specific track segment.

$F_r$ = Composite relative traffic wear factor (rail) for specific track segment.

VI. Time-related Deterioration Of The Track Structure

Time-related deterioration of the track structure is treated in the rail, tie and surfacing unit cost equations. The factors in the equations which account for this are as follows:

1. Rail: $[1 - (0.004) (\frac{G}{D})]$
2. Ties: $[1 - (0.02) (H)]$
3. Surfacing: $[1 - (0.039) (J)]$

The rail factor is based upon a fixed loss due to corrosion of 0.4 percent per year. 1/ Estimated rail life in years is multiplied times 0.004 and subtracted from 1.0 to determine the fraction of total rail cost which is not due to corrosion. For example, if the estimated rail life in a given track segment is 20 years, then 92 percent $[1 - (0.004) (20) = 0.92]$ of the rail replacement cost is due to traffic moving over the rail. Similarily, if the estimated rail life is ten years, then 96 percent of the rail is due to traffic.

The tie factor is based upon an annual loss of the two percent 2/ due to time-related deterioration. The surfacing factor assumes a fixed cost of 3.9 percent per year. This percent loss is determined from a major surfacing

1/ Rail Systems Research Associates, and L. E. Peabody and Associates, Inc. Analysis of Track and Roadbed Maintenance Cost Variability. December 14, 1973, p. 43.

2/ Ibid p. 49.

cycle of 25.6 years at a very low annual tonnage. Based on this estimated life, 3.9 percent ($1.0 \div 25.6 = 0.039$) of the total major surfacing cycle costs are fixed with respect to traffic. Turnout, track crossing and ballasting costs are considered 100% variable with traffic.

## AN ACCOUNTING SYSTEM STRUCTURE

### Introduction

There is little doubt that significant improvements in railroad roadway cost analysis for pricing, maintenance planning and financial control purposes cannot be attained without the development of an accounting infrastructure substantially more refined than that which currently exists with the ICC Uniform System of Accounts. Many railroads, of course, have succeeded in developing parallel responsibility accounting systems for internal managerial control and decision-making.

The purpose of this section is not to introduce a new, proposed industry standard set of accounting procedures and system of accounts, but to briefly describe the basic elements required in the structure of such procedures and systems and to illustrate the use of these elements in this particular study.

### Basic Elements of An Accounting System Structure

A. Detail Expense Identification

The identification of roadway expenses at a level sufficient to permit analysis and control of roadway work activities and their related costs is a prime requisite of any accounting structure. The identification of normal roadway expense items shown here, cross-referenced to ICC Accounts, is divided into four sections:

- Ordinary (non-project/program) expense items. (Refered to herein as non-GMO expense items).

- Expense items resulting from the planning and control of expenditures on a project or program basis.

- Universal expense items - those which are common to other departments or organizations in the railroad (principally overhead items).

- Superintendence expense items.

-
-
-
-
-
-
-

NON PROJECT (GMO)

## 1. ENGINEERING EXPENSE IDENTIFICATION ITEMS

| Expense Identification No. (EIN) | ICC Account | Description |
|---|---|---|
| 001 | 220(Labor) 214(Material) | Spot Rail/Stock Renewals: Labor, rail and services for replacement of new and secondhand rail for minor repairs; costs for repairs and replacement of rail due to failures detected by detector cars or other ultrasonic test equipment; bonding and underground signal circuit costs in connection therewith. |
| 002 | 220 | Transposing Rail: Adzing and Setting Up Track: Labor, material and work train expense for transposing rail on curves, adzing and setting up rail. |
| 003 | 214 | Welding and Track Grinding: Operation of cross-cut rail grinders; on track, rail-top grinding trains; (not covered by GMO). Operating costs of continuous rail welding facilities are charges to EIN 192. |
| 004 | 220 | Operating Detector Cars and Ultrasonic Test Equipment: |
| 005 | 220(Labor) 212(Material) | Replacing Cross Ties: Labor, cross ties and work train costs to replace, install and re-space cross ties. Includes ballast deck and open-deck trestle ties. |
| 006 | 220(Labor) 212(Material) | Replacing Switch Ties: Labor, switch ties and work train costs to replace and install switch ties not included in special work order projects. |
| 007 | 220(Labor) 216(Material) | Replacing Frogs: Labor, frog material and services to replace switch frogs not included in rail renewal or other special work order projects. |
| 008 | 220(Labor) 216(Material) | Replacing Switch Points: Labor, switch point material and services to replace switch points not included in rail renewal or other special work order projects. |

| Expense Identification No. (EIN) | ICC Account | Description |
|---|---|---|
| 009 | 220(Labor)<br>216(Material) | Replacing Switches - Other Material: Labor, material and other expenses for replacement of turnout material excepting switch ties (EIN 006), frogs (EIN 007), switch points (EIN 008), not included in program rail renewal or other special work order projects. Stock rails will be charged to EIN 001. Material such as:<br><br>1. Connecting rods and tie rods.<br>2. Switch stands, keys and locks.<br>3. Gauge plates, switch slide plates and switch plates.<br>4. Heel fillers and floating heel blocks.<br>5. Braces. |
| 010 | 220(Labor)<br>216(Material) | Replacing Insulated Joints: Labor and material expenses for replacement of and repairs to insulated joints not included in program rail renewal or other special work order projects. |
| 011 | 220(Labor)<br>218(Material) | Surface Track Out-of-Face: Labor, material and work train used with out-of-face surfacing associated with program rail renewal preconditioning. |
| 012 | 220(Labor)<br>218(Material) | Ballast Cleaning and Plowing: Cost of operating ballast cleaning and under track equipment including ballast work train. Includes ballast material. |
| 013 | 220(Labor)<br>218(Material) | Ordinary Ballast Repairs: Cost of ballast and labor and work train for unloading this ballast for ordinary track repairs. Loading of ballast at quarries will be charged to EIN 190. Stockpiling ballast at quarries will be charged to EIN 191. |
| 015 | 202 | Miscellaneous Roadway Repairs: Labor, material and other expenses for repairs to roadway (not included in special work order authorities) such as:<br><br>1. Cleaning ditches.<br>2. Restoring embankments and bank protection devices.<br>3. Cleaning right-of-way, clearing right-of-way of spilled freight from revenue cars charge to EIN 168.<br>4. Trimming trees.<br>5. Driving stock off right-of-way (Disposing of dead stock charge to EIN 168). |

| Expense Identification No. (EIN) | ICC Account | Description |
|---|---|---|
| | | 6. Grouting and other methods of roadbed stabilization (non-program).<br>7. Patrolling tracks and right-of-way not covered by storm damage work order.<br>8. Oiling roadway.<br>9. Fighting fires on right-of-way.<br>10. Correct footing conditions (toe paths).<br>11. Servicing fire protection tank cars and pumps.<br><br>Cutting grass and weeds, cutting fireguards and other fire prevention work will be charged to EIN 052. |
| 016 | 220(Labor)<br>216(Material) | <u>Miscellaneous Track Repairs</u>: Labor, OTM material and other costs for miscellaneous repairs to track (not included in other special work order projects) such as:<br><br>1. Inspecting tracks.<br>2. Installing and repairing rail lubricators.<br>3. Painting switch targets.<br>4. track crossing (bolt, bars, including plates, etc.).<br>5. Labor to relocate and rearrange insulated joints (repairs to insulated joints charge to EIN 010).<br>6. Gauging track.<br>7. Replacing bolts, anti-creeper, angle bars.<br>8. Closing open joints.<br>9. Movement of track gangs and their housing where no GMO involved.<br>10. Repairs to bumping posts.<br>11. Material such as:<br>a. Spikes, bolts and nut locks.<br>b. Angle bars, tie plates and tie pads, including abrasion plates.<br>c. Tie plugs, anti-creepers.<br>d. Guard rail and guard rail trim.<br>12. Creosote or pentachlorophenol for applying to ties before replacing plates. |
| 016A | 220(Labor) | <u>Extraordinary Track Repairs-Derailments</u>: Labor and services to repair and restore track damaged by minor derailments (not covered by GMO). Material used for repair will be charged to appropriate EIN. |

| Expense Identification No. (EIN) | ICC Account | Description |
| --- | --- | --- |
| 017 | 220(Labor)<br>216(Material) | Extraordinary Track Repairs-Washouts: Labor and services to repair and restore track damaged by washouts (not covered by GMO). Material used for repair will be charged to appropriate EIN. |
| 018<br>019 | 273 | Crossing at Grade and Other Public Improvements: Labor and material costs for repairs to following:<br>1. Crossings at grade.<br>2. Paving in public streets.<br>3. Public sidewalks.<br>4. Curbing in public streets.<br>5. Gutters in public streets.<br>6. Drainage in public street area.<br>Repairs on lines serving exclusively freight facilities to EIN 018, and those on lines serving both passenger and freight to be charged to EIN 019 (ties and rail to charged to EIN 005 and 001 respectively). |
| 022 | 208 | Minor Bridge, Trestle and Culvert Repairs: Labor, material and other expenses for minor repairs to individual structures when not covered by GMO. |
| 023 | 220(Labor)<br>212(Material) | Renew Bridge Ties: Labor and material costs to cover ordinary renewal of bridge ties. Specially framed and dapped bridge ties should be reported to GMO work order covering. |
| 024 | 208 | Painting Bridges: Labor and material costs for painting steel bridges if not covered by GMO. |
| 025 | 206 | Repair Tunnels: Labor and material costs to make minor repairs when no GMO to cover and for routine inspection of tunnels. |
| 026 | 221 | Repair Snowsheds: Labor and material costs to make minor repairs when no GMO to cover and for routine inspection. Waterline repairs from source to snowshed if for fire protection. |
| 027<br>028<br>029 | 227 | Repair Stations and Office Buildings: Labor and material costs to repair (including painting) of stations and office buildings. |

| Expense Identification No. (EIN) | ICC Account | Description |
|---|---|---|

1. Passenger station buildings
2. Freight station buildings
3. Passenger platforms
4. Yard offices and buildings
5. Roads and walks serving facilities herein listed
6. Ice machines for drinking water in facilities listed herein
7. Air conditioners in buildings listed herein
8. Mail dock conveyors and machinery
9. Station building signs
10. Sewer, water, gas, electric facilities, serving facilities listed herein
11. Fences around buildings listed herein
12. Freight platforms and ramps
13. Stock corrals
14. Freight cranes and derricks (fixed)
15. Track scales
16. Pneumatic tube to communication lines
17. Moving gangs and their housing when not covered by GMO
18. Pavement within ground limits

Repairs to structures listed above serving exclusively freight facilities to be charged to EIN 027. To exclusively passenger and baggage facilities to be charged to EIN 028. Those serving both freight and passenger facilities to be charged to EIN 029.

| | | |
|---|---|---|
| 030 | 265 | <u>Repair Switching Yard Floodlights</u>: Labor and material costs to repair floodlights and floodlight poles and towers in yards. |
| 031 | 244 | <u>Repairing TOFC/COFC Terminals</u>: Labor and materials to repair TOFC/COFC facilities including structures, fixtures, machinery, platforms, roads and walks serving these facilities and other appurtenances. |
| 032<br>033 | 229 | <u>Repair Roadway Buildings</u>: Labor and material for repair (including painting) of M/W shops and roadway buildings: |

1. Maintenance of Way Repair Shops
2. M/W Shop Building Offices
3. M/W Employee Housing (except trailer houses charge EIN 087 )
4. Mobile house trailer parking facilities
5. Domestic water supply including housing, pump, motor and distribution facilities

| Expense Identification No. (EIN) | ICC Account | Description |
|---|---|---|
| | | 6. Tool houses, garages, setoffs<br>7. Sidewalks, driveways and fences serving facilities listed herein<br>8. Sewer, water, gas, electric lines serving facilities listed herein<br>9. M/W Shop Machinery and Equipment<br>10. Pavement within ground limits |
| | | Repairs to structures listed above on lines serving exclusively freight facilities to be charged to EIN 032. To lines serving both passenger and freight to be charged to EIN 033. |
| 034<br>035 | 235 | Repair Diesel Servicing Facilities: Labor, material and other expenses to repair diesel watering, fueling and sanding facilities.<br><br>1. Fuel and water pumps<br>2. Storage tanks<br>3. Servicing platforms<br>4. Boilers for heating lubricating oils<br>5. Fuel and water lines<br>6. Steam lines<br>7. Sewer, water, gas and electrical lines serving facilities herein<br>8. Fences around facilities included herein<br>9. Inspection pits<br>10. Pavement within ground limits<br><br>Repairs to structures listed above for servicing exclusively freight locomotives to be charged to EIN034 . Repairs to structures for servicing both passenger and freight to be charged to EIN 035. |
| 036<br>037 | 235 | Repair Mechanical Department Shops: Labor, material and other expenses to repair Mechanical Department shop buildings.<br><br>1. Car repair shops and sheds<br>2. Diesel repair shops<br>3. Storehouses<br>4. Paint shops<br>5. Test rooms and laboratories<br>6. Material and equipment platforms<br>7. Upholstering shops<br>8. Shop offices |

| Expense Identification No. (EIN) | ICC Account | Description |
|---|---|---|
| | | 9. One spot car repair buildings<br>10. Turntable repair<br>11. Pavement within ground limits<br>12. Sewer, water, gas and electrical lines serving facilities herein<br><br>Repairs to structures for repairs to freight locomotives and cars only are to be charged to EIN 036. Repairs to structures for repairs to both passenger and freight to be charged to EIN 037. |
| 038 | 241 | Repair Docks and Wharves: Labor, material and other expenses to repair docks, wharves and ferry slips; dredging waterways to approaches and around such structures; cribwork, rocks, caissons, guards, piling and other protection. |
| 039 | 253 | Repair Power Plants: Labor, material and other expenses to repair power plants and accessories devoted to utilization of water for power, including fixtures for lighting and heating and utilities serving such facilities.<br><br>1. Fuel tanks<br>2. Furniture<br>3. Hose and appliances for fire protection<br>4. Service platforms<br>5. Foundations except special for machines and other apparatus<br>6. Pavement within ground limits<br>7. Fences other than right-of-way fences<br>8. Wells (but not pumps) |
| 040 | 257 | Repair Electrical Power Transmission Systems: Labor, material and other expenses to repair systems for conveying electricity from producing plants to place or building where used including those for lighting systems for general lighting purposes. Movement of Electrical Gang and their housing when not covered by GMO. |
| 041 | 257 | Repair Steam and Air Power Transmission Systems: Labor, material and other expenses to repair systems for conveying steam and compressed air from producing plants to place or building where used. |

| Expense Identification No. (EIN) | ICC Account | Description |
|---|---|---|
| 042 | 221 | Repair Fences and Signs: Labor, material and other expenses to repair fences and signs:<br>1. Right-of-way boundary fences<br>2. Snow and sand fences including trees or shrubs and associated maintenance services used to control drifting sand or snow<br>3. Farm gates, cattleguards, wing fences and aprons<br>4. Signs other than those used for identifying bridges, stations, signals or other structures and signs used in flagging. |
| 043 | 249 | Repair Signal System: Labor, material and other expenses to repair signals, signal bridges, interlockers, signal towers, and other buildings (if used exclusively for housing signal facilities),furniture fixtures, machinery in connection therewith; also buildings and machinery of power plants used primarily for production of power for operation of signal system. Miscellaneous signalling facilities such as:<br>1. Dragging equipment detectors<br>2. Centralized traffic control systems<br>3. Train order signals<br>4. Switch heaters when operated as part of signal system<br>5. Crossing protection<br>6. Blue light signal at car repair facility<br>7. Hi-wide load detector<br>8. Movement of signal gang and housing when not covered by GMO. |
| 044 | 249 | Repair Hot Box Detector Systems: Labor, material and other expenses for repair of hot box detectors. |
| 047 | 249 | Repair Car Retarder Systems: Labor, material and other expenses including brake shoes for repair of Car Retarder Systems. |
| 048 | 247 | Repair Communications Facilities: Labor, material and other expenses for repair of telephone, telegraph, microwave, radio, radar inductive train communications, pneumatic tube systems in yards, etc. Tube systems in buildings charge to appropriate EIN for building involved. |

| Expense Identification No. (EIN) | ICC Account | Description |
|---|---|---|
| 052 | 202 | Controlling Vegetation: Labor, material and other expenses incurred in connection with vegetation control measures:<br><br>1. Cutting fireguards<br>2. Plowing or discing weeds<br>3. Burning vegetation to reduce fire danger<br>4. Chemical vegetation control application when not covered by GMO |
| 053 | 202 | Repairs due to Storm Damage: Extraordinary charges for labor, material and other expenses necessary to restore and maintain traffic, when not covered by GMO. |
| 054 | 272 | Removing Snow, Ice and Sand: Labor and other charges necessary for snow, sand and ice removal, including repairs, maintenance and supplies for switch heaters when not covered by GMO. |
| 056 | 271 | Small Tools: Cost for repairs and replacement of small roadway and track tools except identifiable signal tools. |
| 057 | 271 | Roadway and Track Supplies: Cost of supplies consumed in connection with roadway maintenance which are not assignable to a specific work function such as:<br><br>1. Fuel for heating<br>2. Fuel and lubricants for operation of motor cars and work equipment (non-highway use only). (When used for both highway and non-highway use EIN 901).<br>3. Ice for drinking water<br>4. Oil and wicks used in lanterns and for lighting of M/W tool houses and quarters.<br>5. Torpedoes, fuses and other train flagging equipment used by M/W & S forces.<br>6. Hard hats, rain gear, safety goggles, etc.<br>7. Utilities (water and electric, etc.) for M/W & S quarters and shops. |
| 058 | 269 | Repair Roadway Machines: Labor, material and other expenses incurred (fuel and lubricants excepted) for repair to M/W roadway machines used for repairs to roadway and structures. |

| Expense Identification No. (EIN) | ICC Account | Description |
|---|---|---|
| 059 | 220 | Work Equipment Lease or Rentals: Cost of long term leases of M/W work equipment. Rentals of equipment for special work order projects will be charged to those projects. |
| 070 | 201 | Repair of M/W Office Furniture and Equipment: Labor, material and services required for repairs to M/W office furniture and equipment such as:<br>1. Desks<br>2. Cabinets<br>3. Blue printers<br>4. Copy machines<br>5. Desk lamps<br><br>Repairs to typewriters, adding machines, desk top calculators and desk top computers charge to EIN 805. |
| 071 | 282 | Miscellaneous M/W & S Expenses: Labor and other expenses such as:<br>1. Attend meetings or courses for instruction (safety meetings EIN 870 )<br>2. Preparation of reports<br>3. Court attendance for the company |
| 072 | 274 | Injuries to Persons: Personal injury charges. |
| 073 | | Damages by Unknown Parties: Not to be used by field forces. Includes uncollectable damages. |
| 080 | 274 | On Call: Paid for but not worked (Electrical and Communications only). |

| Expense Identification No. (EIN) | ICC Account | Description |
|---|---|---|
| 082 | 485 | Service Mechanical Department Facilities: Labor and materials to service Mecanical Department facilities such as: Fire extinguishers, oil sumps and pumps, mechanical car washers, air tank traps, fire hydrants, air conditioners, air compressors, car cleaning facilities, industrial waste separator, filter washing facilities, electric motors, turntable motors, oil separator and sump, sludge traps, storage tanks, clean-up motive power refuse, clean sewers, clean lighting fixtures, and replace lamps. |
| 083 | 302 | Repair Mechanical Department Shop Machinery: Labor and materials to repair Mechanical Department shop machinery and equipment such as: platform jacks, filter washers, steam cleaners, drop tables, air compressors, battery chargers, pumps, electric motors, overhead or Gantry cranes. |
| 084 | 302 | Repair Mechanical Department Mechanized Work Equipment: Labor and material to repair portable equipment such as: shop compressors, platform tractors, fork lifts, personnel carriers (unlicensed), welding machines, ship sweeping machines, mobile craines, material handling equipment. |
| 085 | | Vacation Pay Other Than M/W Accounts:<br>Operation of signals (A/C 404)<br>Bridge tending (A/C 406)<br>Operation of communications (A/C 407)<br>Automotive (A/C 328) |
| 086 | | Holiday Pay Other Than M/W Accounts:<br>Operation of signals (A/C 404)<br>Bridge tending (A/C 406)<br>Operation of communications (A/C 407)<br>Automotive (A/C 328) |

| Expense Identification No. (EIN) | ICC Account | Description |
|---|---|---|
| 087 | 328 | Repairs to Trucks, Autos, House Trailers: Labor and material to repair automotive equipment such as: automobiles, trucks, material handling trailers, house trailers, licensed mobile cranes, licensed personnel carriers. |
| 088 | 326 | Repairs to Work Equipment (Rolling Stock): Labor and material to repair on-track rolling stock work equipment such as: pile driver (which can be moved in train service), Jordan spreader, locomotive cranes. |
| 089 | 404 | Operation of Hot Box Detectors: Labor and materials to service hot box detectors. Work consists of cleaning and testing scanners,bolometers, shutters, transducers, carriers, locators, pumps, etc. Supplies include such items as: recorder paper, lamp bulbs,tubes,fuses and pens. |
| 111 | | Spot Surface Track: Labor and material (except ballast) used for spot surfacing of track. |
| 150 | 379 | Attend Switch Lamps: Labor covers refueling fount and cleaning and replacing of lenses. |
| 151 | 379 | Clean and Oil Switches: Labor involves cleaning and oiling switch plates and other moving switch parts (switch machines excepted). |
| 152 | 404 | Clean Freight Cars: Labor, material and other expenses for cleaning freight cars, cleaning and bedding stock cars and removal of debris. (Cleaning of debris from right-of-way will be charged to EIN 015.) |
| 153 | 373 | Clean Inside Station Buildings: Labor and materials for janitorial work in station buildings: passenger depots, shelter sheds, freight stations, freight sheds. |
| 154 | 373 | Clean Inside Yard Buildings: Labor and materials for janitorial work in yard buildings; yard offices, switch shanties, yardmaster towers. |
| 155 | 314 | Cleaning Debris After Car Repairs by Mechanical Department at Rip Track. |

| Expense Identification No. (EIN) | ICC Acccount | Description |
|---|---|---|
| 156 | 415 | Rerail Locomotives and Cars and Clearing Derailments: Labor and services required to rerail locomotives and cars, also charges for reloading or transferring freight. Materials required for repairs to be charged to appropriate EIN. |
| 157 | 415 | Construct Track Panels: Labor and services required to construct track panels to be charged to this EIN. Materials used to be charged to appropriate EIN. |
| 158 | 373 | Service Freight Stations and Freight Offices: Labor, material and other expenses to service freight station and office facilities and equipment such as: air conditioners, heating equipment, plumbing, fire extinguishers and hydrants, steam generators, air compressors, roof exhaust fans, clean sewers, clean light fixtures and replace lamp. |
| 159 | 373 | Service Passenger Stations and Passenger Offices: Labor, material and other expenses to service passenger stations and office facilities. Facilities same as those listed under EIN 158except those added such as mail docks and conveyors. |
| 160 | 373 | Service Freight and Passenger Stations and Offices: Labor, material and other expenses to serve facilities common to both freight and passenger service. See EIN 158 and 159. |
| 161 | 389 | Service Yark Facilities: Labor, material and other expenses to service yard facilities such as: air conditioners, heating equipment, plumbing, fire extinguishers and hydrants, steam generators, air compressors, electric motors, sumps, pumps, exhaust fans, sewers, water facilities, replacement of lamps and cleaning of light fixtures. |
| 162 | 400 | Service Freight Locomotive Facilities: Labor, material and other expenses to service freight locomotive facilities such as: sumps, oil separator, filter cleaner, sewers and plumbing, engine washer, lube oil facility, fire extinguisher and hydrants, light fixtures including replacement of lamps, sanding facilities and watering facilities. |

| Expense Identification No. (EIN) | ICC Account | Description |
|---|---|---|
| 163 | 400 | Service Passenger Locomotive Facilities: Labor, material and other expenses to service passenger locomotive facilities, see EIN 162 |
| 164 | 400 | Service Freight and Passenger Locomotive Facilities: Labor, material and other expenses to service facilities common to freight and passenger locomotives, see EIN 162. |
| 165 | 402 | Service Trains and Cars in Commercial Service: Labor, material and other expenses to service facilities used in servicing trains and cars in commercial service such as: mechanical car washers, car cleaning pumps, asphalt car heating, watering facilities, trainmen lockerroom and club house facilities. |
| 166 | 376 | Repair Baggage Handling Equipment: Labor, material and other expenses used to repair baggage handling equipment such as: platform tractors, lift trucks, baggage carts, "Mary Anns," cranes and conveyors. |
| 167 | 227 | Repair Freight Handling Equipment: Labor, material and other expenses used to repair freight handling equipment such as: portable unloading ramps, "piggy-packer," lift trucks, portable cranes, platform tractors, freight station trailers, hand trucks, towveyor system. |
| 168 | 417 | Disposal of Dead Livestock: Labor and other expenses to remove and dispose of dead livestock from right-of-way. |
| 169 | 418 | Clear Right-of-Way of Spilled Freight from Revenue Cars: Labor and other expenses required to clear right-of-way of spilled commercial freight. |
| 170 | 404 | Operating and Servicing Signal Facilities: Labor and other expenses to operate and service signal facilities. Work consists of testing systems and cleaning signal roundels, lenses, reflectors, lamp bulbs, contacts, etc. Supplies include lamps, primary batteries, cleaning materials, CTC carrier tubes and fuses. |

| Expense Identification No. (EIN) | ICC Account | Description |
|---|---|---|
| 171 | 404 | Meggering and Sliding Relays: Labor and other expenses to megger cables and wires and sliding relays. |
| 172 | 405 | Service Crossing Protection Facilities: Labor and other expenses to service grade crossing protection facilities. Work consist of cleaning lenses, reflectors, lamp bulbs, contacts, electronic track circuits, etc. Supplies include lamps, primary batteries, cleaning materials, fuses. |
| 173 | 406 | Service Drawbridge Facilities: Labor, material and other expenses to service drawbridge control facilities such as: electric motors, air lines, control systems, lubricating systems. |
| 174 | 406 | Operate Drawbridge: Labor and other expenses to operate facilities. |
| 175 | 407 | Service Communications Facilities:<br>1. Expenses incidential to operation of inside communication facilities.<br>2. Rental of telgraph and telephone circuits, i.e., conductors, pole lines.<br>3. Rental of space or facilities occupied by radio microwave, etc.<br>4. Service, fuel tanks, batteries, tubes, etc. |
| 176 | 404 | Service Car Retarders: Labor and other expenses to service automatic car retarders. Clean and oil electronic equipment, service hydraulic lines and pumps, clean and oil switch machines in retarder system. |
| 177 | 404 | Service ACI Equipment: Test electronic eqipment associated and incidential to the operation of ACI System. |
| 178 | 421 | Service TOFC/COFC Terminals: Labor, material and other expenses to service TOFC/COFC facilities. Buildings, equipment such as: air conditioners, plumbing, heating, fire extinguishers, machinery, light fixtures, etc. |

| Expense Identification No. (EIN) | ICC Account | Description |
|---|---|---|
| 180 | 743 | <u>Repair Purchases and Materials Department Equipment</u>: Labor, material and other expenses used in repair of Purchases and Materials Department equipment such as: unlicensed mobile cranes, platform tractors, hand trucks, fork lifts, personnel carriers (unlicensed), etc. |
| 181 | 743 | <u>Service Purchases and Materials Department Facilities</u>: Labor and other expenses to service Purchases and Materials Department facilities such as: air conditioners, fire extinguishers and hyrants, plumbing and sewers, heating facilities, light fixtures. Change out light globes. |
| 182 | 712 | <u>Service Diesel Fueling Facilities</u>: Labor and other expenses to service diesel fueling facilities. Fuel pumps, storage tanks, contactors, fueling equipment, fuel heating equipment, electric motors, light fixtures, fire extinguishers and hyrants. Unload fuel oil. Change lamps. |
| 190 | 472 | <u>Operate Company Pits and Quarries</u>: Labor, equipment and supplies in connection with quarrying and loading current month poduction shipped from pits, such as:<br>1. operating crusher<br>2. loading ballast, rock or riprap<br>3. repairs to rock crusher<br>4. operate quarry<br>5. repairs to machinery and building in pit<br>6. cost of maintaining and shifting tracks and signals<br>7. operate shovels and end loaders to load rock<br>8. rental of equipment and outside rental |
| 191 | 472 | <u>Stockpile Company Pits and Quarries</u>: Labor, supplies and equipment in connection with stockpiling, blasting down and knocking down ballast, riprap, rock, etc. |
| 192 | 712 | <u>Operate Continuous Welded-Rail Facilities</u>: Labor and other expenses required to operate and service continuous welded-rail facilities. Includes all labor and supplies used to produce and handle rail |

| Expense Identification No. (EIN) | ICC Account | Description |
|---|---|---|
| | | through continuous welding process. Also includes servicing of all equipment, air conditioners, welding machines, mobile cranes, electric motors, grinders, electronic test equipment, index tables, transfer tables and conveyor systems. Supplies used such as: fuel, lubricating oil, abrasive belts and wheels, cutting wheels and thermite welding materials (for producing compromise rails). Labor and material used in connection with repairs is charged to EIN 033. |
| 193 | 471 | Service Automatic Sand Dryer: Labor and other expenses to service automatic sand dryers. |
| | | COMMUNICATIONS DEPARTMENT |
| 201 | 227 | Maintain Public Address System, Stations, Yards, Offices: Maintenance of amplifiers, control console, speakers, cables and associated equipment incidental to the operation of speaker system within station limits. |
| 202 | 235 | Maintain Public Address System Mechanical Department, Shops and Offices: Maintenance of amplifiers, control console, speakers, cables and associated equipment incidental to the operation of speaker system within shop limits. |
| 203 | 247 | Maintain Radios: Labor and material used in connection with the maintenance and repair of two-way VHF radios, i.e., walkie-talkies, base station and mobile units. |
| 204 | 247 | Maintain Microwave: Labor and material connected with the maintenance and repair of microwave terminals and repeaters. |
| 205 | 247 | Maintain Cable, Office Equipment, Teletype and Carrier Equipment: Labor and material for the maintenance and repair of all office equipment, i.e. teletype, wire line carrier, multiplex equipment and data equipment:<br>1. communications offices<br>2. cable pole bridle wires<br>3. inspecting communications offices |

| Expense Identification No. (EIN) | ICC Account | Description |
|---|---|---|
| | | 4. rectifiers<br>5. rewire office<br>6. checking, packing, shipping, receiving, unpacking and storing switchboard lateral conduit, cable boxes, office cable and office wire<br>7. renewal, maintenance and installation of telephones and associated equipment, such as that used on train dispatching and message telphone circuits, and yard or pony circuits, and all drops serving telephones in booths, boxes, way stations, section houses, yard offices and other buildings<br>8. repairing wire trouble in and caused by defective office equipment<br>9. Testing yard telephone circuits<br>10. cutting wires in and out of buildings<br>11. checking, sharpening, cleaning, repairing, shipping, receiving and storing all tools. |
| 206 | 249 | <u>Maintain Hot Box Carrier Equipment</u>: Labor and materials used for the maintenance of and repair of carrier equipment used in connection with hot box detectors. |
| 207 | 247 | <u>Maintain Poles and Appurtenances</u>: Labor and material expense to:<br>1. apply or replace crossarms, anchors, guys and braces<br>2. move, reset, stub, straighten and set poles<br>3. store, load, unload and ship poles<br>4. frame poles |
| 208 | 247 | <u>Maintain Wires and Appurtenances</u>: Labor and material expense to:<br>1. change brackets<br>2. install, replace and transfer pins<br>3. adjust slack<br>4. straighten single circuit, point type or phantom transportation brackets<br>5. renew, transfer, untie and retie wires<br>6. clear wire interruptions<br>7. test and locate trouble on circuits, <u>except</u> testing yard telephone circuits |

| Expense Identification No. (EIN) | ICC Account | Description |
|---|---|---|
| | | 8. check, pack, ship, receive, unpack and store line wire materials<br>9. check foreign line wire attachments<br>10. clear rubbish, bark, limbs or refuse from wires<br>11. locate and check elevation of wires over tracks reported as having impaired clearance and reporting such trouble to owners |
| 209 | 202 | Clearing and Trimming Brush and Trees: Labor and other expenses to trim brush or trees and to remove undergrowth; also to place guys on trees to permit trimming of them by highway authorities or property owner if off right-of-way. |
| 221 | 247 | Travel Time: All time spent traveling between points for the purpose of maintaining communications facilities, except travel time on recollectable or specific work order jobs. |
| 222 | 282 | Reports, Correspondence, Meetings: All time spent writing reports and correspondence, attending safety meetings, writing requisitions, etc. |
| 240 | 407 | Pay of Employees: Accounting for telephone operator. |
| 049 | 237 | Repair Grain Elevators: Labor, material and other expenses to repair grain storage facilities including structures, on loading and off loading equipment, fixtures and roads and walks serving these facilities. |
| 050 | 239 | Repair Storage Warehouses: Labor, material and other expenses to repair storage warehouses including structures, machinery and fixtures. |
| 051 | 265 | Repair Automobile Loading/Unloading Facilities: Labor, material and other expenses to repair automobile loading and unloading facilities including structures, fixtures, machinery and roads and walks serving these facilities and other appurtenances. |

PROJECT (GMO)

## 2. ENGINEERING EXPENSE IDENTIFICATION ITEMS

| Item No. | ICC Account | Description |
|---|---|---|
| 100P | 220(Labor)<br>214(Material) | Program Renewal-Curves: Labor, rail and services for replacement of curve-worn rail. |
| 101P | 220(Labor)<br>214(Material) | Program Rail Renewal-Mainlines: Labor, rail and services for program mainline rail renewal. |
| 102P | 220(Labor)<br>214(Material) | Program Rail Renewal-Branchlines: Labor, rail and services for program branchline rail renewal. |
| 103P | 220(Labor)<br>214(Material) | Program Rail Renewal-Repair Rail: Labor, rail and services for program rail relays to make repair rail. |
| 003P | 214 | Program Welding and Track Grinding: See 003. |
| 006P | 220(Labor)<br>212(Material) | Program Switch Tie Replacement: See 006. |
| 007P | 220(Labor)<br>216(Material) | Program Frog Replacement: See 007. |
| 008P | 220(Labor)<br>216(Material) | Program Switch Point Replacement: See 008. |
| 009P | 220(Labor)<br>216(Material) | Program Replacement of Switches-Other Material: See 009. |
| 010P | 220(Labor<br>216(Material) | Program(Project) Replacement of Insulated Joints: See 010. |
| 016P | 220(Labor)<br>216(Material) | Program(Project) Miscellaneous Track Repairs: See 016. |
| 016AP | 220 | Project Extraordinary Track Repairs-Derailments: See 016A. |
| 017P | 220(Labor)<br>216(Material) | Project Extraordinary Track Repairs-Washouts: See 017. |
| 022P | 208 | Program Minor Bridge, Trestle, Culvert Repairs: See 022. |
| 023P | 220(Labor)<br>212(Material) | Program Bridge Tie Renewal: See 023. |

| Item No. | ICC Account | Description |
|---|---|---|
| 024P | 208 | Program Bridge Painting: See 024 |
| 025P | 206 | Program Tunnel Repair: See 025. |
| 026P | 221 | Program Snowsheds Repair: See 026. |
| 040P | 257 | Program Electrical Power Transmission Systems Repair: See 040. |
| 052P | 202 | Program Vegetation Control: See 052. |
| 053P | 202 | Project Storm Damage Repair: See 053. |
| 054P | 272 | Program Snow, Ice and Sand Removal: See 054. |

## 3. EXPENSE IDENTIFICATION - UNIVERSAL

| Item No. | Description |
|---|---|
| 803 | Office Expenses and Supplies |
| 804 | Office Furniture |
| 805 | Office Machines |
| 807 | Insurance |
| 810 | Depreciation |
| 811 | Joint Facility - Debit (M/W and Gen'l Accts Only) |
| 812 | Joint Facility - Credit (M/W and Gen'l Accts Only) |
| 813 | Rents and Leases, Including Office Machines |
| 814 | Time Share Computer |
| 816 | Personnel Expenses Paid Direct by Company, Other Than Relocation Expenses of Agreement Personnel |
| 817 | Health and Welfare |
| 818 | Club or Association Dues |
| 820 | Fidelity Bonds |
| 821 | Business Car Expense - Officers |
| 822 | AAR Assessments |
| 823 | Automotive Licenses and Fees |
| 824 | Express Charges |
| 825 | Legal Fees |
| 828 | Recollectible Credit |
| 829 | Material Sales |
| 830 | Vacation Pay |
| 831 | Holiday Pay |
| 838 | Performing Jury Duty |
| 839 | Fees, Dues, Memberhips (Force) |
| 840 | Home Sale Loss, Moving Expenses and Transportation Charges for Relocation of Non Agreement Personnel |
| 850 | Adj. Vacation and Paid Holiday Additives |
| 851 | Additives - Supervision |
| 852 | Workmen's Compensation |
| 853 | Meal and Lodging - Force (Other Than Train, Engine and Yard Employees - See EIN 751. |
| 854 | Employee Personal Injury Payments |
| 860 | Accruals - Wages |
| 869 | Physical Examination Fees |
| 870 | Safety Meetings |
| 881 | Salaried Payroll Variance |

| Item No. | Description |
|---|---|
| 902 | Material Store Expense |
| 904 | Gasoline and Oil |
| 905 | Direct Charge Material Less than $50.00 |
| 906 | Ice |
| 909 | Leased Automotive Equipment |
| 910 | Stationery and Printing (Except Tariffs) 358-1 |
| 911 | Freight Charges Direct Charge Material |
| 912 | Utility Bills |
| 913 | Personal Expense |
| 914 | Freight Charges Other Than Direct Charge |
| 915 | General Office - Maintenance |
| 918 | General Office - Operation |

## 4. ENGINEERING EXPENSE IDENTIFICATION - SUPERINTENDANCE

| Item No. | ICC Account | Description |
|---|---|---|
| 113-119 (Incl.) | 201 | Pay of Officers |
| 120-132 (Incl.) | 201 | Pay of Supervisors |
| 136-139 (Incl.) | 201 | Pay of Administrative Supervisors |
| 140-142 (Incl.) | 201 | Pay of Technical Employees |
| 143 | 201 | Pay of Clerical Exempt Employees |
| 144-148 (Incl.) | 201 | Pay of Clerical Employees |
| 149 | 201 | Pay of Salaried Mechanics |

B. Incurring Responsibility (Cost Center)

Representative cost center/responsibility designation for engineering forces at division and maintenance district levels may be represented by the organizational breakdown shown below.

Expense Allocation - Cost Centers

| CODE | Description |
|---|---|
| X400 | Division Engineer |
| X401 | Division Automotive and Work Equipment Shop |
| X402 | Division Structures Supervisor |
| X403 | Division Electrical Supervisor |
| X404-410 | District Roadmasters |
| X411 | Division Signal Supervisor |
| X412 | Division Water and Fuel Supervisor |

Whether it is necessary or desirable to provide further cost center distinction by refinement say, to the work crew or gang level depends on the degree of control deemed necessary by the individual railroad.

C. Expense Groups

Detailed expense items may be grouped into major operations cost accounts and such accounts can be further aggregated into major engineering expense groups for managerial analysis and control. These groupings are shown in the following two sections.

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-
-
-
-
-
-
-
-
-
-
-
-

1. <u>Operations Cost Accounts</u>

| OCA NO. | OVERHEAD |
|---|---|
| 100 | ADMINISTRATIVE |
| | EIN NO.<br>070 - REPAIR OF MofW OFFICE FURNITURE AND EQUIPMENT<br>113-119 INCL. - PAY OF OFFICERS<br>120-132 INCL. - PAY OF SUPERVISORS<br>136-139 INCL. - PAY OF ADMINISTRATIVE SUPERVISORS<br>140-142 INCL. - PAY OF TECHNICAL EMPLOYEES<br>143 - PAY OF CLERICAL EXEMPT EMPLOYEES<br>144-148 INCL. - PAY OF CLERICAL EMPLOYEES<br>149 - PAY OF MECHANICS (SALARIED PAYROLL)<br>851 - ADDITIVES - SUPERVISION<br>860 - ACCRUALS - WAGES<br>881 - SALARIED PAYROLL VARIANCE |
| 101 | BENEFITS |
| | 085 - VACATION PAY - OTHER THAN MofW ACCOUNTS<br>OPERATION OF SIGNALS<br>BRIDGE TENDING<br>OPERATION OF COMMUNICATIONS<br>AUTOMOTIVE<br>086 - HOLIDAY PAY - OTHER THAN MofW ACCOUNTS<br>OPERATION OF SIGNALS<br>BRIDGE TENDING<br>OPERATION OF COMMUNICATIONS<br>AUTOMOTIVE<br>819 - WAGE DISPUTES<br>830 - VACATION PAY<br>831 - HOLIDAY PAY<br>852 - WORKMENS COMPENSATION<br>853 - MEALS AND LODGING - FORCE |

| OCA NO. | OVERHEAD |
|---|---|
| 102 | ADMINISTRATION SERVICES |

EIN NO.
071 - MISCELLANEOUS MofW EXPENSES
802 - OFFICE SUPPLIES
803 - OFFICE EXPENSES
804 - OFFICE FURNITURE
805 - OFFICE MACHINES
807 - INSURANCE
813 - RENTS AND LEASES, INCLUDING OFFICE MACHINES
814 - TIME SHARE COMPUTER
816 - PERSONAL EXPENSES - OFFICERS
818 - FEES, DUES, MEMBERSHIPS (OFFICERS)
820 - FIDELITY BONDS
821 - BUSINESS CAR EXPENSES - OFFICERS
822 - A.A.R. ASSESSMENTS
823 - AUTOMOTIVE LICENSES AND FEES
824 - EXPRESS CHARGES
825 - LEGAL FEES
838 - PERFORMING JURY DUTY
839 - FEES, DUES, MEMBERSHIPS (FORCE)
840 - HOME SALES LOSS - MOVING EXPENSE
869 - PHYSICAL EXAMINATION FEES
870 - SAFETY MEETINGS
902 - MATERIAL STORE EXPENSE
904 - GASOLINE AND OIL
905 - DIRECT CHARGE MATERIAL LESS THAN $50
906 - ICE
909 - LEASED AUTOMOTIVE EQUIPMENT
910 - STATIONERY AND PRINTING
911 - FREIGHT CHARGES DIRECT CHARGE MATERIAL
912 - UTILITY BILLS
913 - PERSONAL EXPENSE
914 - FREIGHT CHARGES OTHER THAN DIRECT CHARGE MATERIAL
915 - GENERAL OFFICE - MAINTENANCE
918 - GENERAL OFFICE - OPERATION

| | |
|---|---|
| 103 | CHANGE IN ASSETS |

EIN NO.
828 - RECOLLECTIBLE CREDITS
829 - MATERIAL SALES
850 - ADJ,VAC,AND PAID HOLIDAY ADDITIVES

| OCA NO. | OVERHEAD |
|---|---|
| 104 | DEPRECIATION - ROAD |
| | 810 - DEPRECIATION - ACCT. 266 |
| 105 | JOINT FACILITIES |
| | 811 - JOINT FACILITY - DR.<br>812 - JOINT FACILITY - CR. |
| 106 | HEALTH & WELFARE |
| | 817 - HEALTH & WELFARE BENEFITS - ACCT. 277 |
| 107 | PERSONAL INJURIES |
| | 072 - INJURIES TO PERSONS - ACCT. 274<br>854 - EMPLOYEE PERSONAL INJURY PAYMENTS - ACCT. 274 |

| OCA NO. | MAINTENANCE |
|---|---|
| 110 | CURVE RAIL PROGRAM<br>100P PROGRAM RAIL RENEWAL - CURVES |
| 111 | MAINLINE RAIL PROGRAM<br>101P PROGRAM RAIL RENEWAL - MAINLINE |
| 112 | BRANCHLINE PROGRAM<br>102P PROGRAM RAIL RENEWAL - BRANCHLINE |
| 113 | RELAYS TO MAKE REPAIR RAIL<br>103P PROGRAM RAIL RENEWAL - REPAIR RAIL |
| 114 | REPAIR RAIL<br><br>001 - RENEW RAIL - STOCK RAIL |
| 115 | OTHER TRACK MAINTENANCE<br><br>007 - REPLACING FROGS<br>008 - REPLACING SWITCH POINTS<br>009 - REPLACING SWITCHES - OTHER MATERIAL<br>010 - REPLACING INSULATED JOINTS<br>016 - MISCELLANEOUS TRACK REPAIRS<br>095 - FORM 203 BALANCING - TRACK - ACCT. 220-10 50%<br>150 - ATTEND SWITCH LAMPS<br>151 - CLEAN AND OIL SWITCHES<br>016P - MISCELLANEOUS TRACK REPAIRS - PROGRAM<br>016AP - ETRAORDINARY TRACK REPAIRS - DERAILMENTS-PROJECT<br>007P - REPLACING FROGS - PROJECT<br>008P - REPLACING SWITCH POINTS - PROJECT<br>009P - REPLACING SWITCHES - OTHER MATERIAL - PROJECT<br>010P - REPLACING INSULATED JOINTS - PROJECT |
| 116 | TRANSPOSING RAIL; ADZING AND SETTING UP TRACK<br><br>002 - TRANSPOSING RAIL, ADZING AND SETTING UP TRACK |
| 117 | WELDING AND TRACK GRINDING<br><br>003 - WELDING AND TRACK GRINDING<br>003P - WELDING AND TRACK GRINDING - PROGRAM |
| 118 | CROSSING AT GRADE AND OTHER PUBLIC IMPROVEMENTS<br><br>018,019 - CROSSING AT GRADE AND OTHER PUBLIC IMPROVEMENTS |

| OCA NO. | MAINTENANCE |
|---|---|
| 120 | CROSS TIE PROGRAM |
| | EIN NO.<br>005 - REPLACING CROSS TIES |
| 121 | SWITCH TIE PROGRAM |
| | 006 - REPLACING SWITCH TIES<br>006P - REPLACING SWITCH TIES - PROJECT |
| 122 | SURFACING |
| | 011 - SURFACE TRACK - OUT OF FACE<br>012 - BALLAST CLEANING AND PLOWING<br>013 - ORDINARY BALLAST REPAIRS<br>011 - SPOT SURFACE TRACK<br>190 - OPERATE COMPANY PITS AND QUARRIES<br>191 - STOCKPILE COMPANY PITS AND QUARRIES |
| 124 | ROADWAY MAINTENANCE AND REPAIRS |
| | 093 - FORM 203 BALANCING - TRACK - ACCT. 202-10 50%<br>015 - MISCELLANEOUS ROADWAY REPAIRS<br>168 - DISPOSAL OF DEAD LIVESTOCK<br>169 - CLEAR RIGHT-OF-WAY OF SPILLED FREIGHT FROM REVENUE CARS |
| 125 | ROADWAY PROTECTION |
| | 042 - REPAIR FENCES AND SIGNS |
| 126 | CONTROLLING VEGETATION |
| | 052 - CONTROLLING VEGETATION<br>209 - CLEARING AND TRIMMING BRUSH AND TREES<br>052P - CONTROLLING VEGETATION - PROJECT |
| 128 | PAINTING BRIDGES |
| | 024 - PAINTING BRIDGES<br>024P - PAINTING BRIDGES - PROJECT |
| 129 | MINOR BRIDGE, TRESTLE AND CULVERT REPAIRS |
| | 022 - MINOR BRIDGE, TRESTLE AND CULVERT REPAIRS<br>094 - B&B WATER SERVICE, ELECT. SIGNAL - ACCT. 208 25%<br>023P - MINOR BRIDGE, TRESTLE AND CULVERT REPAIRS - PROJECT |
| 130 | BRIDGE, TRESTLE AND CULVERT |
| | 023 - RENEW BRIDGE TIES<br>173 - SERVICE DRAWBRIDGE FACILITIES<br>174 - OPERATE DRAWBRIDGE<br>023P - RENEW BRIDGE TIES - PROJECT |
| 131 | TUNNEL MAINTENANCE |
| | 025 - REPAIR TUNNELS<br>025P - REPAIR TUNNELS - PROJECT |

| OCA NO. | MAINTENANCE |
|---|---|
| 132 | ROADWAY BUILDING MAINTENANCE |
| | EIN NO.<br>032-033 - REPAIR ROADWAY BUILDINGS |
| 133 | SNOWSHED MAINTENANCE |
| | 026 - REPAIR SNOWSHEDS<br>026P - REPAIR SNOWSHEDS - PROJECT |
| 135 | CAR RETARDERS |
| | 047 - REPAIR CAR RETARDER SYSTEMS<br>176 - SERVICE CAR RETARDERS |
| 136 | SIGNAL SYSTEM MAINTENANCE |
| | 098 - FORM 203 BALANCING - B&B, WATER SERVICE, ELECT., SIGNAL - ACCT. 249 25%<br>043 - REPAIR SIGNAL SYSTEM<br>170 - SERVICE SIGNAL FACILITIES<br>171 - MEGGARING AND SLIDING RELAYS<br>172 - SERVICING CROSSING PROTECTION FACILITIES |
| 137 | OPERATING DETECTOR CARS |
| | 004 - OPERATING DETECTOR CARS AND ULTRASONIC TEST EQUIPMENT |
| 138 | SAFETY DETECTION MAINTENANCE |
| | 044 - REPAIR HOT BOX DETECTOR SYSTEMS<br>089 - OPERATION OF HOT BOX DETECTORS<br>206 - MAINTAIN HOT BOX CARRIER EQUIPMENT |
| 139 | ELECTRICAL MAINTENANCE, FIELD |
| 140 | STORM DAMAGE |
| | 053 - REPAIRS DUE TO STORM DAMAGE<br>054 - REMOVING SNOW, ICE AND SAND<br>053P - REPAIRS DUE TO STORM DAMAGE - PROJECT<br>054P - REMOVING SNOW, ICE AND SAND - PROJECT |
| 141 | DERAILMENTS |
| | 156 - RERAIL LOCOMOTIVES AND CARS<br>157 - CONSTRUCT TRACK PANELS |
| 142 | FIRE SUPPRESSION AND SPECIAL DAMAGES |

| OCA NO. | MAINTENANCE |
|---|---|
| 145 | STATION, OFFICE AND OTHER BUILDINGS |

EIN NO.
096 - B&B, WATER SERVICE, ELECT., SIGNAL - ACCT. 227 25%
027-028-029 - REPAIR STATIONS AND OFFICE BUILDINGS
030 - REPAIR SWITCHING YARD FLOODLIGHTS
031 - REPAIRING TOFC/COFC TERMINALS
153 - CLEAN INSIDE STATION BUILDINGS
154 - CLEAN INSIDE YARD BUILDINGS
158 - SERVICE STATIONS AND OFFICES-FRT.
159 - SERVICE STATIONS AND OFFICES-PASS.
160 - SERVICE STATIONS AND OFFICES-FRT. & PASS.
161 - SERVICE YARD FACILITIES
178 - SERVICE TOFC/COFC TERMINALS
181 - SERVICE PURCHASING & STORE DEPT. FAC.
167 - REPAIR FREIGHT & HANDLING EQUIPMENT

146 MECHANICAL DEPARTMENT BUILDING MAINTENANCE

036-037 - REPAIR MECHANICAL DEPARTMENT SHOPS
097 - B&B, WATER SERVICE, ELECT., SIGNAL - ACCT. 235 25%

147 ELECTRICAL SYSTEMS

148 WATER SYSTEMS

149 MECHANICAL DEPARTMENT FACILITIY MAINTENANCE

034-035 - REPAIR DIESEL SERVICING FACILITIES
162 - SERVICE LOCOMOTIVE FACILITIES - FRT.
163 - SERVICE LOCOMOTIVE FACILITIES - PASS.
164 - SERVICE LOCOMOTIVE FACILITIES - FRT. & PASS.
182 - SERVICE DIESEL FUELING FACILITIES
193 - SERVICE AUTOMATIC SAND DRYER

150 STEAM AND AIR POWER TRANSMISSION LINE MAINTENANCE

041 - REPAIR STEAM AND AIR POWER TRANS. SYSTEMS
039 - REPAIR POWER PLANTS

151 ELECTRICAL POWER LINE MAINTENANCE

040 - REPAIR ELECTRICAL POWER TRANS. SYSTEMS
040P - REPAIR ELECTRICAL POWER TRANS. SYSTEMS

152 WHARF AND DOCK MAINTENANCE

038 - REPAIR DOCKS AND WHARVES

| OCA NO. | SERVICES |
| --- | --- |
| 153 | COMMUNICATIONS SYSTEM MAINTENANCE |
| | EIN NO. |
| | 048 - REPAIR COMMUNICATION FACILITIES |
| | 175 - SERVICE COMMUNICATION FACILITIES |
| | 201 - MAINT. PUBLIC ADDRESS SYSTEM, STATION, YARDS, OFFICES |
| | 202 - MAINT. PUBLIC ADDRESS SYSTEM, MECH. DEPT., SHOPS AND OFFICES |
| | 203 - MAINTAIN RADIOS |
| | 204 - MAINTAIN MICROWAVE |
| | 205 - MAINTAIN CABLE, OFFICE EQUIPMENT, TELETYPE AND CARRIER EQUIPMENT |
| | 207 - MAINTAIN POLES AND APPURTENANCES |
| | 208 - MAINTAIN WIRES AND APPURTENANCES |
| | 221 - TRAVEL TIME |
| | 908 - COMMUNICATIONS - VOUCHER CODE |
| 154 | COMMUNICATIONS SYSTEM ADDITIONS |
| 157 | TOOLS, SUPPLIES |
| | 056 - SMALL TOOLS |
| | 057 - ROADWAY AND TRACK SUPPLIES |
| 158 | WORK EQUIPMENT AND TRUCKS (RETIRE - REPLACE) |
| | 058 - REPAIR ROADWAY MACHINES |
| | 059 - WORK EQUIPMENT LEASE OR RENTALS |
| | 087 - REPAIR TRUCKS AND AUTOS |
| | 907 - AUTOMOTIVE AND WORK EQUIPMENT |
| 159 | RAIL WELDING |
| | 192 - OPERATE CONTINUOUS WELDED RAIL FACILITIES |
| 160 | OTHER DEPARTMENT FACILITIES AND EQUIPMENT |
| | 082 - SERVICE MECHANICAL DEPARTMENT FACILITIES |
| | 083 - REPAIR MECH. DEPT. SHOP FACILITIES |
| | 084 - REPAIR MECH. DEPT. MECHANIZED WORK EQUIPMENT |
| | 088 - REPAIRS TO WORK EQUIPMENT (ROLLING STOCK) |
| | 152 - CLEAN FREIGHT CARS |
| | 155 - CLEARING DEBRIS AFTER CAR REPAIRS BY MECHANICAL DEPARTMENT AT RIP TRACK |
| | 165 - SERVICE TRAINS AND CARS IN COMMERCIAL SERVICE |
| | 166 - REPAIR BAGGAGE HANDLING EQUIPMENT |
| | 180 - REPAIR PURCHASING AND MATERIALS DEPT. EQUIPT. FOR USE OF COMMUNICATIONS DEPARTMENT ONLY. |

| OCA NO. | OPERATING IMPROVEMENTS |
|---|---|
| | ROADWAY |
| 165 | MAIN LINE |
| 166 | BRANCHES |
| 167 | YARDS |
| 168 | SIDINGS |
| | STRUCTURES |
| 170 | BRIDGES, TRESTLES AND CULVERTS |
| 171 | TUNNELS AND SNOWSHEDS |
| 174 | BANK PROTECTIONS AND JETTIES |
| 175 | FENCES AND SIGNS |
| | BUILDINGS |
| 176 | STATIONS, OFFICES AND OTHER ROADWAY #177 - SERVICE ACI EQUIPMENT |
| 177 | MECHANICAL DEPARTMENT FACILITIES |
| 178 | PURCHASE OF ROADWAY EQUIPMENT |
| 179 | PURCHASE OF HAND TOOLS |
| 180 | DIESEL SERVICING FACILITIES |
| 181 | WHARVES AND DOCKS |
| 182 | POWER PLANTS AND ELECTRIC POWER TRANSMISSION LINES |
| 183 | SIGNAL SYSTEMS |
| | INDUSTRIAL IMPROVEMENTS |
| 185 | TRACK |
| 186 | FACILITIES |
| 187 | BUILDINGS |

| OCA NO. | OPERATING IMPROVEMENTS |
|---|---|
| | PUBLIC IMPROVEMENTS |
| 189 | PUBLIC IMPROVEMENTS OTHER THAN STS. (CANALS, ETC.) |
| 190 | GRADE CROSSINGS |
| 191 | SEPARATIONS |
| 192 | ASSESSMENTS |
| 193 | STREET IMPROVEMENTS, LONGITUDINAL OCCUPANCY |
| | RETIREMENTS |
| 194 | TRACK |
| 195 | BUILDINGS |
| 196 | FACILITIES - INCL. BT&C, SIGNALS, TOOLS |
| 197 | EQUIPMENT |
| 198 | LAND |

## 2. ENGINEERING EXPENSE GROUPS

Engineering Expenditures (In Thousands)

| OCA (Operations Cost Account) | Investment | Project/Program Operating | Ordinary Operating | Miscellaneous |
|---|---|---|---|---|
| | Labor/Material/Other Total | L/M/O/Total | L/M/O/Total | L/M/O/Total |
| Maintenance of Way | | | | |
| Rail | | | | |
| 110 Curve Program | | | | |
| 111 Mainline Program | | | | |
| 112 Branchline Program | | | | |
| 114 Repair Rail | | | | |
| 137 Detector Car | | | | |
| Total Rail | | | | |
| Other Track | | | | |
| 115 Other Rail | | | | |
| 116 Trans. Rail Adz. | | | | |
| 117 Welding, Grinding | | | | |
| 118 Xing & Pub. Imp. | | | | |
| Total Other Track | | | | |
| Ties | | | | |
| 120 Tie Program | | | | |
| 121 Other Replace. | | | | |
| Total Ties | | | | |
| 122 Surfacing | | | | |
| Surfacing Total | | | | |
| Roadway Maintenance | | | | |
| 124 Roadway Maint. | | | | |
| 125 Roadway Protec. | | | | |
| 126 Controlling Veg. | | | | |

Monthly Expenditures

## 2. ENGINEERING EXPENSE GROUPS, CONT.

| OCA | Investment | Project/Program Operating | Ordinary Operating | Miscellaneous |
|---|---|---|---|---|
| | L/M/O/Total | L/M/O/Total | L/M/O/Total | L/M/O/Total |
| Total Roadway Maint. | | | | |
| Total M of W | | | | |
| Maint. of Struct. & Buildings | | | | |
| 145 Station Offices | | | | |
| 146 Mech. Dept. Bldg. | | | | |
| 147 Elect. Systems | | | | |
| 148 Water Systems | | | | |
| Total Buildings | | | | |
| Roadway Structures | | | | |
| 128 Painting Bridge | | | | |
| 129 Minor Bridge | | | | |
| 130 Bridge, Trees, Cul. | | Monthly Expenditures | | |
| 131 Tunnels, Snowshed | | | | |
| 132 Roadway Bldg. | | | | |
| Total Roadway Struc. | | | | |
| Facilities | | | | |
| 149 Mech. Dept. Fac. | | | | |
| 150 Steam, Air Maint. | | | | |
| 151 Elec. Power Maint. | | | | |
| 152 Wharf, Dock Maint. | | | | |
| Total Facilities | | | | |
| Total Maint. of Struc. | | | | |
| Services/ Comm. Systems | | | | |
| 153 Comm. Sys. Maint. | | | | |
| 154 Comm Sys. Adds. | | | | |
| Total Comm. Systems | | | | |

2. ENGINEERING EXPENSE GROUPS, CONT.

| OCA | Investment | Project/Program Operating | Ordinary Operating | Miscellaneous |
|---|---|---|---|---|
| | L/M/O/Total | L/M/O/Total | L/M/O/Total | L/M/O/Total |
| 157 Tools/Supplies | | | | |
| Total Tools/Supplies | | | | |
| 158 A & WE - Total | | | | |
| A & WE - Total | | | | |
| Signal | | | | |
| 135 Car Retard. Maint. | | | | |
| 136 Signal Sys. Maint. | | | | |
| 138 Safety Detect. | | | | |
| Total Signal | | | | |
| 159 Rail Processing | | Monthly Expenditures | | |
| Rail Proces. - Total | | | | |
| Timber Prods & Proc. | | | | |
| 160 Ties | | | | |
| Total Timber P & P | | | | |
| Total Services | | | | |
| Damages | | | | |
| 140 Storm Damage | | | | |
| Storm Damage Total | | | | |
| 141 Derailments | | | | |
| Derailments Total | | | | |
| 142 Fire Sup. & Sp. Dmg. | | | | |
| Fire Sup. & Sp.Dmg. Total | | | | |

## 2. ENGINEERING EXPENSE GROUPS, CONT.

| OCA | Investment | Project/Program Operating | Ordinary Operating | Miscellaneous |
|---|---|---|---|---|
| | L/M/O/Total | L/M/O/Total | L/M/O/Total | L/M/O/Total |
| Total Damages | | | | |
| Overhead | | | | |
| 105 Jt. Fac. - Total | | | | |
| Jt. Facilities - Total | | | | |
| Other | | | | |
| 100 Admin Personnel | | | | |
| 101 Benefits | | | | |
| 102 Admin Services | | | | |
| 103 Change/Assets | | | | |
| Total Other | | | | |
| Total Overhead | | | | |
| Operating Improve. | | | | |
| Roadway | | | | |
| 165 Mainline | | Monthly Expenditures | | |
| 167 Yards | | | | |
| 168 Sidings | | | | |
| Total Roadway | | | | |
| Structures | | | | |
| 170 B, T & Culverts | | | | |
| 171 Tunnels & Snow. | | | | |
| 175 Fences & Signs | | | | |
| Total Structures | | | | |
| Buildings | | | | |
| 176 Stations, Off. | | | | |
| 177 Mech. Dept. Fac. | | | | |
| Total Buildings | | | | |

2. ENGINEERING EXPENSE GROUPS, CONT.

| OCA | Investment | Project/Program Operating | Ordinary Operating | Miscellaneous |
|---|---|---|---|---|
| | L/M/O/Total | L/M/O/Total | L/M/O/Total | L/M/O/Total |
| Equipment | | | | |
| 178 Purchase Equipt. | | | | |
| Other Facilities | | | | |
| 180 Diesel Ser. Fac. | | | | |
| 183 Signal Systems | | | | |
| Total Other Fac. | | | | |
| Total Oper. Improv. | | | | |
| Industrial Improv. | | | | |
| 185 Track | | | | |
| 186 Facilities | | | | |
| 187 Buildings | | | | |
| 188 Land Acq. Exchg. | | | | |
| Total Indus. Improv. | | | | |
| Public Improvement | | | | |
| 189 Public Improv. | | | | |
| 190 Grade Crossings | | | | |
| 191 Separations | | | | |
| 192 Assessments | | | | |
| 193 Street Improv. | | | | |
| Total Public Improv. | | | | |
| Retirements | | | | |
| 194 Track | | | | |
| 195 Buildings | | | | |
| 196 Fac., BTC Tools | | | | |
| 197 Equipment | | | | |
| 198 Land | | | | |
| Total Retirements | | | | |
| Grand Total | | | | |

Monthly Expenditures

D. Expense Descriptions

Each expense item must be indicated as to "nature" of the expenditure. Expense descriptions designations are shown below:

Expense Descriptions

| CODE | Description |
|---|---|
| 1000 | Payroll |
| 2000 | Material |
| 3000 | Supplies |
| 4000 | Services |
| 5000 | Rentals |
| 6000 | Insurance, Losses, Damage and Injury |
| 7000 | Administration |
| 8000 | Depreciation, Retirements, Purchases and Sales |
| 9000 | General |

E. Expense Classification

Expense items must be further distinguished as to "type" of expenditure as represented by the following categories:

Expense Classes

| CODE | Description and ICC Accounts |
|---|---|
| 1 | Investment<br>Property Accounts 01-90, 480, 481 |
| 2 | Project/Program Operating<br>Operating Expense Accounts 201-462 |
| 3 | Ordinary Operating<br>Operating Expense Accounts 201-462 |
| 4 | Income Accounts<br>500 Series Accounts |
| 5 | 100% Recollectible<br>475, 477, 478 |
| 6 | Joint Investment<br>Property Accounts 01-90, 480, 481 |
| 7 | Joint Project/Program<br>Operating Expense Accounts 201-462 |
| 8 | Joint Ordinary Operating<br>Operating Expense Accounts 201-462 |
| 9 | Revenue<br>100 Series Accounts |

## F. Location, Service Function and Production Output

For analysis and control purposes, production track work should be identified by track segment and milepost identifiers. Service function identification can be readily accomplished for all track labor, production track material, track-related structures repair labor and portions of signal labor. Major service-specific facilities may have all maintenance labor accumulated by special work order or project number. Production output reports for program rail renewal, tie renewal, surfacing and ballast cleaning/ renewal can be used as inputs for engineering data bases (track characteristics files), for production material costing, and for program unit production cost development when matched with appropriate labor distribution reports. Service function identification of non-production track and other material costs is ordinarily not obtained since these materials typically are not expensed when applied, but rather when charged out of material stores. While theoretically possible to obtain all track labor costs by specific location in addition to obtaining it by service function designation, reporting complexity usually does not justify the routine capture of ordinary track labor in this fashion. Exceptions may be made where specific track segments are the subject of special test or analyses and are designated by special work order or project number.

Elements described above are incorporated into the sample labor and production material reports shown in Figures F1 through F4.

CS 27

# RAIL PRODUCTION REPORT

NO. OF THIS SHEET ______ TOTAL NO. OF SHEETS ______

STATE [  ] ______ EXTRA GANG NO. ______ MONTH ______ 19 ______ COST CENTER CODE [  ]

PLAN ______

LOCATION NO. [  ]

| LOCATION | | | TRACK REFERENCE | | | | | | DAY | RAIL LAID | | | | | | RAIL RELEASED | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ROUTE SYMBOL | MILE POST LOCATION TO NEAREST HUNDREDTH | WAY E OR W | MAIN BRANCH SIDING YARD (1) | WHICH TRACK (2) | WHICH RAIL (3) | CURVE NO | TIE-IN RAIL EAST END | RAIL SECTION WEST END | DAY OF MONTH | LINEAL FEET | N/S (5) | RAIL SECTION | KIND (4) | MILL | YEAR ROLLED | LINEAL FEET | S/X (5) | RAIL SECTION | KIND | Expense Item (6) | Project WORK ORDER NUMBER (8) |
| | . | | | | | | | | | | | | | | | | | | | | |
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Figure F1

## CROSS TIE PRODUCTION REPORT

STATE ______ EXTRA GANG NO. __________ MONTH __________ 19 ___

PLAN ____________________________________________

COST CENTER CODE [ ]

LOCATION No. [ ]

| LOCATION | TRACK REFERENCE | | | | | | CROSS TIES INSTALLED | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ROUTE SYMBOL | MILE POST LOCATION TO NEAREST HUNDREDTH | LAY (E or W) | MAIN BRANCH SIDING YARD (1) | WHICH TRACK (2) | CURVE NO | DAY OF MONTH | NUMBER | N/S (5) | KIND T-TRTD U-UNTR | SIZE | Expense Item or Line No | Project Work Order Number |
| | . | | | | | | | | | x x | | |
| | . | | | | | | | | | x x | | |
| | . | | | | | | | | | x x | | |
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| | . | | | | | | | | | x x | | |

Figure F2

Figure F3
FROG AND SWITCH REPORT

STATE ______ MONTH ______ 19__ COST CENTER CODE ______

| ROUTE SYMBOL | TRACK REFERENCE | | | LAID | | | | | | | RELEASED | | | | | | | EIN or Line No. | Project Work Order No. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | MP LOCATION TO NEAREST HUNDREDTH | MAIN BRANCH SIDING YARD | SPINB NUMBER | FROGS | | | | SWITCHES | | | FROGS | | | | SWITCHES | | | | |
| | | | | RAIL SECTION | KIND | SIZE | N/S | POINT FEET | POINT INCHES | N/S | RAIL SECTION | KIND | | S/X | POINT FEET | POINT INCHES | S/X | | |
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DISTRIBUTION OF LABOR - ☐ TRACK ☐ B.&B. ☐ SIG. ☐ W.S. ☐ ELEC. ☐ A.& W.E.

☐ Mainline/Branchline ◯ Yards ◯ Other

☐ RECOLLECTIBLE ☐ JOINT ☐ WORK ORDER

COST CENTER YOUR SUPERVISOR ☐☐☐☐

Cost Center WHERE YOU WORK ☐☐

CS 2 ☐0 ☐3

________ DISTRICT ________ GANG ________ GANG NO. ____ MONTH ________ 19 ____

LOCATION NO. ☐☐

IF MONTH WAS ON ONE JOINT FACILITY, ENTER NAME OF FACILITY HERE ——→ ________

| WORK, NAME OF JOINT FACILITY OR RECOLLECTIBLE PROJECTS | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | - | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | TOTAL FOR ACCOUNTING USE ONLY | E I N | Project Work Or |
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| BROUGHT FORWARD | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| HOURS | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

FACILITY
ER FACILITY
* - BOTH FREIGHT AND PASSENGER FACILITY

CORRECT ________________ FOREMAN.

Figure F4