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TRACK RENEWAL SYSTEM AND WOOD TIE REUSE ANALYSIS

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FINAL REPORT

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16. Abstract

This report presents the results of an analytical study of the technical and economic feasibility of applying the track renewal method of railroad track maintenance in the United States. Track renewal, or out-of-face renewal, has long been the prevailing form of track maintenance used in Europe and has recently spread to Asia, Australia, and North America. Current North American activity is very limited, but the carriers and other elements of the railroad community are becoming increasingly interested in the potential advantages of track renewal as an alternative to selective maintenance.

The core of the report consists of a detailed framework for conducting a comparative economic analysis of the track renewal method versus the traditional selective maintenance method. The framework includes detailed descriptions of both methods, unit costs for each major operation under each method, and the comparative present worth long-term costs associated with each method. The framework methodology is presented in detail so that the reader can examine and if necessary modify the built-in assumptions and thereby tailor the framework for application to a specific situation.

A sample economic analysis is presented wherein the framework is used to compare the estimated long-term and first-year costs when they are applied to fourteen specific track maintenance scenarios, each of which represents a particular set of assumptions and conditions. The results of the sample analysis include the following: (1) track renewal offers the prospect of large long-term cost savings over selective maintenance, although only under certain circumstances; (2) wood tie reuse is a critical factor in optimizing the long-term savings; (3) with wood tie reuse, track renewal is likely to be $15,000 to $27,000 cheaper per track mile than selective maintenance over time; (4) the internal rate of return for track renewal is likely to be 25–35 percent; (5) the break-even point for first-year costs is about 32 percent tie replacement for installing wood ties and 75 percent for replacing wood with concrete ties; (6) ballast cleaning costs are reduced by about 28 percent with track renewal; and (7) track occupancy time for maintenance is reduced 60–79 percent with track renewal.

The report also presents a worldwide survey of present and future track renewal machine technology to enable the reader to consider alternatives to the type of machine assumed in the framework and analysis. Also included is a discussion of the use of track renewal machines for abandoning existing track, building new track, and for other nonmaintenance applications. In addition, there is a brief section on two alternatives to track renewal machine ownership and operation by the railroads: (1) railroad leasing and operation, and (2) railroad purchase of services from contractor owner-operator.

The report concludes with the identification of several areas for additional study, principally with respect to the further development and refinement of the framework as a research tool. It also states that the framework should be tested by one or more railroads; the results should be used to strengthen the framework and should also be shared with the railroad community.

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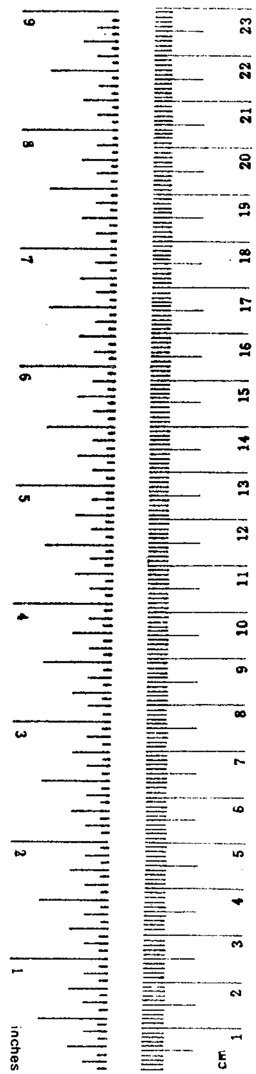
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
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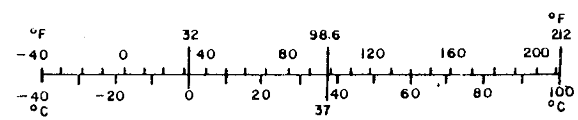
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



PREFACE

This report presents the results of an analytical study of the technical and economic feasibility of the track renewal method of track maintenance for U.S. railroads. It was prepared by Unified Industries Incorporated (UII), under contract to the Federal Railroad Administration (FRA).

The authors wish to thank Ms. Claire L. Orth, the FRA technical monitor, for her continued guidance and cooperation throughout this project. The comments and suggestions offered by Messrs. Philip Olekszyk, Arnold Gross, and Robert E. Kleist of the FRA, Mr. Louis T. Cerny of the American Railway Engineering Association, and Mr. Richard D. Johnson of the National Railroad Passenger Corporation (Amtrak), especially during the preparation of this final report, are also gratefully acknowledged. In addition, the assistance provided by Messrs. Robert Corsetti and Michael E. Dunn of Amtrak, Messrs. R. D. Miles and J. H. Gasper of Canadian National Railways, and the members of the Association of American Railroads' Committee on Track Maintenance Research was particularly helpful for obtaining background data and developing objectives for this project.

This study continued and expanded upon the pioneering research in track renewal done by railroad consultant David R. Burns, and he provided valuable assistance throughout the project.

In addition, the authors wish to thank their UII colleagues. Messrs. Paul Elliott and Kenneth W. Larsen furnished assistance in project direction and in the preparation of the intermediate reports and this final report. Mrs. Virginia O. Clem painstakingly typed the more than 80 tables, as well as all of the text, in this report, contended with seemingly constant revisions, and then transmuted this vast assemblage of paper into a final report.

TABLE OF CONTENTS

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EXECUTIVE SUMMARY

This report presents an analysis of the track renewal method of railroad track maintenance as it could be applied in the United States. The core of the report consists of a detailed framework for conducting a comparative economic analysis of the track renewal method versus the traditional selective maintenance method (chapter II), together with the results of applying the framework to a set of sample scenarios (chapter III).

Selective maintenance, the method by which almost all railroad trackage is presently maintained in the United States and Canada, involves the intermittent and/or periodic replacement or repair of only those track structure components that are defective or failing.

By contrast, track renewal, also known as out-of-face renewal, consists of completely rebuilding the track structure as a single, continuous process that involves renewing and/or adjusting all of the track structure components (rails, ties, ballast, etc.) in a given section of track in a scheduled period of time during which the track is closed to traffic. Following track renewal, such a section is customarily given only light section gang or basic maintenance for perhaps 15, 25, or more years (the length of the period depending upon track structure, traffic, and environmental conditions) until it is again rebuilt under the track renewal method.

The track renewal method is a highly mechanized process involving the use of large, integrated track renewal systems. A typical track renewal system (TRS) is designed around a specialized track renewal machine (TRM) or pair of such machines that moves along the track removing old rail and ties and installing new rails and ties. The rest of the system is made up of other types of conventional track maintenance equipment that perform such tasks as removing/inserting rail fasteners, cleaning the ballast, and aligning and tamping the track.

Track renewal has long been the prevailing form of track maintenance used in Europe. In recent years, spurred largely by the successful European experience, the North American railroad community has become increasingly interested in the potential advantages of track renewal as an alternative to selective maintenance. This interest is based on the prospect of track renewal being able to provide such advantages as significant long-term track maintenance cost savings and a major reduction in the amount of track occupancy time needed for maintenance activities.

To date (mid-1980), North American railroads have had little direct experience with track renewal. Only five TRM's are presently in service (one on Amtrak lines in the Northeast Corridor, one on Canadian National Railways, and three on the National Railways of Mexico), and all of them are being used for what is essentially a specialized purpose -- converting main-line track from wood to concrete ties. Consequently, only limited information is available for assessing the relative costs and benefits of using track renewal instead of selective maintenance to rebuild North American trackage, as well as for determining the various circumstances under which it may or may not be advantageous to apply the track renewal method.

The principal purpose of this report is to provide U.S. railroads and other elements of the North American railroad community with a basic research tool for comparing the track renewal and selective maintenance methods. This tool is in the form of a detailed economic framework for comparing the two methods.

The economic framework (chapter II) begins with detailed descriptions of both selective maintenance and track renewal. Each description includes information and assumptions on the equipment and labor requirements and makeup of each maintenance gang and related support activities, as well as average production rates. Given that railroads differ considerably in their maintenance practices and policies, the selective maintenance description is based on what may be considered a representative but nevertheless hypothetical set of maintenance procedures, which are presented in sufficient detail such that the reader can determine their relevance to specific real world situations and modify them accordingly. The track renewal description is covered in comparable detail, with the assumed production rates and other information being derived from a combination of both North American and European experience; here too, the information is presented so that the reader can examine and if necessary modify the built-in assumptions.

The next step in the economic framework is to develop unit costs for each major operation under both selective maintenance and track renewal and to ascertain the economic impact of reusing and/or disposing of the track structure components removed from track during track renewal. The unit costs per mile include those for materials installed, labor, equipment maintenance, transportation, equipment leases, and capital recovery. The calculated unit costs can then be combined to provide an estimate of first-year costs for each of the two maintenance alternatives. Track structure component reuse/disposal determination is limited to consideration of used wood ties only, on the assumption that the replacement rate for rails, other track material, and ballast would be comparable for both maintenance alternatives. Under track renewal, large-scale wood tie reuse/disposal -- calculated as a net material credit -- can provide a significant economic benefit, especially when used to offset first-year costs. This second step in the framework is presented in sufficient detail such that the reader can modify it to fit a specific situation by making appropriate additions, deletions, or other changes and then carry them forward into the third and final step.

The final step is to determine the comparative long-term costs of track renewal versus selective maintenance. These include net material credit for used ties, first-year costs, and all subsequent annual maintenance costs (discounted to present value) occurring over a defined period or life cycle. Compared on the basis of present worth (the present worth methodology is given in outline form), these long-term costs provide a useful means for helping to ascertain the relative advantages and disadvantages of the track renewal and selective maintenance methods.

A sample economic analysis is presented (chapter III) wherein the framework is used to compare the estimated long-term and first-year costs of both methods when they are applied to fourteen specific track maintenance scenarios. Each scenario represents a particular set of assumptions concerning average tie life, average rail life, and other significant variables.

The principal findings of the sample analysis are as follows:

a. Compared with selective maintenance, track renewal offers the prospect of large long-term cost savings in track maintenance, although only under certain conditions.

b. The long-term cost savings attributable to track renewal are likely to be highest if (1) 25 or more percent of the ties in existing track need to be replaced (track needs upgrading), (2) rail change coincides with tie renewal, (3) ballast cleaning is included, (4) average tie life under track renewal is 15-25 percent longer than under selective maintenance, and (5) net material credit for wood tie reuse/disposal is included.

c. Wood tie reuse (the reuse of ties, with or without repair, in other tracks) and wood tie disposal (the sale of ties for nonrailroad use or scrap) together generate a net material credit of $14,100 to $22,600 per track mile in all fourteen scenarios. (If all ties are simply sold as scrap ties, there is a net material credit of about $6,000 per track mile.)

d. Material credit is a critical factor in optimizing long-term track renewal cost savings. With material credit, the long-term cost differential between both methods favors track renewal in all fourteen scenarios. Twelve of the fourteen scenarios each produce track renewal savings of between $15,100 and $27,000 (present-worth dollars) per track mile. The other two scenarios produce a low of $2,600 per track mile and a high of $29,500 per track mile.

e. Without material credit, the long-term cost differential between the two methods is minimal (no more than $2,100 per track mile in favor of either method) in seven scenarios. It favors track renewal by $8,100 to $13,500 per track mile in four scenarios and selective maintenance by $3,900 to $17,900 per track mile in three scenarios.

f. Without material credit, the internal rate of return on track renewal investment ranges from less than 4 percent to about 35 percent for eleven of the fourteen scenarios (no rate of return can be calculated for the remaining three scenarios because there is no extra first year cost for any of them). With material credit, the rate of return on track renewal is about 25-35 percent for eight scenarios.

g. The long-term cost savings and internal rates of return calculated in the sample analysis must be considered within the context of the duration of the life cycle used in each scenario. In the fourteen sample scenarios, the life cycles range from 15 years (wood tie track under heavy traffic) to 40 years (concrete tie tracks).

h. The long-term costs and cost savings associated with track renewal will differ significantly from those cited in the sample analysis if there are major changes in the assumed daily production rate of the track renewal machine (TRM). In all fourteen sample scenarios, it was assumed that the TRM could install 2,880 wood ties in an average work day (a conservative assumption based chiefly on the actual rates achieved by the Amtrak and Canadian National TRM's). If the assumed rate is increased by 25 percent, there will be an increase of about $2,900 per track mile in long-term track renewal cost savings for all fourteen scenarios. A decrease of about 33 percent in the assumed rate will result in an across-the-board long-term loss of about $5,800 per track mile.

i. First-year costs in all fourteen scenarios are generally much higher for track renewal without material credit than for selective maintenance, principally because most of the track renewal costs occur in the first year. With material credit, however, track renewal is only $2,100 to $6,600 per track mile more expensive in eight of the eleven wood tie scenarios that assume a 25-percent tie replacement rate. In two of the other wood tie scenarios, the costs (with material credit) are the same for both methods. In the scenario that assumes a 50-percent tie replacement rate, track renewal (with material credit) is actually $9,900 per track mile less expensive than selective maintenance.

j. First-year track renewal costs are much higher for converting from wood to concrete ties than for installing new wood ties, owing to the high cost of concrete ties. The cost differential amounts to $28,900-$30,800 per track mile, including material credit.

k. Breakeven analysis of first-year costs reveals that, for wood ties, the breakeven point (zero cost differential) is about 56 percent tie replacement without material credit and about 32 percent with material credit. For wood-to-concrete conversion, the comparable figures are 90 percent and 75 percent, respectively.

l. Ballast cleaning costs are reduced by about 28 percent when this activity is included in the track renewal operation.

m. Track occupancy time required for maintenance is reduced significantly under track renewal; there is a reduction of about 79 percent in the first year and about 60 percent over the track life cycle.

The track renewal system factors used in the economic framework and sample analysis are all based on the assumed use of a specific type of TRM, the Canron P-811. This machine is widely used in Europe and is the only TRM currently in use in the United States and Canada. To understand the full potential of the track renewal concept in North America, however, it is useful to consider the full range of existing and future TRM designs and their potential applications. Accordingly, descriptions of all the major TRM designs are presented in chapter IV, along with their applications, crew sizes, and production capabilities.

In addition to serving as a key element in long-term track maintenance, TRM's can be used for several specialized functions. These include abandonment of existing track and construction of new track. In addition, TRM's can be used to perform major track realignment, convert track from wood to concrete ties, or undertake changes in track class or design (change rail weight, alter tie spacing, etc.).

A principal assumption throughout the study is that each U.S. railroad adopting the track renewal method would own and operate its own TRM. However, there are two other alternatives -- railroad leasing and operation and contractor ownership and operation -- that should be considered by the U.S. railroad community. The principal advantages and disadvantages of these alternatives are discussed briefly in chapter V.

The principal findings of this study are as follows:

a. Under certain conditions, the track renewal method offers significant long-term cost savings in track maintenance over the selective maintenance method.

b. Track renewal reduces the amount of track occupancy time needed to perform maintenance work.

c. The track renewal method produces a completely rebuilt track that is likely to remain in better overall condition over the life cycle of the track than is a selectively maintained track.

d. Track renewal technology has been advancing at a rapid rate in recent years, and this trend appears likely to continue such that future TRM's will achieve higher production rates with less labor and fewer support machines.

e. Although track renewal can produce large savings in labor and equipment costs, it does require a major planning effort and a commitment from management to operate successfully. A shortage of any material or a breakdown by any one of several key machines could have a serious impact upon the efficiency and cost-effectiveness of track renewal applications.

f. Based on the detailed economic framework and the sample analysis, it is evident that the framework itself should be a useful research tool for the U.S. railroad community to use for comparing the track renewal and selective maintenance methods. Given all the variables and options that exist in track maintenance procedures and real world applications, each railroad needs to consider the potential of track renewal from its own perspective.

The preparation of this analytical study has led to the conclusion that there are still several significant areas for additional study in the field of track renewal, especially with respect to the further development and refinement of the economic framework. These study areas include some of the assumptions used in the present study -- as, for example, a possible increase in wood tie service life attributable to track renewal. They also include several follow-on topics, such as the use of track renewal to abandon track and rebuild deteriorated track, the economics of TRM leasing and contracting arrangements, and the cost value of track occupancy time to railroad operating and engineering departments.

In addition, given the hypothetical nature of the framework developed in the present study, the framework should be tested by one or more railroads. The results should be used to strengthen the framework's usefulness and should be shared with the railroad community.

I. INTRODUCTION

This report presents an analysis of the track renewal method of railroad track maintenance and its potential for application in the United States. The analysis was conducted as phase 2 of a Federal Railroad Administration research study of track renewal and an associated topic, the reuse of wood ties. Phase 1 of the study resulted in the preparation and publication of two reports: Track Renewal Systems: A Survey Report,* which provides an overview of track renewal system experience in Europe and North America and reviews previous economic feasibility studies of track renewal, and Wood Tie Reuse: A Survey Report,** which describes European and North American practices in reusing wood crossties removed from track, with emphasis on reuse associated with track renewal.

The present report focuses on the track renewal method in comparison with the selective maintenance method of track maintenance, which is the method by which almost all railroad trackage has been customarily maintained throughout the United States and Canada.

Selective maintenance involves the intermittent and/or periodic replacement or repair of only those track structure components (rails, ties, fasteners, ballast, etc.) that are defective or failing. As a result, there may be considerable variation in the age, condition, and performance of the various component types and individual components in a given section of track.

By contrast, track renewal, which is also referred to as out-of-face renewal, consists of completely rebuilding the track structure as a single, continuous process that involves renewing and/or adjusting all of the track structure components in a given section of track in a scheduled period of time during which the track is closed to traffic. Following the initial rebuilding process, such a track section is customarily given only light section gang or basic maintenance for perhaps 15, 25, or more years (the length of the period depending upon track structure, traffic, and environmental conditions) until it is again rebuilt under the track renewal method.

The track renewal method is a highly mechanized procedure involving the application of large, integrated track renewal systems. A typical track renewal system (TRS) is designed around a specialized track renewal machine (TRM) or pair of such machines that moves along the track picking up old rails and ties and installing new rails and ties as a single continuous process. The TRM is supported by other types of conventional track maintenance equipment that perform such tasks as removing/inserting fasteners, cleaning the ballast, and aligning and tamping the track.

The track renewal method has long been the predominant form of track renewal practiced in Europe. In recent years, spurred largely by the successful European experience, the North American railroad community has become increasingly interested in the potential advantages of this method as an alternative to selective maintenance. This interest is based on the prospect of track renewal being able to provide such benefits as significant long-term track maintenance cost savings and a major reduction in the amount of track occupancy time required for maintenance activities.

As of mid-1980, North American railroads have had little direct experience with track renewal. Only five TRM's are presently in service (one on Amtrak's lines in the Northeast Corridor between Boston and Washington, D.C., one on Canadian National Railways, and three on the National Railways of Mexico). All of these North American TRM's are being used for what is essentially a specialized purpose -- the conversion of main-line track from wood to concrete ties. Consequently, it is difficult to assess the relative costs and benefits of using track renewal instead of selective maintenance to maintain and/or rebuild North America's wood tie trackage. It is also difficult to determine the various conditions and other circumstances under which adoption of the track renewal method may be most advantageous and cost-effective.

The principal purpose of this report is to provide U.S. railroads and other elements of the North American railroad community with a basic research tool for making such assessments and determinations. As presented in this report, the tool consists of a detailed economic framework for comparing the track renewal and selective maintenance methods.

The framework (chapter II) presents a detailed procedure for developing and comparing estimated first-year and long-term costs of maintaining railroad track under both track renewal and selective maintenance. It is intended to be used to examine real world situations, and so it is organized to permit the reader to understand the numerous underlying assumptions, follow the methodology used, modify any of the component elements, and insert procedure-specific or site-specific information as needed.

Given the complexity of the framework, which alone accounts for more than half of this report, the general reader may find it easier initially to read only the introductory portion (pages 5-6) of the framework chapter and then proceed to chapter III in which are given the results of applying the framework to various specific scenarios.

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**Report number FRA/ORD-79/44 prepared by Unified Industries Incorporated for the Federal Railroad Administration (1979), NTIS accession number PB 114044.

This chapter presents a detailed procedure for developing estimated first-year and long-term costs of maintaining railroad track by the track renewal method and selective maintenance method. The costs developed do not include basic, or section gang, type maintenance; the cost of distributing and collecting rails; and some other operations that are presumed to be equal for track renewal and selective maintenance.

The procedure, or framework, for economic evaluation developed here is generalized to provide a representative example of relative costs and to allow some specific first-year and long-term cost comparisons in chapter III. The reader can modify the framework to fit a specific real world situation by changing unit costs, gang and facility descriptions, and production rates assumed in this report as necessary, and carry the changes forward through the cost-benefit procedure of the framework.

The major elements or steps of the framework procedure are shown on the flow chart below. Each step is presented as a separate section of this chapter as noted.

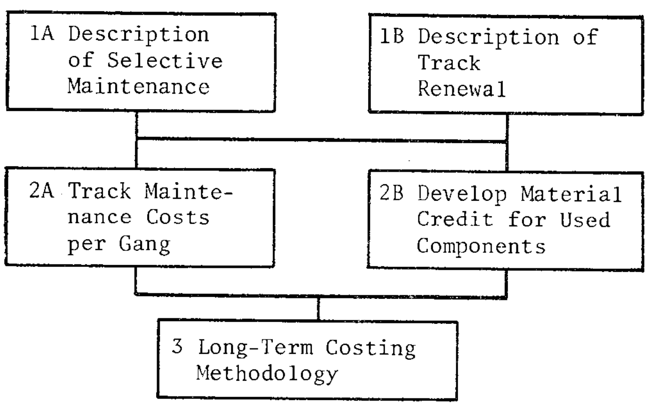


FIGURE 1. ECONOMIC FRAMEWORK FLOW CHART

The first step is to describe the selective maintenance system to be replaced by the track renewal system (1A): what it does; how it operates; support operations required; and equipment, manpower, and production rates in sufficient detail to determine costs per mile. A comparison task (1B) is to describe, in similar detail, the track renewal system. Systems are described in this report for installing wood ties and concrete ties.

After the alternative track maintenance methods are described, costs for each major operation are determined (2A) on a per-mile basis. The costs include materials installed, labor, equipment maintenance, transportation, equipment leases, and capital recovery. Some operations and their costs, such as track inspections and rail grinding, are not calculated in this report because they are not significantly affected by the overall maintenance procedure and the calculation would be unnecessary. After the costs per mile have been determined for each operation, they can be combined for each alternative (if each operation is assumed to be done in the first year) to obtain the estimated first-year costs.

Many track components that are removed from primary tracks can be reclaimed and reused in lower classes of track. Most components that are not reused in track can be sold for other purposes, thus reducing overall costs. The value, or material credit, for used wood ties needs to be calculated (2B) because the track renewal method changes the volume and timing of the used ties. Rails, other track materials (OTM), and ballast were assumed to be replaced at the same rate in each alternative and were ignored. This may not be true in some potential applications of track renewal.

The net material credit expected from track renewal can then be subtracted from the total first-year cost to obtain the net first-year cost of the track renewal method. Then this cost can be compared to the first-year cost of the selective method to find the first-year cost differential.

Because track renewal often involves larger first-year costs and has a significant impact on future track maintenance costs, compared with selective maintenance, it should not be evaluated solely on the basis of first-year costs. Long-term costs need to be determined (3) for the railroad under study, discounted at a fair market rate, and compared for each alternative. Railroad managements usually evaluate capital expenditures on the basis of these "discounted cash flows" and the rate of return obtained from the investment, and cost savings with some considerations for first-year costs and intangible costs and benefits. Other economic criteria required to support a final investment decision, such as sources and methods of financing, tax and insurance costs, etc., were not considered in this study.

To use this framework for a specific situation requires the following procedures:

a. Determine if any of the maintenance operations should be modified. This includes labor, equipment, and production rates.

b. Obtain up-to-date base costs for labor, materials, equipment purchase and maintenance or lease, and transportation charges.

c. Determine which operational cost developments must be changed, and develop new costs following the procedures used in this chapter.

d. Develop long-term track maintenance scenario(s) for the specific site or sites under consideration.

e. Using currently applied inflation and discounting factors, develop long-term costs.

f. Evaluate the results, modify the scenarios and long-term economics as necessary to study alternatives, and develop recommendations for management.

1. Description of Maintenance Systems

The alternative track maintenance methods compared in this study are described in the following subsections. The selective maintenance method is presented first, with only those operations that would be eliminated or altered by track renewal receiving full descriptions. Assumed average production rates are presented for each operation. This is followed by descriptions of track renewal systems for installing wood and concrete ties and assumed production rates.

As shown in figure 1, these descriptions begin the overall procedure.

A. Conventional Selective Track Maintenance

The conventional selective track maintenance operations described below are representative of typical mechanized track maintenance gangs in the United States. Every effort has been made to include every machine and position necessary to conduct the overall operation. The gangs are described in detail so that the reader can compare them to specific real world situations and determine whether or not to use the costs developed in this report or to develop independent costs.

(1) Selective Maintenance Principles and Procedures. The selective method of track maintenance is the traditional way of maintaining railroad track in the United States. It has been used since the very first railway experienced a track component failure, it now enjoys the benefits of an incumbent procedure, and it works.

In simple terms, in selective maintenance, track components are replaced on an individual basis after they fail or wear out. Railroad policy, affected by government regulations, varies as to when the component is actually replaced. Some railroads try to replace components just before failure or wearing out; some components are replaced as soon as the failure is discovered; and some "failed" or wornout components are allowed to remain in place for some time so long as the track is passable.

Originally, selective maintenance was done by section gangs that were responsible for all track inspection and maintenance on a short length or section of the railroad. Virtually all of the work was done by hand. Since about 1950, most track maintenance work has been taken over by traveling mechanized gangs with specific missions: rail gangs change or transpose rails; tie gangs change ties; surfacing gangs realign and resurface the track; and so on. The section gang has been reduced to inspection, emergency repairs, and other maintenance work that does not lend itself to high production mechanization. This level of maintenance is sometimes referred to as basic maintenance.

The mechanized gangs operate over the railway as needed when their particular operations can be utilized effectively. For example, depending on the railroad and the specific track involved, tie gangs are generally not assigned until 12 to 30 percent of the ties in a track length need to be replaced. Mechanized gangs usually operate independently of each other, due to different production rates and somewhat different conditions of the various track components. Because of this, each gang is usually a complete operation, including tampers and other equipment necessary to leave the track passable behind the gang.

(2) Selective Maintenance Gang Descriptions. Mechanized selective maintenance operations that would be eliminated or altered by the track renewal method are described in the following paragraphs. Included for each gang are the operations performed, equipment, and labor operations. Other support operations are not broken down in this detail.

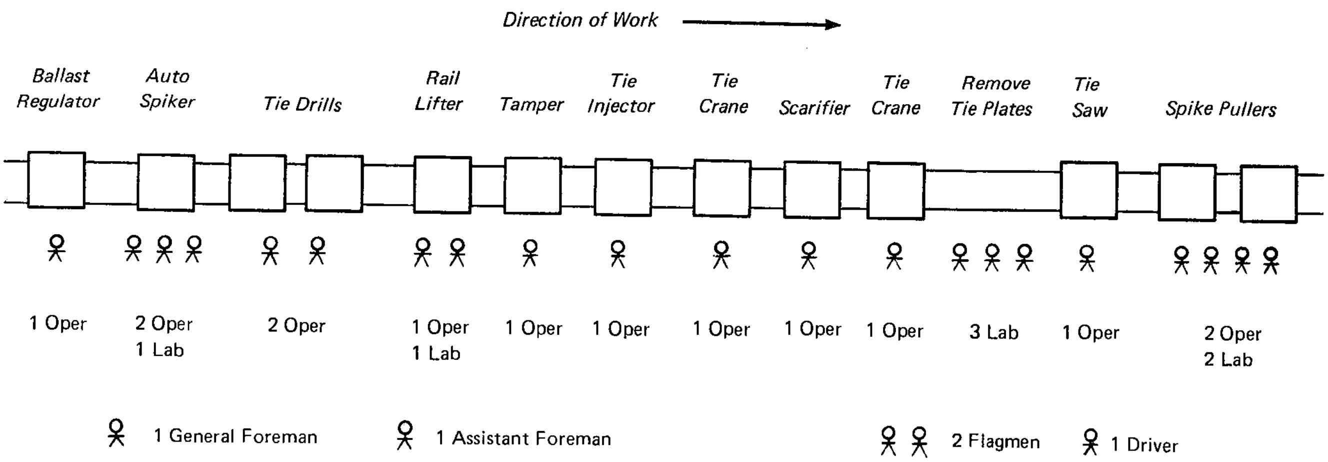
a. Selective Maintenance Operation: Tie Gang. The tie gang is shown graphically in figure 2 on page 7. This gang's function is to replace wornout and failed or failing wood ties with new ties. This mechanized gang is assumed to be able to replace 200 to 2,500 ties per mile, averaging 812 ties replaced (1.0 track mile with 19.5-inch tie centers and a 25 percent tie replacement rate) per 8-hour day (6.5 hours of track occupancy).

b. Selective Maintenance Operation: Ballast Cleaning Gang. The ballast cleaning gang is shown graphically in figure 3 on page 8. This gang's fuction is to undercut and clean existing ballast to improve the track structure. This gang is assumed to be able to cut 8 inches or more below the base of ties at an average 0.615 mile per 8-hour day (6.5 hours of track occupancy). The gang replaces ties that fall off the rails during cleaning, and tamps and compacts the ballast following cleaning.

The support activities of a ballast distribution train and fouled material train are not included in this description.

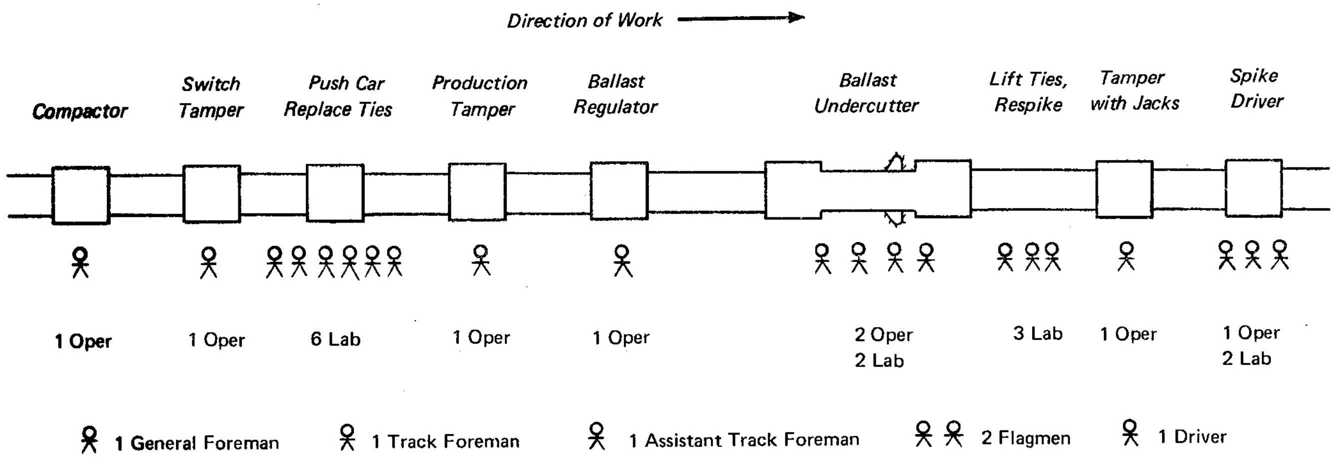
c. Selective Maintenance Operation: Rail Gang. The rail gang is shown graphically in figure 4 on page 9. This gang's function is to replace worn out rail with new or reconditioned rail. For the purpose of this study, it is assumed that the old rail is jointed and the new rail is continuously welded rail (CWR). The rail gang uses the single rail method (one rail at a time is removed and replaced) and installs 4 rail strings (0.54 mile of track) per 8-hour day (6.5 hours of track occupancy).

Support activities also include OTM distribution, OTM cleanup, and planning. Support activities that are not considered in this study, because they would be about the same with track renewal, are: rail inspection (track geometry car, ultrasonic testing); rail distribution; field welding; rail stressing; and rail salvage.



Activity	Equipment	Supervisors				Operators by Grade				Laborers
		GF	TF	ATF	PE	1	2	3	4	
On-site supervision	—	1		1						
Pull spikes from marked ties	2 Hydraulic Spike Pullers					2				
Pick up pulled spikes	Push Cart									2
Saw marked ties, push out tie ends	Tie Shear with Lifting Device					1				
Remove tie plates to side	—									3
Remove tie butts to shoulder	Tie Crane					1				
Scarify tie bed	Scarifier					1				
Position new ties on rails	Tie Crane					1				
Install new ties	Tie Inserter					1				
Tamp new ties	Tamper						1			
Install tie plates, check gage	Rail Lifter					1				1
Drill spike holes	2 Tie Drills					2				
Spike new ties	2 Spike Setter-Drivers					2				1
Fill in cribs and shoulders	Ballast Regulator						1			
Flagmen										2
Driver						1				
Support Activities										
Tie Inspector	Automobile		1							
Tie Distribution Gang	Locomotive, 10 Gondolas, Tie Unloader	1						5		
Tie Cleanup Gang	Burro Crane, 3 Air Dump Cars		1					1		6
Planning	—				1					

FIGURE 2. CONVENTIONAL TIE GANG



Activity	Equipment	Supervisors				Operators by Grade				Laborers
		GF	TF	ATF	PE	1	2	3	4	
Onsite supervision	—	1	1	1						
Drive loose spikes, plug holes	Spike Driver					1				2
Raise track and break up ballast	Tamper with Jacks						1			
Lift ties and respike	—									3
Undercut and clean ballast	Ballast Undercutter								2	
Remove downed ties	—									2
Regulate ballast	Ballast Regulator						1			
Production tamping	Production Tamper						1			
Lift and replace ties	Push Car									6
Tamp switches and finish tamping	Switch Tamper						1			
Stabilize ballast	Ballast Compactor						1			
Flagmen										2
Driver						1				
Support Activities										
Planning					1					

FIGURE 3. CONVENTIONAL BALLAST CLEANING GANG

d. Selective Maintenance Operation: Surfacing and Lining Group. The surfacing and lining gang is shown graphically in figure 5 on page 10. This gang's function is to restore the correct geometric alignment and level the track. This gang is assumed to be able to raise the track line 1 to 3 inches on an average of 1.23 miles of track per 8-hour day (6.5 hours of track occupancy).

The support activity of a ballast distribution train is not included in this description.

(3) Selective Maintenance Operations Not Described. As noted previously, many selective maintenance activities and operations would be unaffected by the track renewal method. These include:

a. Rail inspection (track geometry car, ultrasonic testing, and track walking).

b. Switch repair.

c. Grade crossing repair (this does occur during track renewal, as well as tie gang and rail gang operations).

d. Ditching.

e. Drain pipe repair.

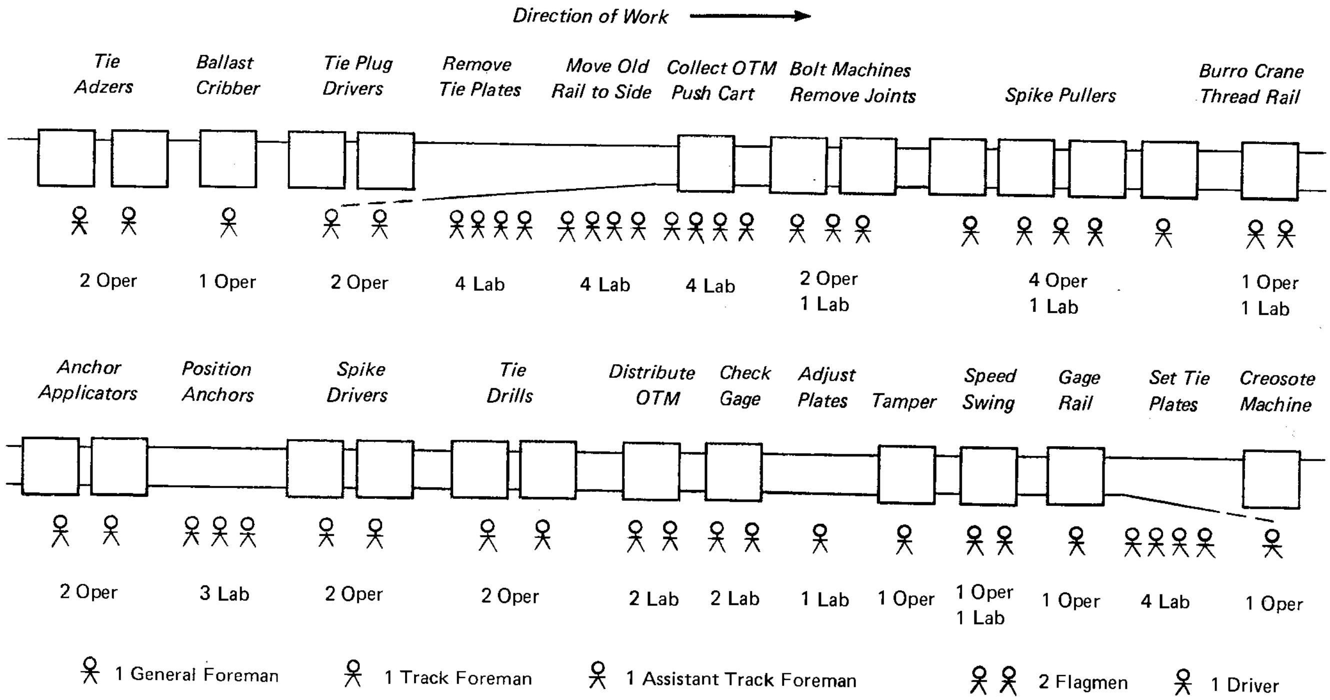
f. Bridge and tunnel repairs.

g. Signal repair and modifications.

h. New ballast requirements and fouled ballast disposal.

(4) Selective Maintenance Production. As the makeup of each gang is likely to differ from equivalent gangs on any particular railroad, so is the average production rate. The selective maintenance production rates assumed in this study are intended to be reasonable for the most productive gangs, but are not taken from any specific railroad's experience. Each gang is assumed to have 6.5 hours of track occupancy time on each work day with a total 8-hour work day so that overtime costs are minimized. Each gang is also assumed to operate for 200 work days per year, which is probably high for gangs in northern and mountain climates but typical for the industry.

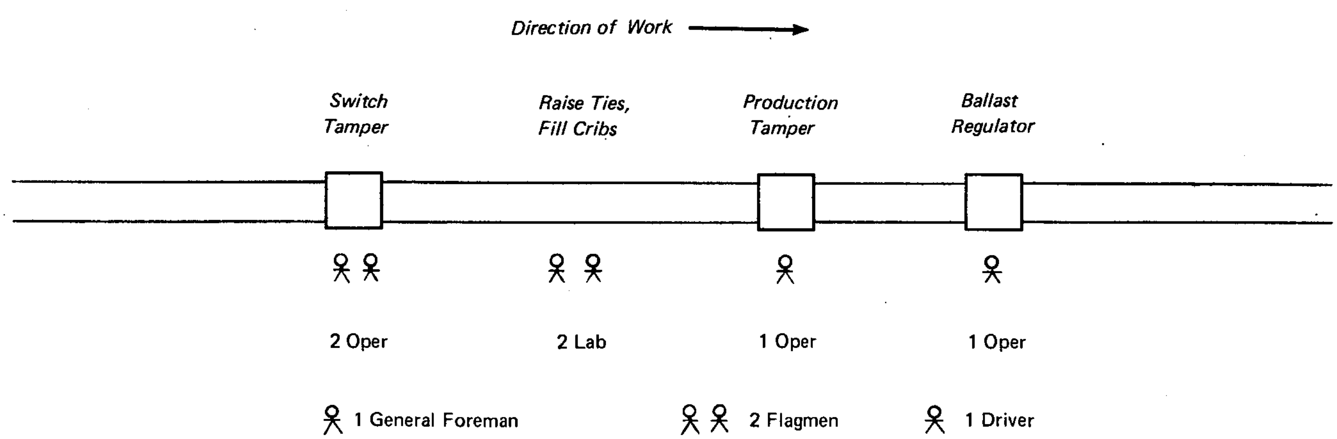
Average daily and annual production rates used in section 2A for these gangs are:



Activity	Equipment	Supervisors				Operators by Grade				Laborers
		GF	TF	ATF	PE	1	2	3	4	
Onsite supervision	—	1	1	2						
Thread new rail into track center	Burro Crane							1		1
Crib ballast between ties to facilitate adzing	Cribber					1				
Pull all spikes, remove any anchors, pile clear of track	4 Hydraulic Spike Pullers					4				1
Remove joint bars and pile clear of track	Bolt Machines, Torch					2				1
Collect and load used OTM	Push Cart									4
Remove old rail to shoulder	—									4
Remove tie plates to shoulder	—									4
Plug all spike holes with treated wood plugs	2 Tie Plug Drivers					2				
Adze tie plate areas on all ties	2 Tie Adzers					2				
Apply creosote to adzed surfaces	Creosote Machine					1				
Place tie plates on all ties	—									4
Set tie plates to correct gage; insert gage plugs	Gager					1				
Sweep plate area and set new rail onto tie plates	Speed Swing							1		1
Tamp ties	Tamper						1			
Straighten tie plates	—									1
Check track gage	Gager									2
Distribute spikes and anchors to installation points	Push Cart									2
Drill spike holes in ties	2 Tie Drills					2				
Drive spikes into ties	2 Spike Setter/Drivers					2				
Set rail anchors on base of rail	—									3
Secure anchors to rail	2 Anchor Applicators					2				
Flagmen										2
Driver						1				
Support Activities										
OTM Distribution Gang	Burro Crane, 2 Gondolas		1			1				2
OTM Cleanup Gang	Burro Crane, 2 Gondolas		1			1				2
Planning	—				1					

FIGURE 4. RAIL GANG

Gang	Daily Production (Track Miles per 6.5-Hour Day)	Annual Production (Track Miles)
Rail Gang	0.54	108
OTM Distribution	0.54	---
OTM Cleanup	2.50	---
Tie Gang (812 ties per mile)	1.00	200
Inspector	6.00	---
Tie Distribution	4.70	---
Tie Cleanup	1.00	---
Surface and Line	1.23	246
Ballast Cleaning	0.615	123



Activity	Equipment	Supervisors: GF	TF	ATF	PE	Operators by Grade: 1	2	3	4	Laborers
Onsite supervision	—	1								
Prepare ballast for tamping	Ballast Regulator*						1			
Tamp every other tie and line track	Production Tamper with Liner						1			
Raise ties; fill in cribs	—									2
Tamp remaining ties; tamp switches	Switch Tamper						2			
Dress ballast — shape shoulder, fill in cribs, sweep track	Ballast Regulator*									
Flagmen										2
Driver						1				
Support Activities										
Planning					1					

**Same machine*

FIGURE 5. TRACK SURFACING AND ALIGNMENT GANG

The rail gang production rate is tied to installation of 4 "strings" of continuously welded rail (CWR) per day, which is averaged by rail gangs on a number of railroads. The rates for the tie gang and surface and line gang have been made by several railroads as shown in the publication, Economics of Concrete and Wood Tie Track Structures.* The ballast undercutting-cleaning production rate is taken from a midwestern U.S. railroad's experience.

B. Track Renewal System Based Maintenance

The track renewal systems described below are representative of the kinds of operations required to rebuild or maintain railroad track using the renewal method. The system for installing concrete ties is very similar to those used by the National Railroad Passenger Corporation (Amtrak) and Canadian National Railways, Ltd. (CN Rail). The system for installing wood ties has no prototype, but is reasonable for the task using a basic engineering solution. As is done with the selective maintenance operations, the TRS's described here have sufficient detail that the reader may make adjustments and recalculate the costs.

(1) Track Renewal Maintenance Principles and Procedures. Track renewal is the primary method of track maintenance in Europe, the Soviet Union, China, India, and some other countries. It was developed in Europe in the early twentieth century and has been progressively more mechanized in the last 30 years. It is an uncommon concept in the United States (some industrial railroads use this method) and is not yet proven to be economically attractive.

A track renewal system (TRS) is a mechanized system designed for maintaining the track and can be used for the major rehabilitation of railroad track structures. The system is designed around a specialized machine or set of machines called a track renewal machine (TRM) or track laying machine (TLM), which takes up existing track and relays new track in a single pass. This specialized machine is supported by a wide range of other track maintenance equipment for such activities as removal of rail fasteners, application of rail fasteners and anchors, ballast cleaning, lining and tamping, etc. This framework describes a TRS built around the Canron P-811 TRM, shown in figure 6. Other TRM designs are discussed in chapter IV.

After the track has been completely rebuilt by the TRS, it should not need any further mechanized attention, other than lining and surfacing, until either the rails need replacing or enough ties need replacing (when either a selective tie gang or a TRS is used). The time will vary depending upon traffic, the environment, and the level of basic maintenance performed.

(2) Descriptions of Systems Based on Canron P-811 Track Renewal Machine. Two similar track renewal systems are described using the Canron P-811 TRM as the key machine in each system. The P-811 operation is described in chapter IV.

Long-term track maintenance operations that would be done under selective maintenance or track renewal at the same cost are not described, as noted in subsection A.

a. Track Renewal System: Wood Tie to Wood Tie. The function of this system is to change 100 percent of the wood ties, replacing them with new or reclaimed wood ties, and to line and surface the track. The system also may simultaneously change both rails and undercut and clean the ballast, but may omit these steps.

The system is shown as two subsystems. The TRM group is shown graphically in figure 7 on page 12. This group changes the ties and rails and applies rail fasteners and anchors. Support activities include preplating of new ties, OTM distribution, OTM cleanup, tie car support for transportation, and planning. Support activities not included are rail inspection (track

*Report number FRA/ORD-78/2 prepared by Battelle-Columbus Laboratories and Bechtel Incorporated for the Federal Railroad Administration (1978), NTIS accession number 188688.

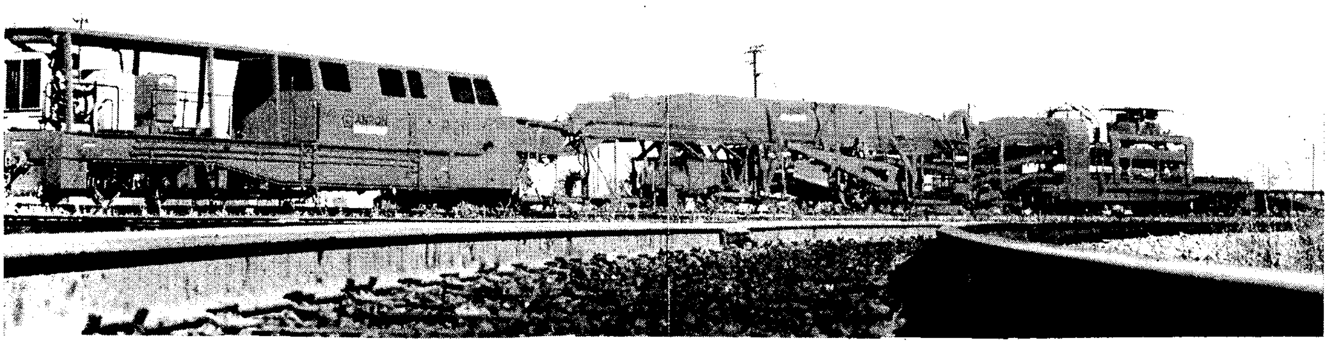
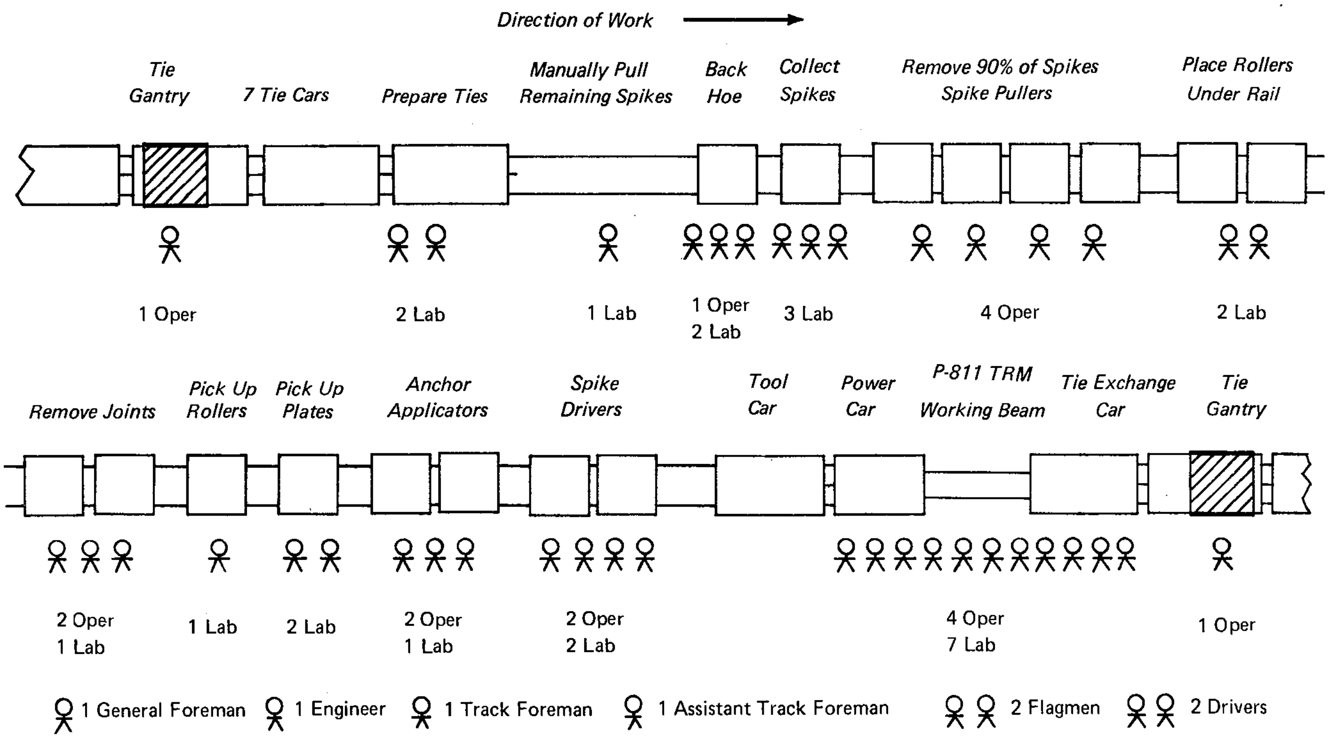


FIGURE 6. CANRON P-811 TRACK RENEWAL MACHINE



Activity	Equipment	Supervisors				Operators by Grade				Laborers
		GF	TF	ATF	PE	1	2	3	4	
Onsite supervision	—	1	1	1	1					
Place rollers under rail, join rail lengths	Push Car, Rail Puller									2
Pull 90% of spikes -- remaining spikes hold gage	4 Hydraulic Spike Pullers					4				
Collect and load spikes	Push Car									3
Prepare cut-in and cut-out locations -- remove ties by hand, crib ballast	Back Hoe						1			2
Manually pull remaining spikes	—									1
Move new ties to P-811, old ties to tie cars, secure ties	7 Tie Cars, 2 Gantry Cranes							2		3
P-811 TRM -- pick up old ties; transfer old ties to tie exchange car; install new ties; install new rails; manually remove old tie plates; manually straighten new tie plates	P-811 TRM								4	6
Drive spikes (outside spikes previously set by preplate operation; inside spikes to be set and driven)	2 Spike-Setter/Drivers					2				2
Place and secure rail anchors on rail base	2 Anchor Applicators					2				1
Pick up rollers	Push Car									1
Pick up tie plates from shoulder	Push Car									2
Disassemble old rails	Bolt Machines, Torch					2				1
Flagmen										2
Driver						2				
Support Activities										
Preplate Operation -- plate all new ties	Hoist, Milling Machine, Preplate Equipment									8
OTM Distribution	Burro Crane, 2 Gondolas		1					1		2
OTM Cleanup	Burro Crane, 2 Gondolas		1					1		2
Tie Car Support for Transportation	Locomotive, 54 Tie Cars							4		
Planning	—				4					

FIGURE 7. TRACK RENEWAL SYSTEM - TRM GROUP - INSTALLING WOOD TIES

geometry car and ultrasonic); CWR distribution; field welding; rail stressing; and CWR pickup.

The second subsystem is the ballast cleaning group. This group is separate so that it can be replaced by the selective maintenance surfacing and aligning gang if the reader wishes to forego ballast cleaning, which is optional with both selective and the track renewal method. The ballast cleaning group is shown graphically in figure 8. The support activities of a ballast distribution train and fouled material train are not included.

This gang is smaller than the equivalent selective maintenance gangs, primarily because it follows directly behind a TRM group that is putting spikes into new ties. There is little need for labor to pick up ties that fall when the track is picked up by the undercutter-cleaner.

b. Track Renewal System: Wood Tie to Concrete Tie. This system differs from the preceding system in that it installs concrete ties instead of wood ties.

Fastening operations behind the TRM are different and the support operations are different. The TRM group is shown graphically in figure 9 on the following page. Support activities include OTM cleanup, tie car support for transportation, and planning. Support activities not included are rail inspection, CWR distribution, field welding, rail stressing, and CWR pickup.

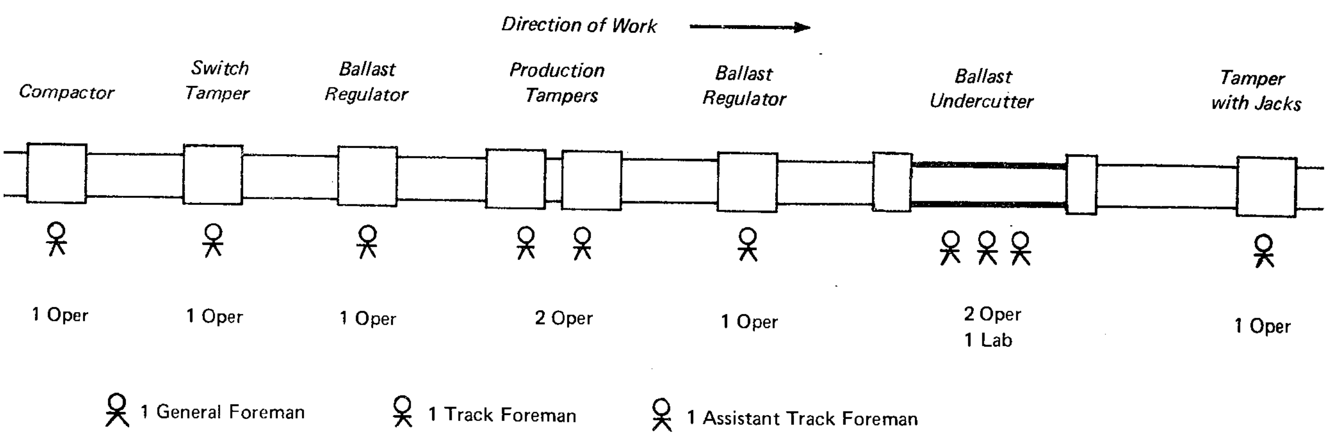
The ballast cleaning group is unchanged (see figure 8).

(3) Production Capabilities of the Canron P-811 TRM. The average daily production volume that can be obtained from a P-811, or any other TRM, depends on a number of factors and would vary from railroad to railroad and even from track to track. The primary variable affecting daily production is the length of time available for production, which is a function of the track occupancy time.

Other factors include the condition of the ties and ballast, the size and makeup of the total TRS crew, management and supervisory skills, the kind of ties being installed, production capacity of the tie cars and associated gangs.

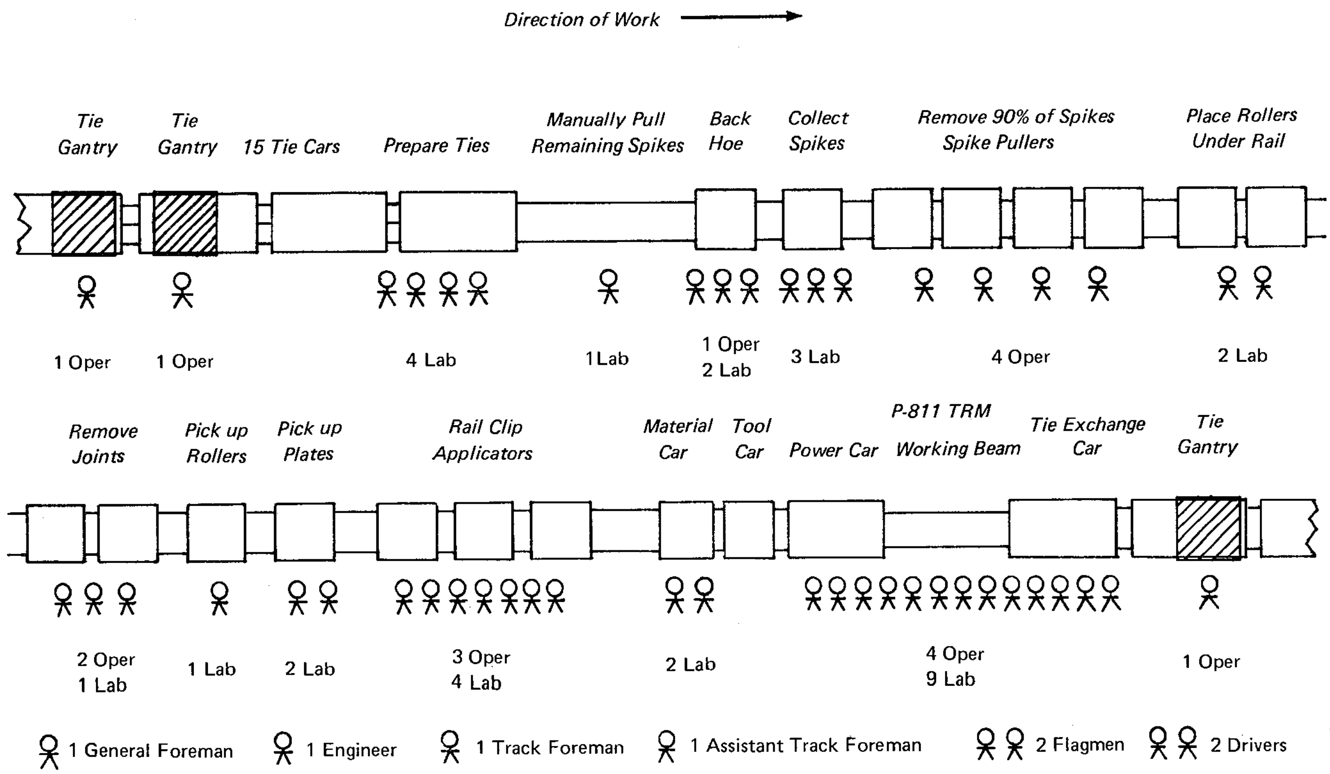
In Italy, the P-811 machines install 800 to 1,600 ties in 80 to 90 minutes of production in a total of 3 to 3.5 hours of track occupancy time. The production time includes breakdowns and downtime to cross turnouts, grade crossings, and other obstructions. The hourly production rate falls into a range of 533 to 1,200 ties installed per hour of production time. The midpoint of this range is 867 ties installed per hour.

Canadian National's P-811 installs an average of 3,000 concrete ties per day (3,692 wood ties removed) in a 5-hour production time of an 8-hour day. The hourly production rate is 600



Activity	Equipment	Supervisors				Operators by Grade				Laborers
		GF	TF	ATF	PE	1	2	3	4	
Onsite supervision	——	1	1	1						
Raise track -- break up ballast	Tamper with Jacks						1			
Undercut and clean ballast									2	1
Regulate ballast	Ballast Regulator						1			
Production tamping and lining	2 Production Tampers with Lining						2			
Regulate ballast	Ballast Regulator						1			
Finish tamp and tamp switches	Switch Tamper						1			
Stabilize ballast	Ballast Compactor						1			

FIGURE 8. TRS BALLAST CLEANING AND SURFACING GROUP



Activity	Equipment	Supervisors				Operators by Grade				Laborers
		GF	TF	ATF	PE	1	2	3	4	
Onsite supervision	——	1	1	1	1					
Place rollers under rails, join rail lengths	Push Car, Rail Puller									2
Pull 90% of spikes — remaining spikes hold gage	4 Hydraulic Spike Pullers					4				
Collect and load spikes	Push Car									3
Prepare cut-in and cut-out locations; remove ties by hand; crib ballast	Back Hoe						1			2
Manually pull remaining spikes	——									1
Move new ties to P-811 and old ties to cars; secure ties	15 Tie Cars, 3 Gantry Cranes							3		5
TRM — pick up old rail and ties; transfer old ties to exchange car; manually move old tie plates to shoulder; install new ties; set tie pads; install new rails	P-811 TRM								4	8
Distribute insulators and rail clips	Gondola									2
Pick up tie plates from shoulder	Push Car									2
Set insulators and rail clips to ties and fasten	3 Clip Applicators					3				4
Pick up rollers	Push Car									1
Disassemble old rails	Bolt Machines, Torch					2				1
Flagmen	——									2
Driver	——					2				
Support Activities										
OTM Cleanup	Burro Crane, 2 Gondolas		1					1		2
Tie Car Support for Transportation	Locomotive, 126 Tie Cars							4		
Planning	——				4					

FIGURE 9. TRACK RENEWAL SYSTEM - TRM GROUP - INSTALLING CONCRETE TIES

concrete ties installed (738 wood ties removed) per hour. In a special test, this machine has installed ties at the rate of 22 per minute, or 1,320 per hour, but that rate was for a short time period without any downtime and cannot be maintained for an extended time.

Amtrak's P-811 has equaled Canadian National's hourly production rate on some days, but averaged only 1,653 concrete ties installed (2,034 wood ties removed) per day in 1979, with over 6 hours available for production each day. This production rate is less than 275 concrete ties installed (339 wood ties removed) per hour.

Amtrak's low production rate resulted from a considerable number of machine breakdowns and operational delays, which Amtrak seemed to be effectively reducing late in the 1979 track laying season. The sustained production during the last two months of the season seems to indicate that the machine will install at least 330 ties per hour of production time (369 wood ties removed) or about 2,000 ties per day in the future.

Based on these production rates, a rate of 576 wood ties installed per hour of production time is used for this study. This rate is less than that maintained for 2 years by Canadian National and by track maintenance contractors in Italy. It is probably a conservative estimate for installing wood ties since the tie pickup process is more complicated than tie installation by the P-811 and CN is picking up 738 wood ties per hour.

The daily production rate is obtained by estimating the TRS and TRM daily operational breakdown. Costing for all gangs is based on an 8-hour work day with 6.5 hours track occupancy time. Within the 6.5 hours, it is estimated that 0.5 hour would be required for travel time between the staging base to the work site and 1.0 hour would be required for startup and cleanup work. This leaves an average of 5 hours per day for production, including downtime. At the rate of 576 ties installed per hour, the daily average ties installed would be 2,880.

A slightly higher daily production rate of 2,940 ties is used for installing concrete ties. This was chosen to conform with the capacity of 14 tie cars. It is still slightly less than the average production rate claimed by Canadian National.

Based on the experience of Amtrak and Italian contractors, the average rates used in this study could be either high or low depending on circumstances. The TRM, and therefore the TRS, daily average capacity during a full 8-hour work shift with approximately 6.5 hours of track occupancy time could range from approximately 1,800 to 5,000 ties installed. Because this is such a high variation, the sample economic analysis in chapter III includes long-term costs calculated for production rates of 1,920 wood ties (1,890 concrete ties) per day installed and 3,840 wood ties (3,990 concrete ties) per day installed.

These are arbitrary rates that correspond to capacities of full tie cars.

Average daily and annual production rates, based on 200 days of production, used in section 2A for track renewal system gangs are:

Gang	Daily Production (Track Miles per 6.5-Hour Day)	Annual Production (Track Miles)
TRS - Wood to Wood	0.886*	177
OTM Distribution	6.0	---
OTM Cleanup	1.5	---
TRS - Wood to Concrete	1.114**	222
OTM Cleanup	1.5	---

*2,880 ties installed at 19.5-inch centers.
**2,940 ties installed at 24.0-inch centers.

2. Cost Factors Associated with Track Maintenance and Wood Tie Reuse

The methodology for obtaining total operational costs and benefits for each operation described in section 1 is described in the following subsections. Operation or gang costs development is presented first, with the discussion organized by type of cost rather than by gang. This is followed by a presentation of how material credit for used wood ties, and other materials, if desired, can be obtained.

The costs and material credits developed in this section are developed with some precision, but they reflect the assumptions made to describe a generalized situation and use costs that were current in January 1980. If the total gang costs and material credits developed here are used without modification, the reader should bear in mind that his first-year and long-term economic evaluation is only general, providing trends but not precise answers.

A. Operational Costs for Track Maintenance

The development of total costs to operate each of the gangs described in section 1 of this chapter is explained here. When all of these costs, plus the material credits (described in section B), are determined, the long-term cost evaluation (described in section 3) can begin.

The procedures described in this section are shown on the flow chart (figure 10), which breaks step 2A in figure 1 down into finer tasks.

Each operation has 5 separate cost areas, each requiring a different procedure. These cost areas are:

a. Capital recovery cost.
b. New material cost.
c. Labor cost.
d. Equipment maintenance and fuel costs.
e. Tie transportation cost.

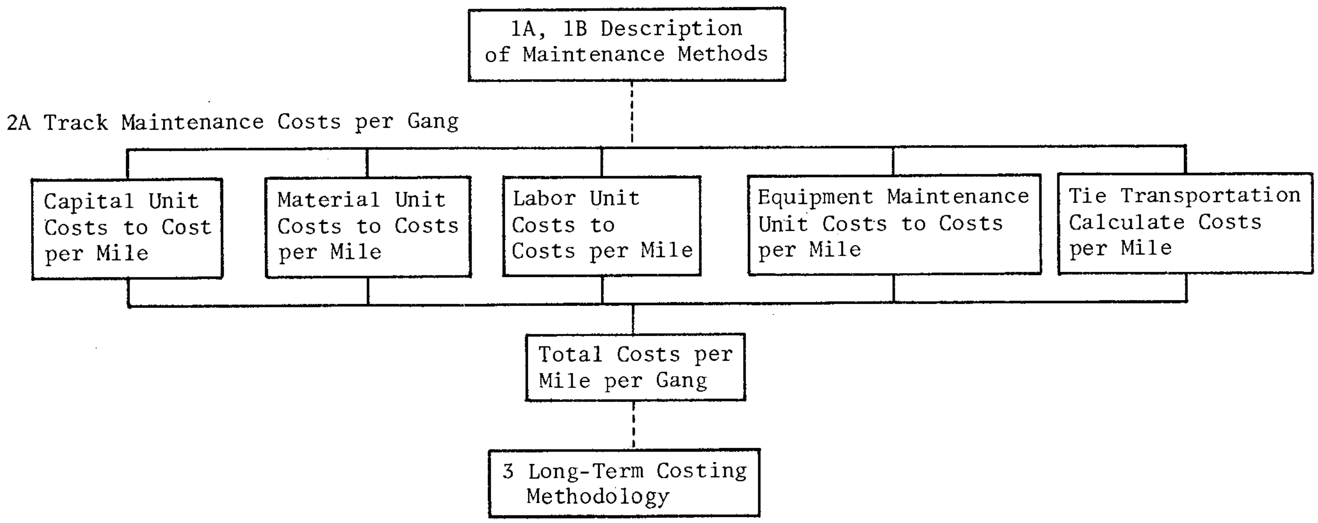


FIGURE 10. TRACK MAINTENANCE COSTS PER GANG FLOW CHART

The procedures to develop these costs for each gang is presented in the following subsections. An "audit trail" of cost tables is provided to the reader for each track maintenance gang so that any gang description or unit cost may be changed to suit specific conditions.

(1) Equipment Capital Recovery Costs. The cost to maintain and run equipment does not in itself cover the full expense of equipment usage. The equipment must be purchased or leased, against which a capital or rental cost is applied. This study has assumed that all track maintenance machinery is purchased new with the exception of flat cars, gondolas, and locomotives which are assumed to be leased from a pool of secondhand equipment on hand in any given railroad's inventory.

The equipment is assumed to be at least 10 years old and already written off or fully depreciated. Because the equipment is usable elsewhere on the railroad, a per diem or daily rental is charged for its use.

Inquiry into railroad industry practice finds that this equipment would be least likely to be purchased new for the track maintenance tasks assigned here. The rental or lease charges used in this study are average figures based on the rates used by several midwestern railroads.

The bulk of the equipment is dedicated track maintenance machinery which normally has a limited service life, after which it has only scrap or possibly spare parts value. While most, if not all, conventional track maintenance machines would already be owned by a railroad, they are continually being replaced with new machines. Thus, while this study assumes that these machines are purchased new, against which a capital recovery cost based on a new cost is assessed, a railroad could alternatively apply a lease cost against the undepreciated value of the machines already on hand, in a site-specific case.

The capital recovery cost (CRC) for a piece of equipment purchased is the equivalent annual cost which covers depreciation (loss in value of the asset) and the interest rate on the capital expended for that piece of equipment. While there are several methods of calculating depreciation, it can be shown that the equivalent annual cost of the capital recovery is the same no matter which method of depreciation is used.

The CRC is calculated for all the track maintenance equipment purchased for the various track maintenance gangs associated with either the selective maintenance or track renewal methods of track maintenance. The CRC for a piece of equipment depends on the purchase price or new cost of the equipment, the service life over which it is being depreciated, the salvage value at the end of its service life, and the interest rate.

Table 1, on page 17, lists all the types of equipment purchased for either method of track maintenance. The table shows the new cost of each piece of equipment as well as its expected service life, in years, or as a function of mileage, wherever possible for the machine type. All cost figures are based on manufacturer's quotes in 1980.

The table also shows the Canron Rail Group's quoted price of $1,900,000 for a P-811 track renewal machine (TRM), which also includes the cost of the gantry crane system with two gantries and the tie exchange car. The 10-year service life was arbitrarily set as an economic period over which the machine may be depreciated, at an annual production rate of about 180 track miles.

Tables 2 through 8, on pages 18 through 24, show the derivation of the annual capital recovery costs for the seven track maintenance gangs that constitute the two methods of track maintenance under study. For example, table 6 lists the equipment required along with the variables and factors necessary to calculate

TABLE 1

EQUIPMENT PURCHASE COST AND SERVICE LIFE

Machine	Depreciation Life (years)	Average Shifts per Year	Average Miles per Year*	New Cost**
Air Compressor	10	200		15,000
Back Hoe	8	200		35,000
Ballast Compactor	8		136	77,000
Ballast Regulator	10	200		72,000
Ballast Sled	10			330,000
Ballast Undercutter/Cleaner	8		136	850,000
Crane, Burro	20	200		190,000
Gaging Machine	8	200		32,800
Motor Car	10	200		5,800
Motor Grader	8	200		67,000
Push Cart	10	200		800
Rail Anchor Applicator	8	200		42,000
Rail Lifter	10	200		5,200
Rail Puller	8	200		500
Speed Swing	10	200		90,000
Spike Driver - Tie Gang	6	200		58,700
Spike Driver - Pneumatic	6	200		1,000
Spike Driver - Rail Gang	6	200		62,700
Tamper	6		284	63,000
Tamper with Jacks	6		284	72,000
Tamper - Production	6		284	140,000
Tamper - Switch	6		284	152,000
Tie Adzer	8	200		4,400
Tie Borer	8	200		2,600
Tie Cribber	8	200		15,700
Tie Crane	8	200		27,300
Tie Inserter	6	200		62,000
Tie Plug Driver	8	200		10,200
Track Renewal Machine (P-811)	10		180	1,900,000
Tie Shear	6	200		62,800
Tie Spacer	8	200		35,000
Tie Sprayer	8	200		4,800
Tie Bed Scarifier	6	200		40,400
Tie Unloader	8	200		89,000
Spike Puller - Tie Gang	6	200		5,300
Spike Puller - Rail Gang	6	200		14,200

*Based on 200 shifts per year.
**Excluding taxes and delivery cost (1980 dollars).

TABLE 2

ANNUAL CAPITAL RECOVERY COST (CRC)*: TIE GANG
(All costs in 1980 dollars)
12% INTEREST RATE

Equipment	Quantity	Item Price	P.P. Total Purchase Price	t Economic Service Life (years)	SV Salvage Value after t	CRF Capital Recovery Factor	SFF Sinking Fund Factor	P. P. X CRF	SV X SFF	Annual CRC	Fraction of Year Charged to Gang	Annual CRC Charged to Gang
Spike Puller	2	5,300	10,600	6	530	.24323	.12323	2,578	65	2,513	200/200	2,513
Tie Shear	1	62,800	62,800	6	3,140	.24323	.12323	15,275	387	14,888	200/200	14,888
Tie Bed Scarifier	1	40,400	40,400	6	2,020	.24323	.12323	9,826	249	9,578	200/200	9,578
Tie Crane	2	27,300	54,600	8	2,730	.20130	.08130	10,991	222	10,769	200/200	10,769
Tie Inserter	1	62,000	62,000	6	3,100	.24323	.12323	15,080	382	14,698	200/200	14,698
Tamper	1	63,000	63,000	8.5	3,150	.19450	.07450	12,254	235	12,019	200/200	12,019
Rail Lifter	1	5,200	5,200	10	260	.17698	.05698	920	15	905	200/200	905
Tie Drill	2	2,600	5,200	8	260	.20130	.08130	1,047	21	1,026	200/200	1,026
Spike Setter/Driver	1	58,700	58,700	6	2,935	.24323	.12323	14,278	362	13,916	200/200	13,916
Ballast Regulator	1	72,000	72,000	10	3,600	.17698	.05698	12,743	205	12,537	200/200	12,537
Burro Crane	1	190,000	190,000	20	9,500	.13388	.01388	25,437	132	25,305	200/200	25,305
Automobile	1	6,000	6,000	5	300	.27741	.15741	1,664	47	1,617	34/200	275
Locomotive	1	400/day (leased)	400/day (leased)	——	——	——	——	——	——	——	43/200	17,200
Tie Unloader	1	89,000	89,000	8	4,450	.20130	.08130	17,916	362	17,554	43/200	3,774
Total			719,500									$139,403

*Annual Capital Recovery Cost (CRC) = (P.P. x CRF) – (SV x SFF).

TABLE 3

ANNUAL CAPITAL RECOVERY COST (CRC)*: BALLAST CLEANING
(All costs in 1980 dollars)

12% INTEREST RATE

Equipment	Quantity	Item Price	P.P. Total Purchase Price	t Economic Service Life (years)	SV Salvage Value after t	CRF Capital Recovery Factor	SFF Sinking Fund Factor	P.P. X CRF	SV X SFF	Annual CRC	Fraction of Year Charged to Gang	Annual CRC Charged to Gang
Spike Driver	1	1,000	1,000	6	50	.24323	.12323	243	6	237	200/200	237
Air Compressor	1	15,000	15,000	10	750	.17698	.05698	2,655	43	2,612	200/200	2,612
Tamper	1	72,000	72,000	10	3,600	.17698	.05698	12,743	205	12,537	200/200	12,537
Ballast Undercutter	1	850,000	850,000	9	42,500	.18768	.06768	159,528	2,876	156,652	200/200	156,652
Ballast Regulator	1	72,000	72,000	10	3,600	.17698	.05698	12,743	205	12,537	200/200	12,537
Production Tamper/Liner	1	140,000	140,000	10	7,000	.17698	.05698	24,777	399	24,378	200/200	24,378
Push Cart	1	800	800	10	40	.17698	.05698	142	2	139	200/200	139
Switch Tamper	1	152,000	152,000	10	7,600	.17698	.05698	26,901	433	26,468	200/200	26,468
Ballast Compactor	1	77,000	77,000	9	3,850	.18768	.06768	14,451	261	14,191	200/200	14,191
Total			1,379,800									$249,751

*Annual Capital Recovery Cost (CRC) = (P.P. x CRF) – (SV x SFF).

TABLE 4

ANNUAL CAPITAL RECOVERY COST (CRC)*: RAIL GANG

(All costs in 1980 dollars)

12% INTEREST RATE

Equipment	Quantity	Item Price	P.P. Total Purchase Price	t Economic Service Life (years)	SV Salvage Value after t	CRF Capital Recovery Factor	SFF Sinking Fund Factor	P. P. X CRF	SV X SFF	Annual CRC	Fraction of Year Charged to Gang	Annual CRC Charged to Gang
Burro Crane	1	190,000	190,000	20	9,500	.13388	.01388	25,437	132	25,305	200/200	25,305
Spike Puller	2	14,200	28,400	6	1,420	.24323	.12323	6,908	175	6,733	200/200	6,733
Bolt Machine	2	1,600	3,200	6	160	.24323	.12323	788	20	759	200/200	759
Speed Swing	1	90,000	90,000	10	4,500	.17698	.05698	15,928	256	15,672	200/200	15,672
Push Cart	2	800	1,600	10	80	.17698	.05698	283	5	279	200/200	279
Ballast Cribber	1	15,700	15,700	8	785	.20130	.08130	3,160	64	3,097	200/200	3,097
Tie Plug Driver	2	10,200	20,400	8	1,020	.20130	.08130	4,107	83	4,024	200/200	4,024
Tie Adzer	2	4,400	8,800	8	440	.20130	.08130	1,771	36	1,736	200/200	1,736
Tie Sprayer	1	4,800	4,800	8	240	.20130	.08130	966	20	947	200/200	947
Gager	1	32,800	32,800	8	1,640	.20130	.08130	6,603	133	6,469	200/200	6,469
Tamper	1	63,000	63,000	10	3,150	.17698	.05698	11,150	179	10,970	200/200	10,970
Tie Drill	2	2,600	5,200	8	260	.20130	.08130	1,047	21	1,026	200/200	1,026
Spike Setter/Driver	1	62,700	62,700	6	3,135	.24323	.12323	15,251	386	14,864	200/200	14,864
Anchor Applicator	2	42,000	84,000	8	4,200	.20130	.08130	16,909	341	16,568	200/200	16,568
Burro Crane	1	190,000	190,000	20	9,500	.13388	.01388	25,437	132	25,305	200/200	25,305
Gondola	2	2.50/day (leased)	5.00/day (leased)	—	—	—	—	—	—	—	200/200	1,000
Burro Crane	1	190,000	190,000	20	9,500	.13388	.01388	25,437	132	25,305	43/200	5,441
Gondola	2	2.50/day (leased)	5.00/day (leased)	—	—	—	—	—	—	—	43/200	215
Total			990,600									140,408

*Annual Capital Recovery Cost (CRC) = (P.P. x CRF) – (SV x SFF).

TABLE 5

ANNUAL CAPITAL RECOVERY COST (CRC)*: SURFACE AND LINE

(All costs in 1980 dollars)

12% INTEREST RATE

Equipment	Quantity	Item Price	P.P. Total Purchase Price	t Economic Service Life (years)	SV Salvage Value after t	CRF Capital Recovery Factor	SFF Sinking Fund Factor	P. P. X CRF	SV X SFF	Annual CRC	Fraction of Year Charged to Gang	Annual CRC Charged to Gang
Ballast Regulator	1	72,000	72,000	10	3,600	.17698	.05698	12,743	205	12,537	200/200	12,537
Production Tamper/Liner	1	140,000	140,000	7	7,000	.21912	.09912	30,677	694	29,983	200/200	29,983
Switch Tamper	1	152,000	152,000	7	7,000	.21912	.09912	33,306	753	32,553	200/200	32,553
Total			364,000									75,073

*Annual Capital Recovery Cost (CRC) = (P.P. x CRF) – (SV x SFF).

TABLE 6

ANNUAL CAPITAL RECOVERY COST (CRC)*: TRM GROUP INSTALLING WOOD TIES
(All costs in 1980 dollars)

12% INTEREST RATE

Equipment	Quantity	Item Price	P.P. Total Purchase Price	t Economic Service Life (years)	SV Salvage Value after t	CRF Capital Recovery Factor	SFF Sinking Fund Factor	P. P. X CRF	SV X SFF	Annual CRC	Fraction of Year Charged to Gang	Annual CRC Charged to Gang
Push Cart	4	800	3,200	10	160	.17698	.05698	566	9	557	200/200	557
Rail Puller	1	500	500	8	25	.20130	.08130	101	2	99	200/200	99
Spike Puller	2	14,200	28,400	6	1,420	.24323	.12323	6,908	175	6,733	200/200	6,733
Back Hoe	1	35,000	35,000	8	1,750	.20130	.08130	7,046	142	6,903	200/200	6,903
TRM (P-811)	1	1,900,000	1,900,000	10	95,000	.17698	.05698	336,262	5,413	330,849	200/200	330,849
Mechanics' Flat Car	1	2.50/day (leased)	2.50/day	—	—	—	—	—	—	—	200/200	500
Spike Setter/Driver	2	62,700	125,400	6	6,720	.24323	.12323	30,501	828	29,673	200/200	29,673
Anchor Applicator	2	42,000	84,000	8	4,200	.20130	.08130	16,909	341	16,568	200/200	16,568
Bolt Machine	2	1,600	3,200	6	160	.24323	.12323	778	20	759	200/200	759
Burro Crane	1	190,000	190,000	20	9,500	.13388	.01388	25,437	132	25,305	30/200	3,796
Gondola	2	2.50/day (leased)	5.00/day	—	—	—	—	—	—	—	30/200	150
Burro Crane	1	190,000	190,000	20	9,500	.13388	.01388	25,437	132	25,305	118/200	14,930
Gondola	2	2.50/day (leased)	5.00/day	—	—	—	—	—	—	—	118/200	590
Locomotive	1	400/day (leased)	400/day	—	—	—	—	—	—	—	200/200	80,000
Tie Milling Machine	1	50,000	50,000	10	2,500	.17698	.05698	8,849	142	8,707	200/200	8,707
Preplating Equipment	1	43,000	48,000	10	2,400	.17698	.05698	8,495	137	8,358	200/200	8,358
Magnetic Hoist	1	35,000	35,000	10	1,750	.17698	.05695	6,194	100	6,095	200/200	6,095
Total			2,692,700									515,265

*Annual Capital Recovery Cost (CRC) = (P.P. x CRF) – (SV x SFF).

TABLE 7

ANNUAL CAPITAL RECOVERY COST (CRC)*: TRS BALLAST CLEANING, SURFACE AND LINE
(All costs in 1980 dollars)

12% INTEREST RATE

Equipment	Quantity	Item Price	P.P. Total Purchase Price	t Economic Service Life (years)	SV Salvage Value after t	CRF Capital Recovery Factor	SFF Sinking Fund Factor	P. P. X CRF	SV X SFF	Annual CRC	Fraction of Year Charged to Gang	Annual CRC Charged to Gang
Tamper with Jacks	1	72,000	72,000	10	3,600	.17698	.05698	12,743	205	12,537	200/200	12,537
Ballast Undercutter	1	850,000	850,000	9	42,500	.18768	.06768	159,528	2,876	156,652	200/200	156,652
Ballast Regulator	2	72,000	144,000	10	7,200	.17698	.05698	25,485	410	25,075	200/200	25,075
Production Tamper/Liner	2	140,000	280,000	10	14,000	.17698	.05698	49,554	798	48,757	200/200	48,757
Switch Tamper	1	152,000	152,000	10	7,600	.17698	.05698	26,901	433	26,468	200/200	26,468
Ballast Compactor	1	77,000	77,000	9	3,850	.18768	.06768	14,451	261	14,191	200/200	14,191
Total			1,575,000									283,679

*Annual Capital Recovery Cost (CRC) = (P.P. x CRF) – (SV x SFF).

TABLE 8

ANNUAL CAPITAL RECOVERY COST (CRC)*: TRM GROUP INSTALLING CONCRETE TIES
(All costs in 1980 dollars)

12% INTEREST RATE

Equipment	Quantity	Item Price	P.P. Total Purchase Price	t Economic Service Life (years)	SV Salvage Value after t	CRF Capital Recovery Factor	SFF Sinking Fund Factor	P. P. X CRF	SV X SFF	Annual CRC	Fraction of Year Charged to Gang	Annual CRC Charged to Gang
Push Cart	4	800	3,200	10	160	.17698	.05698	566	9	557	200/200	557
Rail Puller	1	500	500	8	25	.20130	.08130	101	2	99	200/200	99
Spike Puller	2	14,200	28,400	6	1,420	.24323	.12323	6,908	175	6,733	200/200	6,733
Back Hoe	1	35,000	35,000	8	1,750	.20130	.08130	7,045	142	6,903	200/200	6,903
TRM (P-811)	1	1,950,000	1,950,000	10	97,500	.17698	.05698	345,111	5,556	339,555	200/200	339,555
Maintenance Flat Car	1	2.50/day (leased)	2.50/day	—	—	—	—	—	—	—	200/200	500
Materials Car (Gondola)	1	2.50/day (leased)	2.50/day	—	—	—	—	—	—	—	200/200	500
Clip Applicator	3	25,000	75,000	6	3,750	.24323	.12323	18,242	462	17,780	200/200	17,780
Bolt Machine	2	1,600	3,200	6	160	.24323	.12323	778	20	759	200/200	759
Burro Crane	1	190,000	190,000	20	9,500	.13388	.01388	25,437	132	25,305	147/200	18,599
Gondola	2	2.50/day (leased)	5.00/day	—	—	—	—	—	—	—	147/200	735
Locomotive	1	400/day (leased)	400/day	—	—	—	—	—	—	—	200/200	80,000
Total			2,285,300									472,720

*Annual Capital Recovery Cost (CRC) = (P.P. x CRF) – (SV x SFF).

the CRC for each piece of equipment in the TRM group of the wood-to-wood TRS. An interest rate of 12 percent was assumed for the capital recovery.

There are several convenient formulas by which CRC can be calculated. The formula used in this study is:

CRC = (P.P. x CRF) - (SV x SFF)*

where CRC = annual capital recovery cost,

P.P. = total purchase price for each type of equipment piece,

CRF = capital recovery factor for a given time period (service life) and interest rate (obtainable from tables of discrete compound interest rates),

SV = salvage value at the end of equipment service life, and

SFF = sinking fund factor for a given time period and interest rate (obtainable from tables of discrete compound interest rates).

The annual capital recovery cost for a P-811 TRM is calculated as follows: ($1,900,000 x 0.17698) - ($95,000 x 0.05698) = $330,848.90.

The total annual cost of capital recovery for the TRM-group changing rails and all ties is $515,265.40. This also includes the cost of the wood tie preplating equipment. The total investment outlay for all equipment for this gang is $2,692,700 (excluding equipment costs incurred in tie transportation which are calculated separately).

Table 9 shows the final step in the derivation of this cost for the various gangs. The CRC per mile for each gang is calculated by dividing the gang's annual cost by its respective annual production rate. The per-mile CRC for the TRM gang is higher than that of the tie and rail selective maintenance gangs combined. This is due to the relatively large capital cost of the track renewal machine itself.

In summary, the methodology used to derive the capital recovery cost per mile for each track maintenance gang, is as follows: (a) calculate the annual capital recovery cost for each piece of equipment working with the various gangs; (b) sum these costs to find the total annual CRC for the respective gangs; (c) divide the sums by each gang's respective annual production rate to find the CRC per mile for each gang.

(2) New Materials Costs. The new materials cost per mile for each track maintenance gang is calculated directly from the unit costs for each track component shown in table 10. The unit costs listed are based on the Association of Americal Railroads (AAR) statistics and current (1980) prices quoted by manufacturers.

For each gang, the cost per mile for materials installed is calculated by summing the total cost of the individual track components installed by that gang, as shown in tables 11

*Canada, John R., Intermediate Economic Analysis for Management and Engineering, Prentice-Hall, Inc., 1971, page 37.

TABLE 9

ANNUAL CAPITAL RECOVERY COST (CRC) PER MILE PER OPERATION

Gang	Annual CRC Charged to Gang ($/year)	Annual Production (miles/year)	Cost per Mile ($/mile)
Tie Gang	139,403.32	200	697.02
Conventional Ballast Cleaning	249,751.83	122	2,047.15
Rail Gang	140,407.78	108	1,300.07
Track Surface and Alignment	75,073.32	246	305.18
Track Renewal Machine Gang (wood)	515,265.40	177	2,911.10
Ballast Cleaning and Surfacing with TRS	283,679.27	122	2,325.24
Track Renewal Machine Gang (concrete)	472,720.43	222	2,129.37

TABLE 10

MATERIAL COSTS

Item	Unit	Cost
Rail (112 to 140 pounds/yard in 39-foot lengths, in plant welding approximately $24/weld)	Ton	$417.00
Spikes	Each	$0.25
Rail Anchors	Each	$0.84
Tie Plates (16 inches)	Each	$4.55
Wood Tie (7 inches x 9 inches x 8 feet 6 inches hardwood)	Each	Cost range $12.40 to $15.93* Average used $13.50
Concrete Tie	Each	Approximately $40.00 + 0.11¢/mile for transportation
Tie Plugs	Each	$0.0085
Gage Plugs	Each	$0.032
Preservative	Tie	$0.10

*AAR 1979 statistics

through 17, on pages 27 to 28. For most components, including ties and fastenings, the individual component totals are derived by multiplying the unit cost per component by the number of units of that component installed per mile. In the case of rail, the unit cost is quoted by the ton and must be converted to a per mile cost as a function of the rail weight.

Some of the other (steel) track materials (OTM) are reused by most railroads. The reuse percentages applied in this study to used tie plates, track spikes, and rail anchors are 95 percent, 50 percent, and 50 percent, respectively. However, if the new rail installed is of a different weight than the worn rail removed, whether the rail is changed by a conventional rail gang or a track renewal machine, all the steel OTM must be changed. In this case it is assumed that all new tie plates, spikes and rail anchors are installed. Steel OTM reuse according to the above percentages is assumed for the conventional tie renewal operation.

The new materials cost development for a conventional rail gang and a TRM gang (wood ties installed), shown in tables 12 and 14, respectively, have assumed that the new rail installed is heavier than the worn rail (132-pound rail is replacing 115-pound rail), thus necessitating a 100-percent change in steel OTM for both gangs.

Tables 13 and 15 show the new materials cost development for the same rail and TRM gangs assuming that the rail weight remains constant, thus allowing for steel OTM reuse.

The significantly higher new materials cost for a TRM gang over that of both the rail and tie gangs, reflects the fact that track renewal replaces 100 percent of the ties. The cost of ballast has been excluded from the overall comparison since it is assumed that the ballast requirements are equal for both methods of track maintenance and are difficult to calculate.

(3) Labor Costs. Labor costs are developed for each operation by compiling the labor required, by classification, from the operation descriptions presented in section 1. Daily labor costs per classification used are shown in table 18, on page 29. Column (2) costs, base pay plus fringe benefits, are used for positions normally filled from the local division's manpower. Column (4) costs include per diem costs for traveling positions.

Tables 19 to 25, on pages 30 to 33, show the development of total annual labor costs for each operation. No overtime was charged to either method of track maintenance in this study. The number of positions of each classification for each operational gang is multiplied by the daily labor rate. The resulting cost is multiplied by the assumed days worked per year for the specific gang. Note that some support gangs do not need to work 200 days a year to keep up with the main operation. The annual labor costs for each classification are then summed for the entire operation.

Annual labor costs are then converted to labor costs per mile by dividing by the assumed number of miles worked by each operation each year.

TABLE 11

NEW MATERIALS COST PER MILE: TIE GANG REPLACING 25 PERCENT OF THE TIES

Material	Unit	Cost/Unit	Number/Mile	Cost/Mile
Wood Tie	Each	$ 13.50	812	$10,962.00
Spikes	Each	$ 0.25	1,624	$ 406.00
Tie Plates	Each	$ 4.55	81	$ 368.55
Rail Anchors	Each	$ 0.84	812	$ 682.08
Total Without Anchors				$11,736.55
Total With Anchors				$12,418.63

TABLE 12

NEW MATERIALS COST PER MILE: RAIL GANG REPLACING JOINTED LIGHT RAIL WITH 132-POUND CWR

Material	Unit	Cost/Unit	Number/Mile	Cost/Mile
Rail	Ton	$417.00	232.32	$ 96,877.44
Factory Welding of Rail	Welds	$ 24.00	270.77	$ 6,498.46
Tie Plates	Each	$ 4.55	6,500	$ 29,575.00
Spikes	Each	$ 0.25	13,000	$ 3,250.00
Anchors	Each	$ 0.84	6,500	$ 5,460.00
Tie Plugs	Each	$ 0.0085	13,000	$ 110,50
Gage Plugs	Each	$ 0.032	1,625	$ 52.00
Preservative	Tie	$ 0.10	3,250	$ 325.00
Total				$142,148.40

TABLE 13

NEW MATERIALS COST PER MILE: RAIL GANG REPLACING 132-POUND CWR WITH 132-POUND CWR

Material	Unit	Cost/Unit	Number/Mile	Cost/Mile
Rail	Ton	$417.00	232.32	$ 96,877.44
Factory Welding of Rail	Weld	$ 24.00	270.77	$ 6,498.46
Tie Plates	Each	$ 4.55	325	$ 1,478.75
Spikes	Each	$ 0.25	6,500	$ 1,625.00
Anchors	Each	$ 0.84	3,250	$ 2,730.00
Tie Plugs	Each	$ 0.0085	13,000	$ 110.50
Gage Plugs	Each	$ 0.032	1,625	$ 52.00
Preservative	Tie	$ 0.10	3,250	$ 325.00
Total				$109,697.15

TABLE 14

NEW MATERIALS COST PER MILE: TRS REPLACING JOINTED LIGHT RAIL WITH 132-POUND CWR AND INSTALLING WOOD TIES

Material	Unit	Cost/Unit	Number/Mile	Cost/Mile
Rail	Ton	$417.00	232.32	$ 96,877.44
Factory Welding of Rail	Welds	$ 24.00	270.77	$ 6,498.46
Tie Plates	Each	$ 4.55	6,500	$ 29,575.00
Spikes	Each	$ 0.25	13,000	$ 3,250.00
Anchors	Each	$ 0.84	6,500	$ 5,460.00
Wood Ties	Each	$ 13.50	3,250	$ 43,875.00
Total				$185,535.90

TABLE 15

NEW MATERIALS COST PER MILE: TRS REPLACING 132-POUND CWR WITH 132-POUND CWR AND INSTALLING WOOD TIES

Material	Unit	Cost/Unit	Number/Mile	Cost/Mile
Rail	Ton	$417.00	232.32	$ 96,877.44
Factory Welding of Rail	Welds	$ 24.00	270.77	$ 6,498.46
Tie Plates	Each	$ 4.55	325	$ 1,478.75
Spikes	Each	$ 0.25	6,500	$ 1,625.00
Anchors	Each	$ 0.84	3,250	$ 2,730.00
Wood Ties	Each	$ 13.50	3,250	$ 43,875.00
Total				$153,084.65

TABLE 16

NEW MATERIALS COST PER MILE: TRS NOT REPLACING RAILS AND INSTALLING WOOD TIES

Material	Unit	Cost/Unit	Number/Mile	Cost/Mile
Tie Plates	Each	$ 4.55	325	$ 1,478.75
Spikes	Each	$ 0.25	6,500	$ 1,625.00
Anchors	Each	$ 0.84	3,250	$ 2,730.00
Wood Ties	Each	$ 13.50	3,250	$ 43,875.00
Total				$ 49,708.75

TABLE 17

NEW MATERIALS COST PER MILE: TRS REPLACING LIGHT JOINTED RAIL WITH 132-POUND CWR AND INSTALLING CONCRETE TIES

Material	Unit	Cost/Unit	Number/Mile	Cost/Mile
Rail	Ton	$417.00	232.32	$ 96,877.44
Factory Welding of Rail	Welds	$ 24.00	270.77	$ 6,498.46
Concrete Ties (including hardware)	Each	$ 40.00	2,640	$105,600.00
Total				$208,975.90

TABLE 18

DAILY LABOR COSTS BY CLASSIFICATION

Title	Base Pay per Day ($)	Base Pay Plus 41% Fringe Benefits ($)	Expenses per Day ($)	Total Labor Cost ($)
Project Engineer	119.54*	168.55	40.00	208.55
General Foreman	105.74**	149.09	40.00	189.09
Tie Inspector	84.64	119.34	40.00	159.34
Track Foreman	73.60	103.78	12.00	115.78
Track Foreman, Assistant	69.52	98.02	12.00	110.02
Operator Grade 4	90.64***	127.80	40.00	167.80
Operator Grade 3	73.76	104.00	12.00	116.00
Operator Grade 2	72.00	101.52	12.00	113.52
Operator Grade 1	65.68	92.61	12.00	104.61
Laborer	62.84	88.60	12.00	100.60

*Monthly salary of $2,600.
**Monthly salary of $2,300.
***To encourage experienced operators/mechanics to stay with the large machines, they should be paid a premium and full expenses.

This step is shown for all operations in table 26, on page 33.

(4) Equipment Maintenance and Fuel Costs. The cost of maintaining a piece of track machinery includes the costs of spare parts; grease; hydraulic and engine oils; and labor to maintain and repair the machine. It is usual for a major track maintenance gang to have one or more mechanics assigned to it on a full-time basis. These mechanics are not normally paid from the track maintenance crew's budget, but are instead accounted for in the cost to maintain the track maintenance machinery. The cost of fuel to run a machine is usually lumped together with maintenance costs, though calculated as a separate item. The overall maintenance cost for a machine or set of machines depends on many variables such as operator and mechanic skills, track design, track condition, machine design, and environmental conditions.

Upon investigation of these maintenance costs for individual pieces of conventional track maintenance equipment, it was discovered that while some railroads have attempted to compile these costs, the figures lacked consistency to give a statistically valid cost per time period of work. As an alternative to providing inconsistent (though site-specific or actual) track machinery maintenance costs, a method incorporating ICC accounting rules and AREA techniques relating maintenance costs to machine cost and usage is used to calculate track machine maintenance cost. The costs calculated by this method are shown in table 27, on page 34.

The method used to determine equipment maintenance cost stems from ICC accounting practices that require railroads to total the undepreciated value of work equipment (ICC Account 37) and to total the amount spent on maintaining work equipment (ICC Account 269). For most railroads, the ratio between the total undepreciated value and the total maintenance budget is in the region of five to one. This suggests that on the average, it takes 20 percent of the undepreciated value of work equipment to maintain that equipment each year.

A more detailed review of this relationship between capital and maintenance cost, done by the AREA, showed that the five-to-one ratio was not universal to all pieces of track maintenance equipment, but that heavy-use machines require more maintenance at a higher cost proportionately than do light-use machines. AREA Committee 27 designated three categories of track maintenance machinery -- light-use, average-use, and heavy-use -- and arbitrarily set the ratio between annual maintenance and capital cost at 1:10, 2:10, and 3:10 (or 0.1, 0.2, and 0.3), respectively, for the three categories.

This latter method was used to derive the maintenance costs of all conventional track maintenance machinery with the exception of the ballast undercutter. The cost to maintain this particular machine bears no such relationship to its purchase price and is therefore based on railroad and contractor experience with ballast undercutting/cleaning. The excessive wear rate of several maintenance points, particularly the

TABLE 19

ANNUAL LABOR COSTS: TIE GANG

Labor Classification		Number per Gang	Daily Labor Rate ($)	Daily Labor Cost ($)	Days Worked per Gang per Year	Annual Labor Cost Charged per Gang ($)
General Foreman	S	1	189.09	189.09	200	37,818.00
Operator - Grade 1	S	12	104.61	1,255.32	200	251,064.00
Operator - Grade 2	S	2	113.52	227.04	200	45,408.00
Laborer	S	7	100.60	704.20	200	140,840.00
Tie Inspector	S	1	159.34	159.34	34	5,417.56
Tie Cleanup:						
Track Foreman	S	1	115.78	115.78	200	23,156.00
Operator - Grade 3	S	1	116.00	116.00	200	23,200.00
Laborer	S	6	100.60	603.60	200	120,720.00
Tie Train:						
Track Foreman	D	1	103.78	103.78	43	4,462.54
Operator - Grade 3	D	1	104.00	104.00	43	4,472.00
Trainman	D	4	125.00	500.00	43	21,500.00
Supplementary:						
Driver	D	1	92.61	92.61	200	18,522.00
Flagman	D	2	88.60	177.20	200	35,440.00
Planning:						
Engineer	S	1		31,200 per year	1/2 man-year	15,600.00
Total						$747,620.10

S - System personnel, includes per diem.
D - Division personnel, no per diem cost.

TABLE 20

ANNUAL LABOR COSTS: BALLAST CLEANING

Labor Classification		Number per Gang	Daily Labor Rate ($)	Daily Labor Cost ($)	Days Worked per Gang per Year	Annual Labor Cost Charged per Gang ($)
General Foreman	S	1	189.09	189.09	200	37,818.00
Track Foreman	S	1	115.78	115.78	200	23,156.00
Assistant Track Foreman	S	1	110.02	110.02	200	22,004.00
Operator - Grade 4	S	2	167.80	335.60	200	67,120.00
Operator - Grade 2	S	5	113.52	567.60	200	113,520.00
Operator - Grade 1	S	1	104.61	104.61	200	20,922.00
Laborer	S	13	100.60	1,307.80	200	261,560.00
Supplementary:						
Driver	D	1	92.61	92.61	200	18,522.00
Flagman	D	2	88.60	177.20	200	35,440.00
Planning:						
Engineer	S	1		31,200 per year	1/2 man-year	15,600.00
Total						$615,662.00

S - System personnel, includes per diem.
D. - Division personnel, no per diem cost.

TABLE 21

ANNUAL LABOR COSTS: RAIL GANG

Labor Classification		Number per Gang	Daily Labor Rate ($)	Daily Labor Cost ($)	Days Worked per Gang per Year	Annual Labor Cost Charged per Gang ($)
General Foreman	S	1	189.09	189.09	200	37,818.00
Track Foreman	S	1	115.78	115.78	200	23,156.00
Assistant Track Foreman	S	2	110.02	220.04	200	44,008.00
Operator - Grade 3	S	2	116.00	232.00	200	46,400.00
Operator - Grade 2	S	1	113.52	113.52	200	22,704.00
Operator - Grade 1	S	19	104.61	1,987.59	200	397,518.00
Laborer	S	28	100.60	2,816.80	200	563,360.00
Material Distribution:						
Track Foreman	D	1	103.78	103.78	200	20,756.00
Operator - Grade 3	D	1	104.00	104.00	200	20,800.00
Laborer	D	10	88.60	886.00	200	177,200.00
Steel Cleanup:						
Track Foreman	D	1	103.78	103.78	43	4,462.54
Operator - Grade 3	D	1	104.00	104.00	43	4,472.00
Laborer	D	2	88.60	177.20	43	7,619.60
Supplementary:						
Driver	D	1	92.61	92.61	200	18,522.00
Flagman	D	2	88.60	177.20	200	35,440.00
Planning:						
Engineer	S	1		31,200 per year	1/2 man-year	15,600.00
Total						$1,439,836.14

S - System personnel, includes per diem.
D - Division personnel, no per diem cost.

TABLE 22

ANNUAL LABOR COSTS: SURFACE AND LINE

Labor Classification		Number per Gang	Daily Labor Rate ($)	Daily Labor Cost (R)	Days Worked per Gang per Year	Annual Labor Cost Charged per Gang ($)
General Foreman	S	1	189.09	189.09	200	37,818.00
Operator - Grade 2	S	4	113.52	454.08	200	90,816.00
Laborer	S	2	100.60	201.20	200	40,240.00
Driver	D	1	104.61	104.61	200	20,922.00
Flagman	D	2	100.60	201.20	200	40,240.00
Planning:						
Engineer	S	1		31,200 per year	1/2 man-year	15,600.00
Total						$245,636.00

S - System personnel, includes per diem.
D - Division personnel, no per diem cost.

TABLE 23

ANNUAL LABOR COST: TRM GROUP - INSTALLING WOOD TIES

Labor Classification		Number per Gang	Daily Labor Rate ($)	Daily Labor Cost ($)	Days Worked per Gang per Year	Annual Labor Cost Charged per Gang ($)
General Foreman	S	1	189.09	189.09	200	37,818.00
Project Engineer	S	1	208.55	208.55	200	41,710.00
Track Foreman	S	1	115.78	115.78	200	23,156.00
Assistant Track Foreman	S	1	110.02	110.02	200	22,004.00
Operator - Grade 4	S	4	167.80	671.20	200	134,240.00
Operator - Grade 3	S	2	116.00	232.00	200	46,400.00
Operator - Grade 2	S	1	113.52	113.52	200	22,704.00
Operator - Grade 1	S	10	104.61	1,046.10	200	209,220.00
Laborer	S	24	100.60	2,414.40	200	482,880.00
Material Distribution:						
Track Foreman	D	1	103.78	103.78	30	3,113.40
Operator - Grade 3	D	1	104.00	104.00	30	3,120.00
Laborer	D	2	88.60	177.20	30	5,316.00
Steel Cleanup:						
Track Foreman	D	1	103.78	103.78	118	12,246.04
Operator - Grade 3	D	1	104.00	104.00	118	12,272.00
Laborer	D	2	88.60	177.20	118	20,909.60
Supplementary:						
Driver	D	2	92.61	185.22	200	37,044.00
Flagman	D	2	88.60	177.20	200	35,440.00
Planning:						
Engineer	S	1		31,200 per year	4 man-years	124,800.00
Preplate Ties:						
Laborer	D	8	64.00	512.00	240	122,880.00
Tie Car Switching:						
Trainman	D	4	125.00	500.00	200	100,000.00
Total						$1,497,273.04

S - System personnel, includes per diem.
D - Division personnel, no per diem cost.

TABLE 24

ANNUAL LABOR COST: BALLAST UNDERCUTTING, SURFACE AND LINE IN TRS

Labor Classification		Number per Gang	Daily Labor Rate ($)	Daily Labor Cost ($)	Days Worked per Gang per Year	Annual Labor Cost Charged per Gang ($)
General Foreman	S	1	189.09	189.09	200	37,818.00
Track Foreman	S	1	115.78	115.78	200	23,156.00
Assistant Track Foreman	S	1	110.02	110.02	200	22,004.00
Operator - Grade 4	S	2	167.80	335.60	200	67,120.00
Operator - Grade 2	S	7	113.52	794.64	200	158,928.00
Laborer	S	1	100.60	100.60	200	20,120.00
Total						$329,146.00

S - System personnel, includes per diem.
D - Division personnel, no per diem cost.

TABLE 25

ANNUAL LABOR COST: TRM GROUP INSTALLING CONCRETE TIES

Labor Classification		Number per Gang	Daily Labor Rate ($)	Daily Labor Cost ($)	Days Worked per Gang per Year	Annual Labor Cost Charged per Gang ($)
General Foreman	S	1	189.09	189.09	200	37,818.00
Project Engineer	S	1	208.55	208.55	200	41,710.00
Track Foreman	S	1	115.78	115.78	200	23,156.00
Assistant Track Foreman	S	1	110.02	110.02	200	22,004.00
Operator - Grade 4	S	4	167.80	671.20	200	134,240.00
Operator - Grade 3	S	3	116.00	348.00	200	69,600.00
Operator - Grade 2	S	1	113.52	113.52	200	22,704.00
Operator - Grade 1	S	9	104.61	941.49	200	188,298.00
Laborer	S	31	100.60	3,118.60	200	623,720.00
Steel Cleanup:						
Track Foreman	D	1	103.78	103.78	147	15,255.66
Operator - Grade 3	D	1	104.00	104.00	147	15,288.00
Laborer	D	2	88.60	177.20	147	26,048.40
Tie Car Switching:						
Trainman	D	4	125.00	500.00	200	100,000.00
Supplementary:						
Driver	D	2	92.61	185.22	200	37,044.00
Flagman	D	2	88.60	177.20	200	35,440.00
Planning:						
Project Engineer	S	1		31,200 per year	4 man-years	124,800.00
Total						1,517,126.16

S - System personnel, includes per diem.
D - Division personnel, no per diem cost.

TABLE 26

LABOR COST PER MILE PER OPERATION

Gang	Annual Labor Cost Charged per Gang ($/year)	Annual Production (miles/year)	Cost per Mile ($/mile)
Tie Gang	747,620.10	200	3,738.10
Conventional Ballast Cleaning	615,662.00	122	5,046.41
Conventional Rail Gang	1,439,836.14	108	13,331.16
Track Surfacing and Alignment	245,636.00	246	998.52
Track Renewal System (wood)	1,497,273.04	177	8,459.17
Ballast Cleaning and Surfacing with TRS	329,146.00	122	2,697.92
Track Renewal Machine (concrete)	1,517,126.16	222	6,833.90

TABLE 27

EQUIPMENT MAINTENANCE AND FUEL COST

Machine	Purchase Cost ($)	Maintenance Ratio	Use/Year		Maintenance Cost/Shift or Mile ($)	Engine Horsepower	Engine Utilization Ratio	Fuel Cost/ Shift ($)	Total Cost ($)	
			Shifts	Miles					Per Shift	Per Mile
Air Compressor	15,000	0.2	200		15	60	0.75	17	32	
Back Hoe	35,000	0.2	200		35	120	0.50	22	57	
Ballast Compactor	77,000	0.3		104	116	92	0.75	25		141
Ballast Regulator	72,000	0.2	200		72	175	0.5	33	105	
Ballast Sled	330,000	0.2	200		325	200	0.75	56	381	
Ballast Undercutter/Cleaner	850,000	——		104	3,025	352	0.80	104		3,129
Crane, Burro	190,000	0.05*	200		48	150	0.5	28	76	
Gaging Machine	32,800	0.2	200		33	15	0.5	3	36	
Motor Car	5,800	0.1	200		3	10	0.5	2	5	
Motor Grader	67,000	0.2	200		67	120	0.5	22	89	
Push Cart	800	0.1	200		1				1	
Rail Anchor Applicator	42,000	0.2	200		42	45	0.5	8	50	
Rail Lifter	5,200	0.1	200		3	10	0.5	2	5	
Rail Puller	500	0.1	200		1				1	
Speed Swing	90,000	0.1	200		45	122	0.5	23	68	
Spike Driver – Tie Gang	58,700	0.3	200		88	60	0.75	17	105	
Spike Driver – Pneumatic	1,000	0.3	200		2				2	
Spike Driver – Rail Gang	62,700	0.3	200		94	60	0.75	17	111	
Tamper	63,000	0.3		227	83	90	0.70	23		106
Tamper with Jacks	72,000	0.3		227	95	90	0.70	23		118
Tamper – Production	140,000	0.3		227	185	150	0.75	37		222
Tamper – Switch	152,000	0.3		227	201	150	0.75	37		238
Tie Adzer	4,400	0.2	200		4	12	0.5	2	6	
Tie Borer	2,600	0.2	200		3	3	0.5	1	4	
Tie Cribber	15,700	0.2	200		16	15	0.5	3	19	
Tie Crane	27,300	0.2	200		27	75	0.85	24	51	
Tie Inserter	62,000	0.3	200		93	75	0.85	24	117	
Tie Plug Driver	10,200	0.2	200		10	15	0.5	3	13	
Track Renewal Machine (P-811)	1,950,000			180	790**	640***	0.5	119		832****
Tie Shear/Saw	62,800	0.3	200		94	120	0.75	33	127	
Tie Spacer	35,000	0.1	200		18	60	0.5	11	29	
Tie Sprayer	4,800	0.1	200		2	12	0.5	2	4	
Tie Bed Scarifier	40,400	0.3	200		61	75	0.85	24	85	
Tie Unloader	89,000	0.2	200		89	60	0.75	17	106	
Spike Puller – Tie Gang	5,300	0.3	200		8	10	0.5	2	10	
Spike Puller – Rail Gang	14,200	0.3	200		21	15	0.5	3	24	

*The burro cranes used in the track maintenance gangs described in this study are loaded well below their capacity and last longer than most other track maintenance machines.

**Based on more than 3 years of experience in Italy by Valditerra Construction Company. ($775 for a P-811 TRM installing concrete ties.)

***This total horsepower includes the main engine, plus self-propelled gantry cranes.

****$907 for a P-811 TRM installing concrete ties.

undercutter chain, on an undercutter operating in U.S. track conditions with relatively cemented ballast results in a maintenance cost that is proportionately higher (as a function of its new cost) than for other pieces of track maintenance machinery. A midwestern railroad has found that an undercutter chain, for example, lasts about 20 miles and can be rebuilt only once. Each new chain costs about $14,000, according to several manufacturers.

Similarly, the cost estimate to maintain a P-811 track renewal machine (TRM) is based on railroad or contractor operations with a P-811 TRM (in Europe), and is not derived as a function of its new cost. Much of its new cost is invested in its large frame and support structure, as well as in its moving parts. The TRM is also relatively simple with no highly stressed parts as with an undercutter. The large capital cost, therefore, does not warrant a proportionately high maintenance cost in this case. Amtrak and Canadian National Railways did not have sufficient experience with their P-811 TRM's to provide any estimates of maintenance costs.

Fuel cost is calculated as a separate item. For all the pieces of maintenance equipment, including the undercutter and TRM, the fuel consumption for a machine is based on its engine horsepower (HP) and the engine utilization during a shift. The technique used to calculate fuel consumption for each machine is 0.4 pound of fuel consumed for each rated horsepower for each fully utilized hour of operation, where each gallon of fuel weighs approximately 7.2 pounds. Fuel cost for each machine is derived by applying a $1 per gallon rate to the calculated fuel consumption per machine.

Table 27 lists all the machines involved in the selective maintenance and track renewal methods of track maintenance, as described in section 1. For each machine, the maintenance and fuel cost is calculated and summed, giving the total cost per shift or per mile. A number of machines have a wear rate or service life that is more appropriately related to mileage rather than shift, i.e., miles per year rather than shifts per year. For these machines, the maintenance cost per mile is calculated directly. The cost per shift is converted to a per-mile cost via the annual production rate of the maintenance gang with which the machine is working. This is shown in tables 28 to 34, on pages 36 to 39.

For example, a tie crane's new cost is shown in table 27 to be $27,300, and it has a designated maintenance ratio of 0.2 (average-use machine). Its annual maintenance cost is calculated to be $5,460, and its maintenance cost per shift comes to approximately $27. It has an engine horsepower of 75 and an 85-percent engine utilization during a standard shift. The fuel consumption is calculated by:

$$\frac{0.4 \text{ pound} \times 75 \text{ HP} \times 6.7 \text{ hours} \times 0.85}{7.2 \text{ pounds per gallon}} \quad \text{(utilization factor)}$$

$$= 24 \text{ gallons (rounded).}$$

The fuel cost per shift for a tie crane is $24 at $1.00 per gallon. The total maintenance cost per shift is $27 + $24 = $51.

(5) Tie Transportation Costs. The track renewal method for installing wood or concrete ties and the selective maintenance gang have different costs associated with transporting new ties to the work site and used ties from the work site to either disposal or sorting for reuse or sale. Transportation of other materials is assumed to be identical for selective maintenance and track renewal and is not considered in this framework.

The tie transportation cost determination procedures for each alternative are presented in the following paragraphs. For each alternative, the assumptions made are presented. Then the annual tie transportation costs are calculated. Finally, the costs are converted to costs per mile of track renewed.

Tie Transportation Cost: TRS Wood to Wood

The assumptions made for this analysis are the following:

a. Tie cars are 70-ton capacity, 60-foot flat cars with a capacity of 480 wood ties per car.

b. Number of tie cars per daily use = 6.

c. Daily TRS production = 2,880 ties [480 x 6].

d. Average distance TRS site to tie plant = 300 miles, which requires 4 days of transit time each way.

e. Average 12-day turnaround required:

4 x 2 days	plant-to-site-to-plant
2 days	at site (1 in use, 1 ready)
2 days	at plant (loading, offloading)
12 days	- total

Number of consists required to support 5 days per week production = 10, or 60 cars, plus one extra car for tie handling or 61 total cars.

f. There is one interim switching per 300 miles.

g. Number of working days for transportation = 280 per season. With a 12-day turnaround, each car averages 23.33 round trips per year.

h. Modifications to flat cars include removable gantry crane rails and tiedown equipment. Materials and labor cost for conversion is $2,000 per car. No salvage value for this modification. This is a capital cost.

i. Lading cost = $0.00034 x loaded miles x net loaded weight in hundreds of pounds per car per loaded miles.

j. Tare cost = $0.17213 x round trip mileage per car.

k. Yard terminal cost (cost to make up trains) = $89.47 per car per round trip.

l. Intertrain cost (interim terminal cost) = $10.21 per car per round trip.

m. Car leasing cost = $2.50 per car per day. This is the per diem cost on an approximately 10-year-old car.

TABLE 28

ANNUAL EQUIPMENT MAINTENANCE COST PER MILE: TIE GANG

Machine	Number	Cost of Maintenance per Machine per Shift	Total Maintenance Cost per Machine Type per Shift	Number Days per Year	Annual Cost per Machine Type	Annual Track Gang Production	Cost per Mile per Machine Type*
Spike Puller	2	10.00	20.00	200	4,000	200	20.00
Tie Shear	1	127.00	127.00	200	25,400	200	127.00
Tie Bed Scarifier	1	85.00	85.00	200	17,000	200	85.00
Tie Crane	2	51.00	102.00	200	20,400	200	102.00
Tie Inserter	1	117.00	117.00	200	23,400	200	117.00
Tamper	1	—	—	200	—	200	106.00
Rail Lifter	1	5.00	5.00	200	1,000	200	5.00
Tie Drill	2	4.00	8.00	200	1,600	200	8.00
Spike Setter/Driver	1	105.00	105.00	200	21,000	200	105.00
Ballast Regulator	1	105.00	105.00	200	21,000	200	105.00
Automobile	1	5.00	5.00	34	170	200	0.85
Locomotive	1	Leased	—	—	—	—	—
Tie Unloader	1	106.00	106.00	43	4,558	200	22.79
Burro Crane	1	76.00	76.00	200	15,200	200	76.00
Total							$879.64

*Some machine maintenance costs are given as cost per mile in table 27.

TABLE 29

ANNUAL EQUIPMENT MAINTENANCE COST PER MILE: BALLAST CLEANING

Machine	Number	Cost of Maintenance per Machine per Shift	Total Maintenance Cost per Machine Type per Shift	Number Days per Year	Annual Cost per Machine Type	Annual Track Gang Production	Cost per Mile per Machine Type*
Pneumatic Spike Driver	1	2.00	2.00	200	400	122	3.28
Air Compressor	1	32.00	32.00	200	6,400	122	52.46
Tamper with Jacks	1	—	—	200	—	122	118.00
Ballast Undercutter	1	—	—	200	—	122	3,129.00
Ballast Regulator	1	105.00	105.00	200	21,000	122	172.13
Production Tamper	1	—	—	200	—	122	222.00
Push Cart	1	1.00	1.00	200	200	122	1.64
Switch Tamper	1	—	—	200	—	122	238.00
Ballast Compactor	1	—	—	200	—	122	141.00
Total							$4,077.51

*Some machine maintenance costs are given as cost per mile in table 27.

TABLE 30

ANNUAL EQUIPMENT MAINTENANCE COST PER MILE: RAIL GANG

Machine	Number	Cost of Maintenance per Machine per Shift	Total Maintenance Cost per Machine Type per Shift	Number Days per Year	Annual Cost per Machine Type	Annual Track Gang Production	Cost per Mile per Machine Type *
Burro Crane	1	76.00	76.00	200	15,200	108	140.74
Spike Puller	2	24.00	48.00	200	9,600	108	88.89
Bolt Machine	2	2.00	4.00	200	800	108	7.41
Speed Swing	1	68.00	68.00	200	13,600	108	125.93
Push Cart	2	1.00	2.00	200	400	108	3.70
Ballast Cribber	1	19.00	19.00	200	3,800	108	35.19
Tie Plug Driver	2	13.00	26.00	200	5,200	108	48.15
Tie Adzer	2	6.00	12.00	200	2,400	108	22.22
Tie Sprayer	1	4.00	4.00	200	800	108	7.41
Gager	1	36.00	36.00	200	7,200	108	66.67
Tamper	1	---	---	200	---	108	106.00
Tie Drill	2	4.00	8.00	200	1,600	108	14.81
Spike Setter/Driver	1	111.00	111.00	200	22,200	108	205.56
Anchor Applicator	2	50.00	100.00	200	20,000	108	185.19
Burro Crane (OTM Distrib.)	1	76.00	76.00	200	15,200	108	140.74
Gondola (OTM Distribution)	2	Leased	---	200	---	108	0.00
Burro Crane (OTM Cleanup)	1	76.00	76.00	43	3,268	108	30.26
Gondola (OTM Cleanup)	2	Leased	---	43	---	108	0.00
Total							$1,228.87

*Some machine maintenance costs are given as cost per mile in table 27.

TABLE 31

ANNUAL EQUIPMENT MAINTENANCE COST PER MILE: SURFACE AND LINE

Machine	Number	Cost of Maintenance per Machine per Shift	Total Maintenance Cost per Machine Type per Shift	Number Days per Year	Annual Cost per Machine Type	Annual Track Gang Production	Cost per Mile per Machine Type*
Ballast Regulator	1	105.00	105.00	200	21,000	246	85.37
Production Tamper	1	---	---	200	---	246	222.00
Switch Tamper	1	---	---	200	---	246	238.00
Total							$545.37

*Some machine maintenance costs are given as cost per mile in table 27.

TABLE 32

ANNUAL EQUIPMENT MAINTENANCE COST PER MILE: TRM GROUP INSTALLING WOOD TIES

Machine	Number	Cost of Maintenance per Machine per Shift	Total Maintenance Cost per Machine Type per Shift	Number Days per Year	Annual Cost per Machine Type	Annual Track Gang Production	Cost per Mile per Machine Type *
Push Cart	4	1.00	4.00	200	800	177	4.52
Rail Puller	1	1.00	1.00	200	200	177	1.13
Spike Puller	2	24.00	48.00	200	9,600	177	54.24
Backhoe	1	57.00	57.00	200	11,400	177	64.41
P-811 Track Renewal Machine	1	——	——	200	——	177	832.00
Mechanics Flat Car	1	Leased	——	200	——	177	0.00
Spike Setter/Driver	2	111.00	222.00	200	44,400	177	250.85
Anchor Applicator	2	50.00	100.00	200	20,000	177	112.99
Bolt Machine	2	2.00	4.00	200	800	177	4.52
Burro Crane (OTM Distrib.)	1	76.00	76.00	30	2,280	177	12.88
Gondola (OTM Distribution)	2	Leased	——	30	——	177	0.00
Burro Crane (OTM Cleanup)	1	76.00	76.00	118	8,968	177	50.67
Gondola (OTM Cleanup)	2	Leased	——	118	——	177	0.00
Locomotive	1	Leased	——	200	——	177	0.00
Tie Milling Machine	1	——	——	200	5,000**	177	28.25
Tie Preplating Equipment	1	——	——	200	4,800**	177	27.12
Magnetic Hoist	1	——	——	200	3,500**	177	19.77
Total							$1,463.35

*Some machine maintenance costs are given as cost per mile in table 27.
**10 percent of purchase price.

TABLE 33

ANNUAL EQUIPMENT MAINTENANCE COST PER MILE: BALLAST CLEANING, SURFACE AND LINE

Machine	Number	Cost of Maintenance per Machine per Shift	Total Maintenance Cost per Machine Type per Shift	Number Days per Year	Annual Cost per Machine Type	Annual Track Gang Production	Cost per Mile per Machine Type *
Tamper with Jacks	1	—	—	200	—	122	118.00
Ballast Undercutter	1	—	—	200	—	122	3,129.00
Ballast Regulator	2	105.00	210.00	200	42,000	122	344.26
Production Tamper	2	—	—	200	—	122	444.00
Switch Tamper	1	—	—	200	—	122	238.00
Ballast Compactor	1	—	—	200	—	122	141.00
Total							$4,414.26

*Some machine maintenance costs are given as cost per mile in table 27.

TABLE 34

ANNUAL EQUIPMENT MAINTENANCE COST PER MILE: TRM GROUP INSTALLING CONCRETE TIES

Machine	Number	Cost of Maintenance per Machine per Shift	Total Maintenance Cost per Machine Type per Shift	Number Days per Year	Annual Cost per Machine Type	Annual Track Gang Production	Cost per Mile per Machine Type *
Push Cart	4	1.00	4.00	200	800	222	3.60
Rail Puller	1	1.00	1.00	200	200	222	0.90
Spike Puller	2	24.00	48.00	200	9,600	222	43.24
Backhoe	1	57.00	57.00	200	11,400	222	51.35
P-811 Track Renewal Machine	1	—	—	200	—	222	907.00
Mechanics Flat Car	1	Leased	—	200	—	222	0.00
Materials Car (Gondola)	1	Leased	—	200	—	222	0.00
Rail Clip Applicators	3	25.00	75.00	200	15,000	222	65.57
Bolt Machine	2	2.00	4.00	200	800	222	3.60
Locomotive	1	Leased	—	200	—	222	0.00
Burro Crane	1	76.00	76.00	147	11,172	222	50.32
Gondola	2	Leased	—	147	—	222	0.00
Total							$1,127.58

*Some machine maintenance costs are given as cost per mile in table 27.

Note: The transportation costs in assumptions a through m, inclusive, were obtained from a midwestern railroad with more than 8,000 miles of track.

Annual tie transportation costs are calculated as follows:

a. Lading cost:

$0.00034 x 600 miles x 1,320* (hundreds of pounds) = $269.28 per car per round trip

*Note: 480 ties per car at 275 pounds per tie = 132,000 pounds
Net weight in hundreds of pounds = 1,320.00

$269.28 x 23.33 round trips x 60 cars = $376,938.14

b. Tare cost:

$0.17213 x 600 miles = $103.28 per car per round trip

$103.28 x 23.33 round trips x 60 cars = $144,571.34

c. Yard terminal cost:

$89.47 per car per round trip

$89.47 x 23.33 round trips x 60 cars = $125,240.11

d. Intertrain costs:

$10.21 per car per round trip

$10.21 x 23.33 round trips x 60 cars = $ 14,291.96

e. Leasing cost:

Total number of cars = 6 (number per consist) x 10 (number of consists) + 1 (extra empty car) = 61

Total lease cost = (61 cars x $2.50 per day per car) x 280 days per season = $ 42,700.00

f. Capitalization cost:

61 cars x $2,000 per car = $122,000.00

Capital recovery cost per year = capital cost x capital recovery factor at 12 percent over 10 years = $122,000 x 0.17698 = $ 21,591.56

Total annual tie transportation cost = $725,333.16

Total tie transportation cost per mile =

$$\frac{\$725{,}333.16 \text{ per year}}{177 \text{ miles per year}} = \$4{,}097.93$$

Tie Transportation Cost: TRS Wood to Concrete

The assumptions made for this analysis are as follows:

a. Tie cars are 70-ton capacity, 60-foot flat cars with a capacity of 210 concrete ties per car. (Concrete ties assumed to weigh 625 pounds each).

b. Number of cars per daily consist = 14.

c. Daily TRS production = 2,940 ties (210 x 14).

d. Average distance TRS site to plant = 300 miles, which requires 4 days of transit time each way.

e. Average 12-day turnaround required:

4 x 2 days plant-to-site-to-plant
2 days at site (1 in use, 1 ready)
2 days at plant (loading, offloading)

12 days - total

Number of consists required to support production = 10, or 140 cars, plus one extra car for tie handling, or 141 total cars.

f. There is one interim terminal per 300 miles.

g. Number of working days for transportation = 280 per season. With a 12-day turnaround, each car averages 23.33 round trips per year.

h. Modifications to flat cars include removable gantry cranes, rails, and tiedown equipment. Materials and labor costs for conversion is $2,000 per car. No salvage value for this modification. This is a capital cost.

i. Lading cost = $0.00034 x loaded miles x net loaded weight in hundreds of pounds per car per loaded miles.

j. Tare cost = $0.17213 x round trip mileage per car.

k. Yard terminal cost (cost to make up trains) = $89.47 per car per round trip.

l. Intertrain cost (interim terminal cost) = $10.21 per car per round trip.

m. Car leasing cost = $2.50 per car per day. This is the per diem cost on an approximately 10-year-old car.

Annual tie transportation costs are calculated as follows:

a. Lading cost:

$0.00034 x 600 miles x 1,320 (hundreds of pounds) = $269.28 per car per round trip

$269.28 x 23.33 round trips x 140 cars = $ 879,522.34

b. Tare cost:

$0.17213 x 600 miles = $103.28 per car per round trip = $ 337,333.14

c. Yard terminal cost:

$89.47 per car per round trip x 23.33 round trips x 140 cars = $ 292,226.91

d. Intertrain cost:

$10.21 per car per round trip x 23.33 round trips x 140 cars = $ 33,347.90

e. Leasing cost:

Total number of cars = 14 (number per consist) x 10 (number of consists) + 1 (extra empty car) = 141

Total lease cost = (141 cars x $2.50 per day per car) x 280 days per season = $ 98,700.00

f. Capitalization cost:

Number of cars = 141

Total capitalization = 141 x $2,000 per car = $282,000.00

Capital recovery cost per year = $282,000 x 0.17698 (at 12 percent and depreciated over 10 years)	=	$ 49,908.36
Total annual tie transportation cost	=	$1,691,038.65

Tie transportation cost per mile =

$$\frac{\$1,691,038.65}{222 \text{ miles per year}} = \$7,617.29$$

Tie Transportation Cost: Selective Tie Gang

The assumptions made for this analysis are the following:

New Tie Delivery

a. 375 tie capacity per tie car (gondola).

b. Consist of 10 cars used to distribute 3,750 ties (4.7 track miles) per day.

c. Average distance from plant to work site = 300 miles.

d. 12-day turnaround time (600 miles).

e. Tie gang production rate = one mile (800 ties) per day; two sets or consists of tie cars required, or 20 cars.

f. Tie cars return empty from work site to tie plant.

g. One interim terminal per 300 miles.

h. Number of working days for transportation = 280 per season. With a 12-day turnaround, each car averages 23.33 round trips per year.

i. Lading cost = $0.00034 x loaded miles x net loaded weight in hundreds of pounds per car per loaded mile.

j. Tare cost = $0.2182 (gondola) x round trip mileage per car.

k. Yard terminal cost = $89.47 per car per round trip.

l. Intertrain cost = $10.21 per car per round trip.

m. Car leasing cost = $2.50 per car per day.

Scrap Tie Disposal

a. Air dump cars used to haul away scrap tie butts. Capacity per air dump car = 280 ties (of tie butts).

b. Tie cleanup production rate = 800 ties per day, using 2 cars, for a total of 12 cars full time.

c. Average distance from work site to disposal site = 100 miles.

d. 4-day round trip (200 miles).

e. Air dump cars return empty to site.

f. No interim terminal.

g. Lading cost = $0.00034 x loaded miles x net loaded weight in hundreds of pounds per car per loaded mile.

h. Tare cost = $0.2182 (gondola) x round trip mileage per car.

i. Yard terminal cost = not applicable.

j. Intertrain cost = not applicable.

k. Car leasing cost = $6.50 per air dump car per day.

Annual tie transportation costs are calculated as follows:

New Ties	Scrap Ties
a. Lading cost $0.00034 x 300 m. x 1,031.25 (hundreds of pounds) = $105.19 per car per round trip $105.19 x 23.33 x 20 cars = $49,081.65	a. Lading cost $0.00034 x 100 m. x 825 (hundreds of pounds) = $28.05 per car per round trip $28.05 x 70 trips x 12 cars = $23,562.00
b. Tare cost $0.2182 x 600 m. = $130.92 per car per round trip $130.92 x 23.33 x 20 cars = $61,087.27	b. Tare cost $0.218 x 200 m. = $43.64 per car per round trip $43.64 x 70 trips x 12 cars = $36,657.60
c. Yard terminal cost $89.47 per car per round trip $89.47 x 23.33 x 20 cars = $41,746.70	Not applicable
d. Intertrain cost $10.21 per car per round trip $10.21 x 23.33 x 20 cars = $ 4,763.99	Not applicable
e. Car leasing cost Total lease cost = (20 cars x $2.50 per day per car) x 280 days per season = $14,000.00	e. Car leasing cost Total lease cost = (12 cars x $6.50 per day per car) x 280 days per season = $21,840.00
Total cost per year $170,679.61	Total cost per year $82,059.60
Total miles per year - 200	Total miles per year - 200
Total cost per mile - $853.40	Total cost per mile - $410.30

(6) Manual Tie Change Cost. One item of basic maintenance is charged to the track renewal system but not to selective maintenance. This is the assumed requirement to manually replace some ties during the renewal cycle to keep the track up to a given classification. Federal Railroad Administration (FRA) track safety standards do not allow for two adjacent ties to be failed in Class 5 track, the class used in the chapter III analysis.

The cost to change a tie by a basic maintenance gang is assumed to be the material cost of a tie plus one man-hour of a local laborer. While not exact, it is sometimes quoted as a reasonable rule of thumb in the industry. Using the costs assumed in the material and labor sections:

Tie cost	$13.50
One man-hour ($100.60 per day/8 hours per day)	$12.58
Total	$26.08

A methodology for predicting the incidence of tie replacements during the renewal cycle is developed in chapter III.

(7) Summary Cost per Mile per Operation. The cost elements for each operation or gang developed in the preceding subsections are combined to give total costs to perform each operation in table 35 below.

The operational type costs of labor, equipment maintenance, new materials, and transportation are combined in subtotals. The primary differences between track renewal and selective maintenance are in labor costs and material costs. A conventional rail gang costs more in labor by itself than the entire track renewal system. Obviously, track renewal offers significant labor savings, even in the first year.

The track renewal method has much higher new material costs than the selective tie and rail gangs combined -- assuming that the tie gang replaces 25 percent of the ties in the track. This materials cost differential more than offsets the labor savings from track renewal in the first year as evidenced by the total costs per mile. Track renewal installing wood ties, with ballast cleaning and rail change, costs $211,904.87 per mile (TRM group cost of $202,467.45 plus ballast cleaning and surfacing cost of $9,437.42), while selective maintenance, replacing 25 percent of the ties and both rails and ballast cleaning, costs $189,343.65 (the combined cost for tie gang,

TABLE 35

SUMMARY OF PER-MILE COST TOTALS FOR EACH TRACK MAINTENANCE OPERATION
(All Costs in 1980 Dollars)

Gang	Operational Costs				Total Operational	Capital Recovery	Total Cost per Mile
	Labor Cost	Equipment Maintenance	New Materials	Transportation			
Tie Gang	3,738.10	879.64	11,736.55	1,263.70	17,617.99	697.02	18,315.01
Conventional Ballast Cleaning	5,046.41	4,077.51	N/A	N/A	9,123.92	2,047.15	11,171.07
Rail Gang	13,331.16	1,228.87	142,148.40*	N/A	156,708.43	1,300.07	158,008.50
Track Surface	998.52	545.37	N/A	N/A	1,543.89	305.18	1,849.07
Track Renewal Machine (wood ties)	8,459.17	1,463.35	185,535.90*	4,097.93	199,556.35	2,911.10	202,467.45
Ballast Cleaning and Surface with TRS	2,697.92	4,414.26	N/A	N/A	7,112.18	2,325.24	9,437.42
Track Renewal Machine (concrete ties)	6,833.90	1,127.58	208,975.90	7,617.29	224,554.67	2,129.37	226,684.04

*Assumes that new rail is installed to replace lighter existing rail, thus requiring all new tie plates and spikes.

ballast cleaning, rail gang, and track surfacing), a difference of $22,561.22. Most of this difference can be eliminated by reusing and selling the ties removed by the track renewal system as shown in the next subsection.

B. Development of Material Credit for Used Track Components

Material credit is the net value of used track components (rails, ties, spikes, etc.) removed from track by maintenance operations, after they have been transported to a sorting, reclamation, and salvage facility and either made ready for reuse or sold.

While each track component merits attention in its own right in this area, this report will deal with material credit for wood ties only. There are two reasons for ignoring rail and other track materials:

- Most railroads cascade rail and OTM into lesser trackage until they are no longer useful, then sell them for scrap. This is not a new area for the railroad industry.

- It has been assumed in the framework development that there is no difference between selective maintenance and track renewal in the replacement and reuse of rail and OTM.

The remainder of this section on material credit will develop material credit for used ties only. If the reader develops a scenario in which reuse of other track components is affected by conversion to track renewal, he can use the methodology presented here to develop the material credit or material cost of these components.

The procedures described in this section are shown in figure 11, which breaks step 2B in figure 1 down into detailed elements.

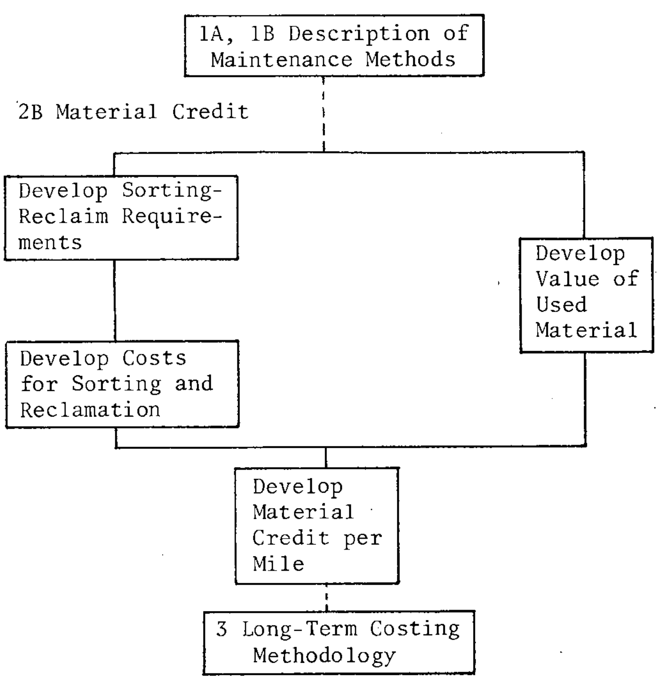


FIGURE 11. MATERIAL CREDIT DETERMINATION FLOW CHART

The value of a reusable tie is a function of its remaining service life and is calculated as a value proportionate to that of a new tie's estimated service life and new cost. The net value or material credit of a used tie is therefore its relative value, i.e., its value compared with that of a new tie minus the cost of transporting the tie to a tie reuse facility, sorting, and reclaiming the tie.

Tie transportation costs were calculated separately in part A, providing for both the costs of transporting new ties from a new tie plant to the TRS worksite, and for transporting removed used ties from the same site to a tie reuse facility. These costs were included in the track renewal machine gang's total cost (table 35). Since the cost of transporting the used ties has in effect been charged to or paid for by the track renewal system, the transportation cost becomes a sunk cost and is not counted again with the development of material credit for the used ties. Thus, the process of reclaiming the used ties generated by a TRS starts at the tie reuse facility and the relevant costs are those associated with sorting and reclaiming the used ties.

The costs of sorting and reclaiming ties include all labor, materials, and equipment (capital and maintenance) costs. Sorting costs principally involve the cost of an experienced tie inspector classifying the used ties into reuse categories. Since the reusable ties have in fact been replaced prematurely in changing over from selective maintenance to track renewal, these ties require only routine plugging and adzing (customarily done anyway under selective maintenance), in addition to retreatment with wood preservative. In this study, reclamation costs do not entail the cost of repairing failed ties. While some failed ties should be reparable, this study assumed that failed ties would be sold for nonrailroad track uses.

Tie sorting and reclamation costs were developed around two plant models which are based on North American experience with large-scale wood tie reuse associated with track renewal operations.

The following subsections discuss large-scale wood tie reuse experience in North America; develop two model plants for sorting and reclaiming wood ties with unit costs calculated; calculate the value of a used tie; and calculate the net material credit for a used tie.

(1) Large-Scale Wood Tie Reuse in North America. It is possible to realize some value from virtually all wood ties that are removed from railroad tracks. The monetary value and application will vary with tie conditions, market supply and demand, reclamation and transportation costs, and environmental constraints.

Being a fairly large piece of timber that has been chemically treated to retard insect damage and rot, a used wood tie has a number of potential uses that can provide either revenue or savings for the tie's owner. The major applications that wood ties can be used in are:

a. Reuse in railroad track. If the tie's mechanical properties have not deteriorated beyond repair, it can be reclaimed and reused in a class of track that it is capable of supporting. This can vary over the entire range of track from industrial sidings to high-speed or high tonnage main lines. The market includes both the original tie owner and other railroads, particularly short lines and industries.

b. Engineering. Wood ties have been used for cribwork and other civil engineering applications for a long time. The railroad's own engineering department will usually have some need for such ties. Highway departments and construction firms also provide a potential market.

c. Landscaping and agriculture. Railroad ties are popular in landscaping applications for light cribwork, raising gardens, and providing borders. Farmers use ties for fencing, erosion control, and light cribbing.

d. Energy. Most wood ties consist of 2 to 3 cubic feet of wood. When dry, this much wood can develop a considerable amount of energy. Wood ties in quantity can be used to develop steam heat for a manufacturing plant or to drive steam generators to develop electricity. The rapid rise in energy costs today is making this alternative more attractive. The high chemical content of the ties requires that they be cut into small chips and burned in special furnaces so as to meet air pollution regulations.

The methods of reuse that are used depend on market demand, transportation costs, environmental constraints, the supply of suitable ties, and the general economics of tie reuse. For reuse in track, the technical aspects of reclaiming ties also affect reuse. Experience to date shows the technical feasibility of reclaiming at least the better quality used ties.

Tie reuse economics are affected by many variables, some of which are necessarily affected by local conditions. So, it is not possible to develop one reuse combination that is most efficient for the railroad industry.

Large-scale wood tie reuse has been common in Europe for many years because European track renewal methods produce large volumes of reusable ties and because hardwood ties are both scarce and relatively expensive. In most cases the ties are shipped to central, mechanized plants which sort the ties into use categories and then reclaim the ties for those categories. Such fixed plants in France, Germany, and the Soviet Union are described in other publications.*

*"Wood Tie Reuse - A Survey Report," report number FRA/ORD-79-44 prepared by Unified Industries Incorporated for the Federal Railroad Administration (1979), NTIS accession number 300866.

"Refurbishment of Railroad Crossties - A Technical and Economic Analysis," report number FRA/ORD-77/76 prepared by Stanford Research Institute for the Federal Railroad Administration (1977), NTIS accession number 283447.

For remote locations, the Soviets have developed a mobile tie reconditioning unit which rides on a single flat car approximately 70 feet long. It is equipped to:

a. Pull broken spikes from ties.

b. Plug spike holes.

c. Blow dirt from the tie's surface and cracks.

d. Adze the tie plate area.

e. Drill spike holes.

f. Drill horizontal holes through the end of split ties, thread the holes, and drive hardwood antisplitting dowels into the holes.

g. Apply creosote or other preservative to exposed wood surfaces.

A second rail car, highway vehicle, or stationary plant is required to support this plant and includes an air compressor, tool shop, and a lathe for antisplitting dowels.

The mobile plant can recondition up to 400 ties in a 7-hour shift. It is manufactured for both domestic and export markets.

Until the track renewal methodology came into use in North America, wood tie reuse was only marginal in the railroad industry. Reuse was primarily limited to:

a. Ties removed from abandoned track.

b. Ties removed from main line trackage before failure.

These ties are sorted on site into usable and nonusable categories and given standard rail gang type maintenance as needed, including plugging, adzing, and treatment of the adzed wood. The ties have nearly always been cascaded into the lowest classes of track, sidings, and light branch lines.

The performance of these ties has been somewhat mixed, leading to a general distrust of reusing wood ties within the industry. Mishandling of the ties may be partially responsible for short lifespans. Many of the ties are allowed to dry out and split before they are processed and reinstalled in track.

Until recent years, wood ties were plentiful and inexpensive, providing little incentive for reuse in track. Many ties are removed by sawing into 3 pieces, which, of course, eliminates any further use for the ties other than energy.

Several factors have combined in recent years to create an interest on the part of railroads for tie reuse in track. Included among these factors are:

a. Wood tie prices have risen at a higher rate than the general economic inflation in recent years with no indication of stabilizing.

b. Localized shortages of wood ties have slowed tie replacement programs on some railroads and led to some concern about tie supplies in the future.

c. Deferred maintenance on secondary lines, sidings, and yard tracks has created a larger market for ties in the 1980's.

While several railroads routinely cascade ties into lower class tracks and several new tie producers have occasionally sorted and processed these ties, no large-scale tie reuse programs existed in North America until 1978. This came into being because of track renewal systems installing concrete ties on Amtrak and Canadian National (CNR). Each system removes over 300,000 wood ties per season, most of which still have some effective service life left in them.

When CNR began its concrete tie program in 1976, it shipped all of the wood ties removed by the TRS back to the concrete tie manufacturing plant in Edmonton, Alberta, using the cars that delivered the concrete ties. Since the program began in track that had received normal maintenance up to the previous year, a large number of these used ties were suitable for reuse in main and secondary tracks.

Although the concrete tie program did not need wood tie reuse to justify it (softwood ties were failing at a rapid rate on high tonnage curved track), CNR recognized reuse as an opportunity to increase its benefits from the program. In 1978, it awarded a contract to an Edmonton contractor to sort the wood ties and repair those ties that are reusable. The contractor disposes of the remaining ties himself.

A small plant with fixed equipment is processing about 2,000 ties per day on one shift. Equipment consists of cranes and conveyors to move the ties, an adzing machine, and creosote handling equipment. There is no equipment for repairing split ties. They are sold or scrapped. The total manpower for the facility is 15 men, including supervision.

The spikes and tie plates are removed from all ties. Then the ties are sorted into 3 groups: scrap, main line use, and secondary line use. Then, the reusable ties are manually plugged. This is followed by adzing in an automatic adzing machine that cuts both rail seats simultaneously. The rail seats are then coated with creosote. Finally, the reusable ties are bundled and turned over to CNR.

The original sorting breakdown of ties was approximately 20 percent main line use, 40 percent secondary line use, and 40 percent scrap. This varies considerably over time, depending upon the track the ties were removed from, the amount of maintenance given the track in recent years, and the length of time the ties wait to be processed. Tie classification specifications used in Edmonton are as follows:

Grade A Category -- Ties for reuse in track carrying more than 25 million gross tons (MGT):

a - Tie shall be sawed on all 4 sides.

b - Tie shall be 8 feet to 8.5 feet long and 7 inches to 7.5 inches deep.

c - Adzing prior to repair shall not exceed 0.5 inch in depth.

d - Tie shall have no transverse cracks.

e - Tie shall be sound with no signs of rot.

f - Tie shall not be spike killed.

g - Tie may contain a single split up to 1 inch deep extending the full length of the tie.

h - Tie may contain a single split up to one-half the depth of the tie extending from the end of the tie, but not through the tie plate area.

i - There shall be no damage due to dragging equipment, derailment, or fire.

Grade B Category -- Ties for reuse in track carrying less than 25 MGT:

Any tie not included in either category A or the scrap tie category.

Scrap Tie Category:

a - Tie less than 5 inches deep.

b - Tie having one or more transverse cracks.

c - Adzing more than 1.5 inches in depth.

d - Tie previously turned; that is, used both top and bottom.

e - Tie contains a split for the entire depth of the tie, extending more than one-third the length of the tie.

f - Tie contains multiple splits extending from one end through the entire depth of tie and through the tie plate area.

g - Tie crushed more than 1 inch in depth in tie plate area.

h - Tie is spike killed.

i - Tie damaged by derailment, dragging equipment, or fire.

In 1979, CNR began local processing of the used wood ties removed from two of the three operating regions in which the TRS operates each season. This was done for three reasons:

a. The contractor, located in Edmonton, could not dispose of scrap ties which slowed his overall operation and thus CNR's tie reuse program. This was caused by a flooding of the used wood tie market when the Canadian government approved the abandonment of several thousand miles of little-used granger trackage in Manitoba, Saskatchewan, and Alberta.

b. The cost of transporting ties as much as 1,500 miles to Edmonton is an unnecessary expense because of the local need for used ties and the fact that the general service rail cars used to deliver concrete ties to the TRS operation do not necessarily have to return to Edmonton.

c. Most of the main-line ties removed by the TRS can be reused without repairs. CNR has a large internal market for ties with 11-inch tie plates. The ties removed by the P-811 have 14-inch tie plates. Most of these ties can be reused without adzing, simplifying the tie handling operation. Because of the high demand, CNR has no need to upgrade plate-cut ties (through adzing) for main lines.

To reduce its need for specially equipped tie cars, CNR ships concrete ties to temporary staging bases in conventional rail cars and stockpiles them until needed. After the day's TRS production, the tie cars are moved to the staging base and the used wood ties removed and replaced with new concrete ties. An 8-man crew sorts the wood ties into main-line, secondary line, and scrap ties using cranes and no other equipment.

The tie classification specifications used by the local tie sorting crew are the same as those used by the contractor in Edmonton, with one exception: Grade A ties cannot be plate cut at all. Although the reuse percentage varies with every trainload of ties, it averaged about 60 to 70 percent in 1979.

When its concrete tie program began in 1978, Amtrak also began to remove large quantities of mostly good wood ties from the track. In 1979, a contractor was selected to sort and reclaim these wood ties. The plant is located near the concrete tie manufacturing plant in Littleton, Massachusetts. After the wood ties are unloaded, the cars are reloaded with concrete ties and returned to the TRS worksite.

The following sequence of operations is performed with these ties:

a. Unload ties. Depending on the backlog of ties on hand, the ties are either put into storage on the ground near the sorting line or are unloaded directly onto the sorting line. This is done by a tie crane mounted on a truck.

b. Loosen and remove spikes and tie plates. The ties are aligned side-by-side on conveyor belt by hand. The easier-to-remove spikes are loosened manually using spike bars, while all of the remaining spikes are removed by hydraulic spike pullers. The spikes and tie plates are then put into separate containers.

c. Inspect ties. The ties are inspected, on each end (using a mirror) and on top, and then marked for Classes I (main-line use); II (secondary line use); III (fit for reuse on other railroads or for landscaping); or X (scrap).

d. Plug ties. Treated, hardwood plugs are driven into the spike holes of Classes I, II, and some III ties by hand.

e. Sort ties. Ties are manually sorted into groups of five ties in each class. A tie crane picks the ties up from the conveyor and makes bundles of 25 ties in each class. Class III ties are banded and moved to storage areas by forklift trucks. Class X ties are moved to storage areas and stacked loosely. Classes I and II ties are moved to the adzer or to surge storage as necessary.

f. Adze and treat ties. Ties for reuse in railroad track are dumped onto a short conveyor that feeds a dual headed adzer. Ties are manually aligned on the conveyor and checked for residual metal in the rail seat area that can damage the adzing tools. Any metal found is removed by hand. After the ties are adzed, the rail seat areas are automatically treated with a wood preservative. The ties then run off the end of the conveyor and are picked up by a forklift truck and stacked in a storage area or next to an outgoing truck.

g. Load ties. A tie crane loads the reclaimed Classes I and II ties into gondolas for shipment to Amtrak.

Amtrak tie classification specifications are as follows:

Class I -- Ties for reuse in main tracks, main leads in yards, and curved track in excess of 2°00':

- a - Tie shall be structurally sound, without indications of excessive weathering and/or wood deterioration, and shall have been previously treated with wood preservative.
- b - Tie dimensions shall be 8'6" (+3" or -1") x 6.75" (minimum) x 8" (minimum).
- c - Plate cutting shall not exceed 3/8".
- d - Spike holes will be capable of retaining tie plugs.
- e - If an antisplitting device is used, no split may exceed 3/4" in width or 12" in length.
- f - If no antisplitting device is used, no split may exceed 1/2" in width or 12" in length.

Class II -- Ties for reuse in yards and lightly used sidings:

a - Tie shall be structurally sound, without indications of excessive weathering and/ or wood deterioration, and shall have been previously treated with wood preservative.

b - Tie dimensions shall be 8'6" (+3" or -1") x 6.75" (minimum) x 8" (minimum).

c - Plate cutting shall not exceed 3/4".

d - Spike holes will be capable of retaining tie plugs.

e - If an antisplitting device is used, no split may exceed 1" in width or 12" in length.

f - If no antisplitting device is used, no split may exceed 1/2" in width or 12" in length.

Class III -- Ties not satisfactory for reuse in Amtrak tracks.

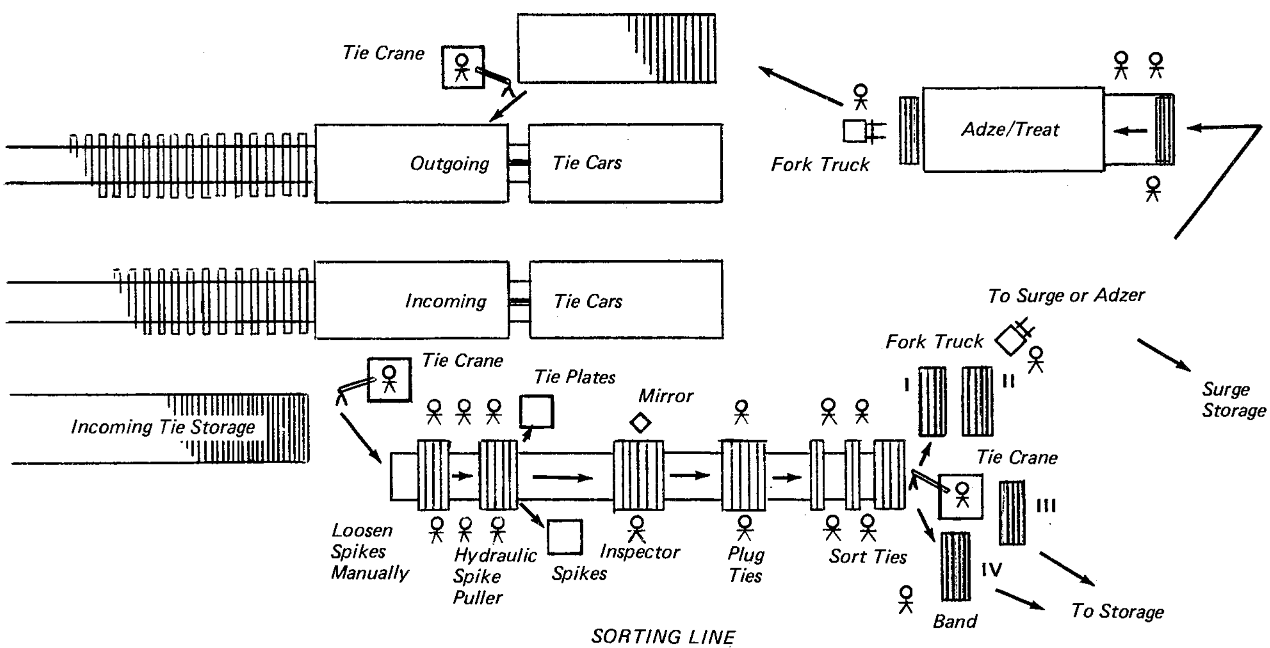
The entire wood tie operation is outdoors, although the adzer is enclosed. A schematic plan of the operation is shown in figure 12, below. It includes the normal labor complement and a list of the equipment.

The plant could be made mobile so that it can operate near the staging base for the TRS. The adzing machine could be mounted on a rail car or highway vehicle. The sorting line could also be mounted on a rail car or vehicle or simply be made portable to be set up on the ground. The remaining equipment is already capable of moving on highways or railroad cars.

This plant sorts an average of 2,000 ties per day (one 8-hour shift). The breakdown of ties into classes varies with virtually every trainload of ties because of the tie age and track conditions. The 1979 seasonal average (for 300,000 ties) was approximately as follows:

Class	Description	Percent
I	Amtrak No. 1 - Main lines	23
II	Amtrak No. 2 - Secondary lines	4
III	Reuse in non-Amtrak secondary tracks	13
III	Reuse in cribbing and landscaping	55
X	Scrap	5
		100

In 1979, the contractor sold Class III ties for industrial railroad sidings for $6.00 to $8.50 each. Class III ties for cribbing and landscaping were sold for $4.00 to $5.50 each. The contractor was successful in finding markets for reusable used ties in 1979, selling most of the Class III ties by the end of the year. The contractor was attempting to develop a market for the scrap ties, probably as wood chips for heating purposes. A major unsolved problem in this area is the residual metal in wood ties that ruins wood chip tooling.



Equipment:		Manpower:	
	3 Tie Cranes		1 Inspector
	2 Forklift Trucks		21 Laborers
	2 Hydraulic Spike Pullers/Compressor		2 Mechanics
	2 Conveyor Belts		1 Foreman
	1 Adzer-Treatment Machine		

FIGURE 12. AMTRAK WOOD TIE SORTING PLANT

In summary, a large-scale wood tie reuse operation is possible with unskilled labor and little mechanization or capital expense. It can be mobile or located in a permanent plant and operated by a railroad or outside contractor. Since the ties coming into the plant and the internal and external market for ties would vary from railroad to railroad, tie reuse should be tailored to the specific railroad. Finally, a wood tie has a market value whether or not it is suitable for reuse in track.

(2) Projected Wood Tie Sorting and Reuse Costs. Two wood tie sorting and repair plants are developed in this subsection as models for use in the United States and to develop the costs for determining material credit. These plants are similar to the plant serving Amtrak's tie sorting needs and are similar to each other. The main difference between them is that one is a fixed plant on a permanent site, while the other is mobile.

Each plant has some advantages. The fixed plant would probably have higher productivity and be more capable of handling other tasks. It should be under a roof and therefore able to operate in all weather. The mobile plant would be closer to the TRS, reducing transportation costs. It could be located adjacent to the new tie plant that is supplying the TRS at any given time and thus reduce tie transportation costs to a minimum. It also has lower capital investment requirements.

Both plant models are developed fully in the following paragraphs. The mobile plant has the lower unit cost, which is used in the material credit calculation and in the analysis in chapter III.

Tie Sorting Plant Model - Fixed Location

Purpose: Sort wood ties removed from track by a track renewal system (TRS) and reclaim those ties that are reusable without major repair work.

Location: Can be anywhere on the railroad, but a location near to (or part of) the principal new tie plant is preferable if TRS tie cars are used to haul ties. If ties are transshipped into general revenue cars, the best location would likely be near the demand point for that type of revenue car.

Operation: Wood ties are sorted into usable and scrap categories; usable ties are plugged, adzed, drilled, and treated by immersion in creosote. In an 8-hour shift, 2,500 ties are sorted, of which 1,875 ties are adzed, drilled and treated. This rate will keep up with a TRS over a full year (240 working days). Or a second shift can be worked on occasions, as necessary.

A layout for this plant is shown in figure 13. The cost development includes the costs of labor, materials, equipment maintenance, and capital recovery for those ties that are reused. No cost is attached to scrap ties.

Labor cost development is shown in table 36. The labor cost per tie is obtained by dividing the daily labor cost ($770.75) by the average number of reusable ties produced per day (1,875), which results in a labor cost of $0.41 per tie.

Material cost per tie is determined as follows:

4 tie plugs at $0.0085	$0.034
Preservative	$0.880
Total per tie	$0.914

The capital investment in the plant is shown in table 37. The total of $926,100 is multiplied by 0.10 (a typical plant maintenance cost ratio), to develop an estimate of the annual maintenance cost. This is divided by 240 working days per year and 1,875 ties reclaimed per day to obtain the facilities maintenance cost per tie.

$$\text{Facilities maintenance costs} = \frac{\$926{,}100 \times 0.10}{240 \times 1{,}875} = \$0.21 \text{ per tie}$$

All the equipment is assumed to be purchased new and depreciated over 8 or 10 years. Capital recovery cost (CRC) includes depreciation and interest on the invested capital, as explained in section A. The interest rate is assumed to be 12 percent. A 5-percent salvage value is assumed for all the equipment. While each machine is depreciated over 8 or 10 years as shown in table 37, the building is depreciated over 20 years.

Table 38 shows the CRC developments for each item. The total annual capital recovery cost is divided by the number of ties reclaimed per year to obtain the CRC per tie as follows:

$$\text{CRC} = \frac{149{,}800.42}{240 \times 1{,}875} = \$0.33 \text{ per tie}$$

The resulting total cost of sorting and reclaiming ties in the fixed plant is the sum of the above costs as shown below:

Cost Element	Cost per Tie
Labor	$0.411
Material	$0.914
Equipment maintenance	$0.21
Capital recovery	$0.33
Total per tie	$1.87

Tie Sorting Plant Model - Mobile Plant

Purpose: Sort wood ties removed from track by a track renewal system (TRS) and reclaim those ties that are reusable without major repair work.

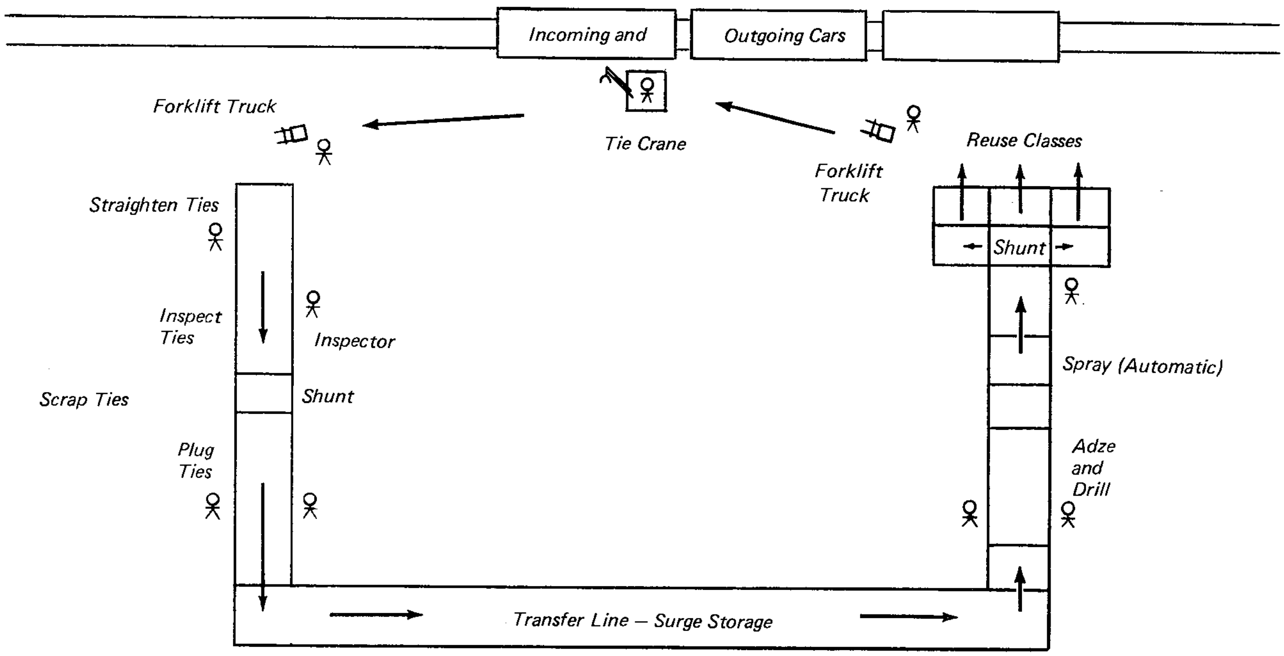


FIGURE 13. FIXED PLANT LAYOUT

TABLE 36

FIXED PLANT LABOR REQUIREMENTS AND COSTS

Number	Position	Daily Rate, Including Benefits	Daily Cost
1	Foreman	$78.46	$ 78.46
2	Mechanic	69.23	138.46
1	Inspector	69.23	69.23
1	Tie Crane Operator	60.00	60.00
2	Fork Truck Driver	55.38	110.76
2	Adzer Operator	55.38	110.76
4	Laborer	50.77	203.08
13		Total	$770.75

Location: The plant is temporarily located near the TRS operations for part of the TRS season and moved as necessary.

Operation: Wood ties are removed from rail cars; sorted into usable and scrap categories; reusable ties are plugged, adzed, treated by immersion, and drilled; ties are loaded into rail cars or highway vehicles for reuse or sale. In an 8-hour shift, 2,500 ties are sorted, of which 1,875 ties are adzed, drilled, and treated per shift.

A layout for this plant is shown in figure 14, on the following page. Cost development is by the same method as for the fixed tie plant.

Labor cost is developed in table 39. The daily labor cost of $1,033.83 is divided by 1,875 ties per day to obtain a labor cost of $0.55 per tie. Materials cost is the same as the fixed plant cost: $0.914 per tie.

The capital investment is shown in table 40. The facilities maintenance cost is obtained as was done for the fixed plant.

$$\text{Facilities maintenance cost} = \frac{\$203{,}100 \times 0.10}{240 \times 1{,}875} = \$0.05 \text{ per tie}$$

Table 41 shows the development of annual capital recovery cost. Cost per tie is obtained by:

TABLE 37

FIXED TIE PLANT CAPITAL COSTS

Number	Description of Equipment	Economic Life	Cost (approximate)
1	Tie Crane with Flatbed Truck	8	32,300
2	Fortlift Truck	8	70,000
2	Tie Adzer (or 1 Double Adzer)	8	8,800
1	Tie Treatment Sprayer	8	4,800
4	Conveyor Belt, 20 feet long by 9 feet wide	8	100,000
2	Tilting Shunt, Air Operated	8	30,000
1	Air Compressor	10	15,000
1	Conveyor Belt, 40 feet by 9 feet Gravity Roller	8	40,000
1	Tie Flipper, Air Operated	8	20,000
2	Tie Drill	8	5,200
1	Prefabricated Steel Building 60 feet x 80 feet	20	600,000
		Total	$926,100

TABLE 38

CAPITAL RECOVERY COSTS FOR A FIXED TIE SORTING PLANT

Capital Items	[P.P.	X	CRF]	—	[SV	X	SFF]	=	Annual CRC
1 Tie Crane	$ 32,300	X	.20130	—	$ 1,615	X	.08130	=	$ 6,370.69
2 Fork Trucks	70,000	X	.20130	—	3,500	X	.08130	=	13,806.45
2 Tie Adzers	8,800	X	.20130	—	440	X	.08130	=	1,735.67
1 Sprayer	4,800	X	.20130	—	240	X	.08130	=	946.73
4 Conveyors	100,000	X	.20130	—	5,000	X	.08130	=	19,723.50
2 Shunts	30,000	X	.20130	—	1,500	X	.08130	=	11,834.10
1 Compressor	15,000	X	.17698	—	750	X	.05698	=	7,889.40
1 Long Belt	40,000	X	.20130	—	2,000	X	.08130	=	3,944.70
1 Flipper	20,000	X	.20130	—	1,000	X	.08130	=	1,205.62
2 Drills	5,200	X	.20130	—	260	X	.08130	=	2,611.96
1 Building	600,000	X	.13388	—	30,000	X	.01388	=	79,911.60
					Total CRC per year			=	$147,800.42

P.P.—Purchase Price SV—Salvage Value SFF—Sinking Fund Factor CRF—Capital Recovery Factor

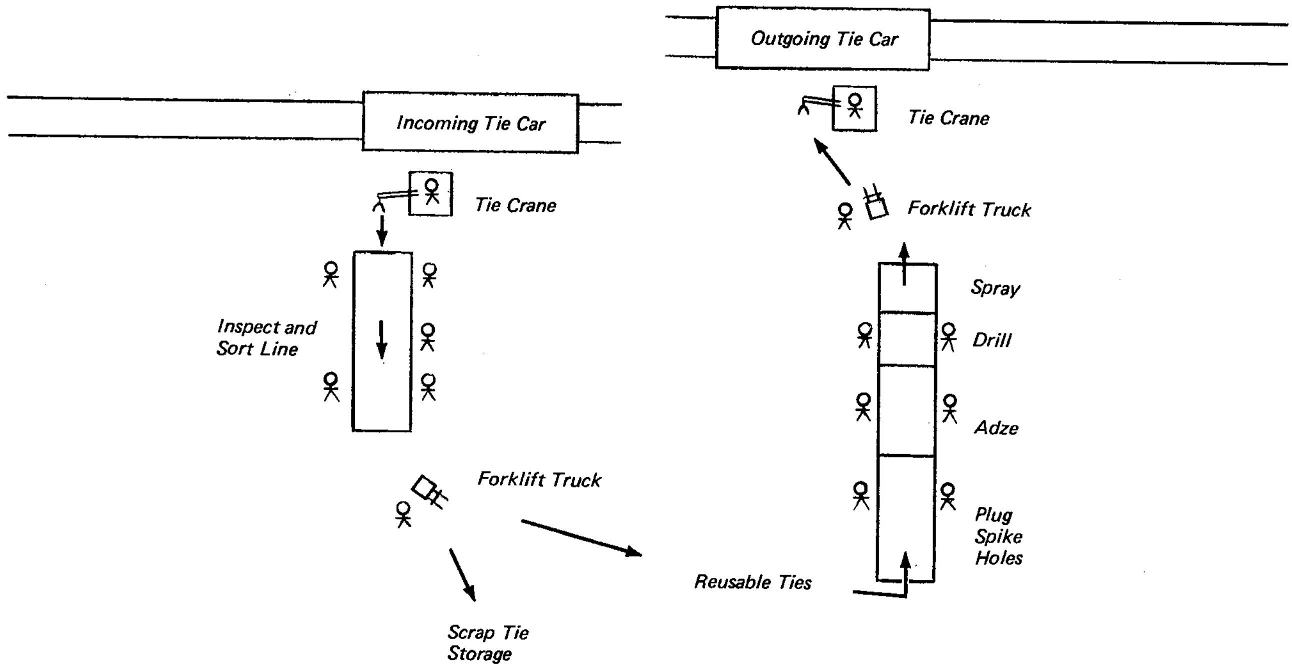


FIGURE 14. MOBILE TIE SORTING PLANT LAYOUT

TABLE 39

MOBILE PLANT LABOR REQUIREMENTS AND COSTS

Number	Position	Daily Rate, Including Benefits	Daily Cost
1	Foreman	$78.46	$ 78.46
2	Mechanic	69.23	138.46
1	Inspector	69.23	69.23
2	Tie Crane Operator	60.00	120.00
2	Forklift Truck Driver	55.38	110.76
2	Adzer Operators	55.38	110.76
8	Laborers	50.77	406.16
18		Total Daily Labor Cost:	$1,033.83

$$\text{CRC} = \frac{\$40,058.43}{240 \times 1,875} = \$0.09 \text{ per tie}$$

The resulting total cost of sorting and reclaiming ties in the mobile plant is the sum of the above costs as shown below:

Cost Element	Cost per Tie
Labor	$0.55
Material	$0.91
Equipment maintenance	$0.05
Capital recovery	$0.09
Total per tie	$1.60

This unit cost is used in the calculation of material credit in this report.

(3) Value of Used Wood Ties. It is difficult to develop a universal figure that represents the value of a used wood tie. The literature on the subject is vague and the values used in other studies vary widely. The key variables associated with used tie value are the cost of a new tie; the effective remaining life of the used tie compared to a new tie; and the cost of replacing the used tie when it fails. The value of money, or discount rate, is also important.

In the narrow area of interest of tie value, the cost of getting that tie ready for use

TABLE 40

MOBILE TIE PLANT CAPITAL COSTS

Number	Description of Equipment	Economic Life	Capital Cost (approximate)
2	Tie Crane with Flatbed Truck	8	64,300
2	Forklift Truck	8	70,000
2	Tie Adzer (or 1 Double Adzer)	8	8,800
1	Tie Treatment Sprayer	8	4,800
2	Conveyor Belt, Gravity Rollers	8	50,000
2	Tie Drill	8	5,200
		Total	$203,100

TABLE 41

CAPITAL RECOVERY COSTS FOR A MOBILE TIE SORTING PLANT

Capital Items	[P.P.	X	CRF]	—	[SV	X	SFF]	=	Annual CRC
2 Tie Cranes	$64,300	X	.20130	—	$3,215	X	.08130	=	$12,682.21
2 Fork Trucks	70,000	X	.20130	—	3,500	X	.08130	=	13,806.45
2 Adzers	8,800	X	.20130	—	440	X	.08130	=	1,735.67
1 Sprayer	4,800	X	.20130	—	240	X	.08130	=	946.73
2 Belts - Gravity	50,000	X	.20130	—	2,500	X	.08130	=	9,861.75
2 Drills	5,200	x	.20130	—	260	X	.08130	=	1,025.62
					Total CRC per year			=	$40,058.43

is not relevant. That was discussed in the previous subsection and will be subtracted from the tie value to obtain the net value, or material credit per tie, in the next subsection.

The value of a used tie should be proportionate to that of a new tie, based on each tie's service and the new tie's value, which is its purchase cost. In determining the value, the future replacement of the used ties during the life cycle of a new tie must be considered. This means additional costs at some time(s) in the future to replace the used tie, including material, labor, and equipment cost incurred by a tie gang.

An effective way to determine this value utilizes the present value method where all future costs are discounted back to their present value. The present value of all the costs incurred in installing a new tie over its life cycle is equated with the present value of all the costs of installing used ties over the same cycle. While the initial value of the used tie is unknown, its remaining service life can be estimated by inspection. Solving the equation with one unknown (material value of the used tie) will provide this value, which is proportionate to the cost and service life of a new tie.

The process for calculation of used wood tie value is illustrated in the following example:

A track renewal machine removes wood ties from track in which the average tie life is 24 years (similar to several scenarios used in chapter III). The track has received regular tie gang replacements every 6 years, so that 25 percent of the ties are 6 years old;

25 percent are 12 years old; 25 percent are 18 years old; and 25 percent are 24 years old. It can be assumed that these groups of ties have 18, 12, 6, and 0 years of remaining life. Those ties with no remaining life have no value for track reuse and are dealt with later.

The 18-, 12-, and 6-year remaining life ties have an average remaining life of 12 years. Using this average simplifies the mathematics without having much effect on the result. It is therefore to be expected that if these ties are reinstalled in track with an average of 24-year tie life, they will last an average 12 years, at which point they will be replaced by selective tie gangs.

The labor, capital recovery, equipment maintenance, and tie transportation costs associated with replacing 812 ties by a tie gang total $6,578.46 (taken from table 35). The cost per tie is $8.10. The cost of a new tie is assumed to be $13.50 (from table 10). The discount rate is assumed to be 10 percent.

The replacement cycles and costs are shown below:

New Tie

Replacement Cost	Material Value	Year
$8.10	$13.50	1
0	0	12
$8.10	$13.50	24

Used Tie

Replacement Cost	Material Value	Year
$8.10	X	1
$8.10	X	12
$8.10	X	24

There is equivalence for the alternatives at year 24, at which point the costs are not considered. Using the present value method and equating the new tie to used tie alternatives:

$$\$8.10 + \$13.50 = \$8.10 + X + 0.3186\ (\$8.10 + X)$$

0.3186 is the discount factor in year 12 at 10 percent.

Solving for X, the value of a used tie in this situation is $8.28.

At other average tie lives, the value of a used tie would be higher or lower as calculated.

If the used tie is installed in a track which is programed for complete renewal in the year in which the tie should fail and need replacement, the value of the used tie would be increased by the discounted replacement cost, $8.10 x 0.3186 = $2.58. Some railroads may want to attempt this long-term programing of track renewals and tie placement to maximize savings, but it would be very complex and require a long-term commitment to the track renewal method. The added value is not used in the determination of material credit in this report.

If a used tie is reinstalled in a very lightly used track where it will rot before it ever fails mechanically, it will have very nearly the same reuse life as a new tie would have. Under these circumstances the used tie value could be assumed to be equal to that of a new tie.

The ties which are not reused in track also have some value as they can be used in landscaping, fencing, landfills, or as energy. The size of the market for each use varies from region to region and affects the market value of the ties. The current and projected value and shortage of fuels may lead to a long-term growth market for wood ties for steam plants. Wood ties are being sold by at least one railroad for as little as $1.00 per tie, but the buyer usually has to pick them up behind a tie gang. Amtrak's tie sorting contractor has been receiving $4.00 to $7.00 per tie, sold in volume and already palletized. For this study, the scrap ties have been assigned a net value of $2.00. This value is probably conservative and the reader may wish to adjust it for local conditions in modifying the framework details.

(4) <u>Material Credit Calculation: Net Economic Impact of Reuse or Disposal</u>. The material credit for ties, or any track component, is the difference between the full net value of the material and the cost of preparing the material for reuse or sale. In the example above, the ties for reuse would be worth $8.28 – $1.60 = $6.68 per tie, assuming the mobile tie sorting plant is used. The ties sold for scrap would be worth $2.00 per tie as no particular cost is assumed in the economic framework for preparing these ties.

With the assumption that 75 percent of the ties in a mile are reusable, the material credit per mile is calculated as follows:

Reuse ties - 0.75 x 3,250 ties per mile x $6.68 per tie	=	$16,282.50
Scrap ties - 0.25 x 3,250 ties per mile x $2.00 per tie	=	$ 1,625.00
Total material credit per mile	=	$17,907.50

If 50 percent of the ties are defective, the material credit per mile is:

Reuse ties - 0.50 x 3,250 ties per mile x $6.68 per tie	=	$10,855.00
Scrap ties - 0.50 x 3,250 ties per mile x $2.00 per tie	=	$ 3,250.00
Total material credit per mile	=	$14,105.00

If the discounted tie gang costs could be eliminated by scheduled tie placement in future renewal trackage, the $2.58 savings per tie could be added for the ties to be reused. In the first example this would be:

0.75 x 3,250 ties per mile x $2.58 = $6,288.75, which when added to the original material credit ($17,907.50), results in a total credit of $24,196.25.

Several other combinations of situations were calculated and are shown in table 42. The graph in figure 15 can be used to determine the material credit where the average tie life is 20, 24, 30, or 36 years, all scrap ties are sold, and the average remaining life in the reused ties is one-half the expected life of a new tie.

3. Long-Term Costing Methodology

The final element of the economic analysis framework is the development of long-term costs for each alternative. This follows the logical progression of describing the alternative systems and developing costs and material credits for each operation and is broken down into tasks in figure 16, on page 57.

Long-term costs encompass all costs and credits that occur over a track maintenance cycle being evaluated. The cycle or period of analysis evaluated usually coincides with the rail life and average life of the ties. Thus, long-term costs include first-year costs, credit for used materials, and all annual maintenance costs occurring over a defined period of analysis.

With track renewal, the track is essentially rebuilt in the first or renewal year. Between track renewals, only light basic maintenance is usually performed. With selective maintenance, mechanized tie gangs periodically change at least 25 percent of the ties, as explained earlier, to maintain the track during the renewal cycle.

It is expected that track renewal would normally represent a higher initial expense in the first year. However, the extent to which the first-year loss would be recovered and perhaps surpassed to show a net cost savings must be investigated. A comprehensive cost comparison between these two methods of track maintenance must therefore show the cost of maintaining a proposed track structure by either method, over the long term.

All costs that occur after the first year are discounted back to their present value, so as to provide a standardized basis of comparison. If the first-year cost is added to the discounted annual maintenance costs, in the case of either method, to give the present work of the alternative cash flows, a decision based on least cost or cost effectiveness can be made.

One frequently used measure of long-term project feasibility is the development of present worths of costs for each alternative over the project life. When comparing alternatives for a new project, the lowest present worth (PW) cost is usually chosen unless other factors make a higher cost alternative more attractive. The return on investment may be higher with a higher cost alternative, and many corporations consider return on investment to be an important criterion for evaluation of alternatives. In addition, non-economic criteria, or factors not easily quantified in dollars, may be used in the evaluation. For example, the savings in track occupancy time

TABLE 42

MATERIAL CREDIT POSSIBILITIES

Percent Failed Ties	Percent Ties Reused	Average Remaining Life of Ties Reused (years)	Ties Reinstalled/ Replaced in Future By	Tie Reuse Plant Type	Percent Ties Sold for Salvage	Material Credit per Mile ($)	New Tie Life (years)
25	75	10	Tie Gang	Mobile	25	15,981.87	20
25	75	12	Tie Gang	Mobile	25	17,907.50	24
25	75	12	Tie Gang	Fixed	25	17,249.37	24
25	75	12	TRS	Mobile	25	24,196.25	24
50	50	12	Tie Gang	Mobile	50	14,105.00	24
50	25	12	Tie Gang	Mobile	75	10,302.50	24
25	75	15	Tie Gang	Mobile	25	20,466.88	30
25	75	18	Tie Gang	Mobile	25	22,587.50	36
100	0	--	--------	------	100	6,500.00	N/A

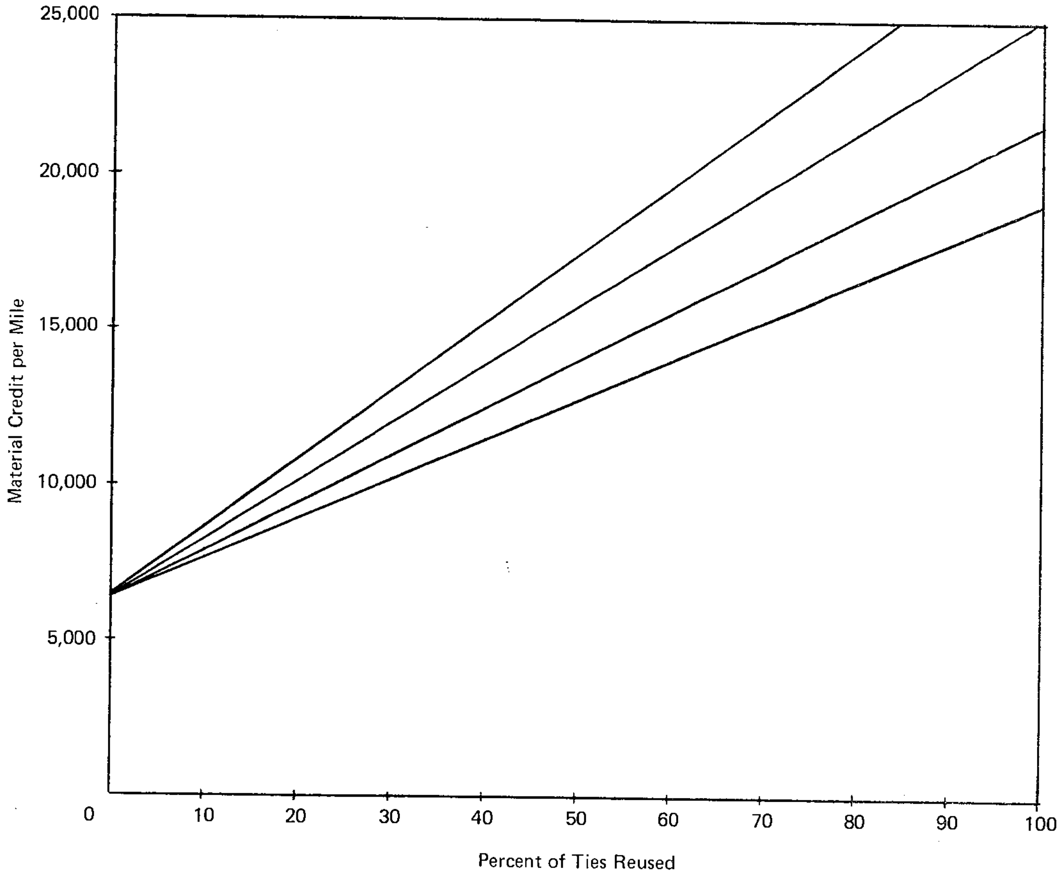


FIGURE 15. MATERIAL CREDIT BY REUSE PERCENTAGE

offered by track renewal may be important to management even though such savings are difficult to cost.

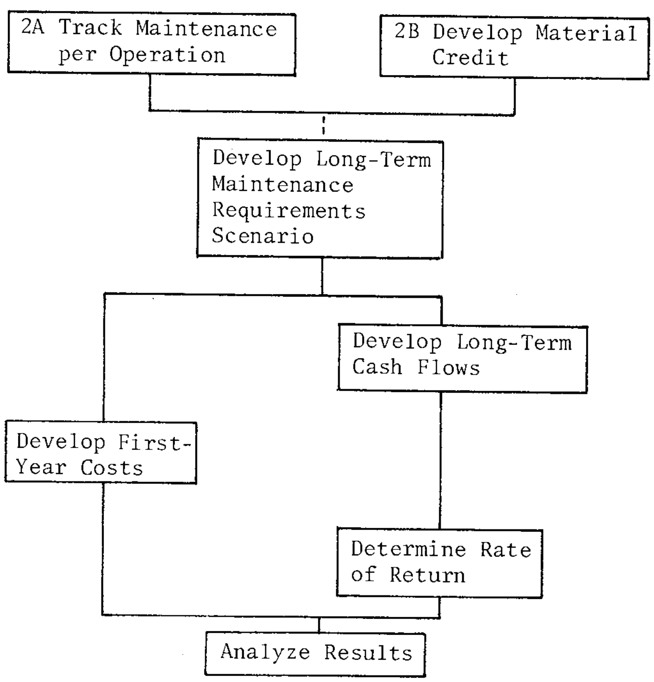


FIGURE 16. LONG-TERM COSTING FLOW CHART

The present worth method of comparison is outlined below and is used in chapter III to develop estimated costs/benefits from track renewal.

Step 1: Determine first-year and long-term track maintenance requirements by the selective and track renewal methods. For the first year, this entails determining the number of ties per mile to be replaced, whether or not the rails will be replaced, whether or not the ballast is to be cleaned, and if the track should be surfaced and lined. For future years, these operations should be projected as necessary to the year in which track renewal would be repeated. That projection will have to be based on an assumption about tie life and may be subject to error. Tie life for the selectively maintained track, as well as rail life and surfacing cycles, should be predictable from the railroad's past experience.

The scheduling of future tie gangs and track renewal must be based on railroad policy as well as assumed average tie life. In chapter III, long-term costs are projected for situations in which tie life is the same under selective maintenance and track renewal and also for situations in which tie life is longer under track renewal.

One method for estimating the future year in which either a tie gang or a TRS must renew the track is by using the chart developed by the Forest

Products Laboratory, shown in figure 17. For any assumed average tie life and maintenance policy, the year in which the track should be retied can be determined.

After the long-term requirements have been established, the comparison period has to be determined. Normally, if the track would be renewed in a given year (such as year 30), the economic evaluation should cover up to the preceding year (such as years 1 to 29).

There are possible complications that would require a different method for determining the comparison period but they will not be discussed here. A text on management or engineering economics should be consulted.

Step 2: Using the operation or gang costs and benefits explained in section 2, calculate the total costs for each alternative in each future year. Figure 18 shows a worksheet that can be used for this step. After the costs are entered for each gang in each year, the yearly subtotals are entered in the "Total Cost 1980 Constant $" row.

Step 3: Inflate annual costs. Most corporations require that future costs be expressed in inflated dollars. The worksheet shows factors for 5 percent inflation. These factors can be obtained from economic tables or by the formula:

$$\text{Inflation factor} = (1 + i)^n$$

where i = annual inflation rate

n = number of years

Note that for the first year on the worksheet, $n = 0$, and in subsequent years, n is one less than the year number shown. Some analysts would prefer to list the first year on the worksheet as year 0 to simplify the equation.

Step 4: Discount the inflated future costs to current dollars, or discounted cash flows. To account for the time value of money, nearly all corporations require that future cost/benefits be discounted at a specific rate to reflect the time value of money or cost of money to the corporation.

The worksheet in figure 18 shows a 10-percent discount rate. The discount factor may be obtained from economic tables or by the formula:

$$\text{Discount factor} = \frac{1}{(1 + i)^n}$$

Step 5: Sum the discounted cash flows for each alternative to obtain their respective present worth costs.

At this point, the difference between the two (or more) alternatives constitutes the net worth of savings to the company in current dollars over the life of the comparison by selecting the lower cost alternatives. The framework is set up for calculating this savings on a per-mile basis. It should, of course, be multiplied by the number of miles to be rebuilt during the year by track renewal to determine the full effect of the savings, if any, for the year's operations.

A target rate of return of 10 percent was used to discount the cash flows and obtain the long-term present worth costs for the alternatives. The determination of the actual rate of return, based on the cost savings accruing to the lower cost investment alternative over the maintenance cycle evaluated, can be calculated in several ways and is not presented in this framework. Actual rates of return reflecting an investment in track renewal were calculated for several scenarios and are shown in chapter III.

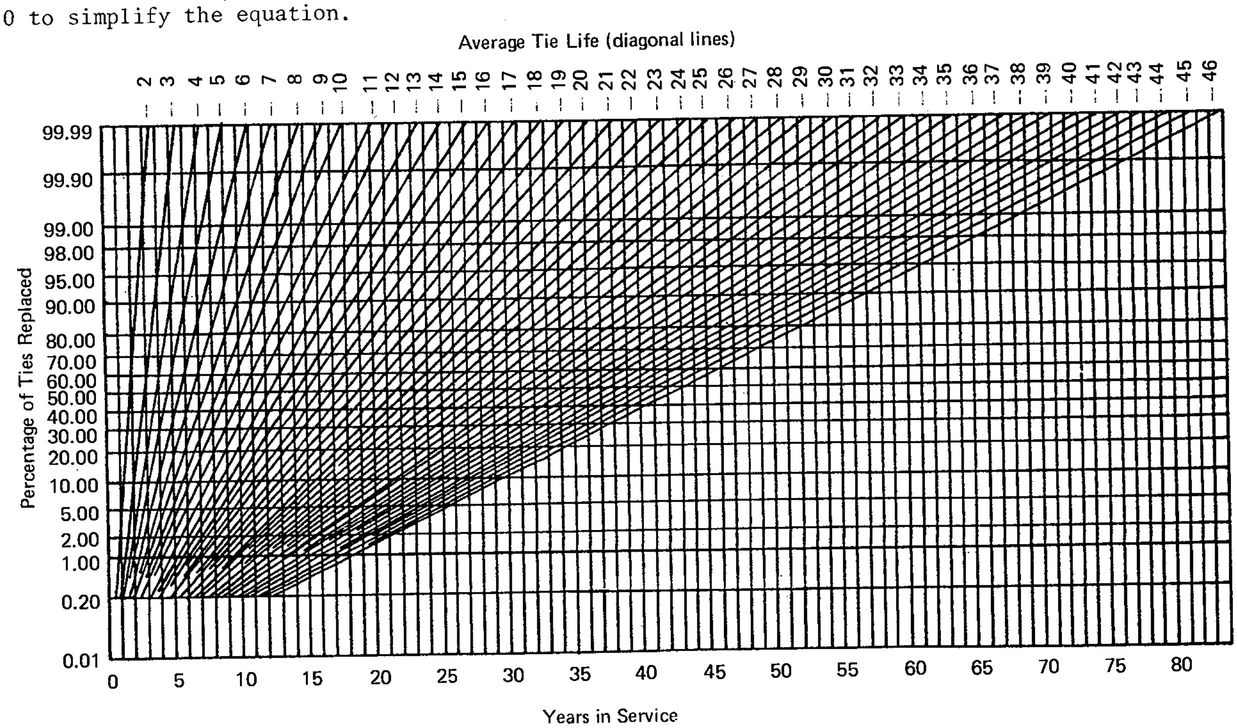


FIGURE 17. CHART FOR DETERMINING PROBABLE LIFE OF TIES

Scenario:

Alternative:

Year / Maintenance Gang														
Tie Gang														
Ballast Cleaning/Undercutting Gang														
Rail Gang														
Surfacing Gang														
TRM Gang														
Total Cost 1980 Constant $														
Inflation Factor @ %														
Inflated $														
Discount Factor @ %														
Discounted Cash Flow														

FIGURE 18. LONG-TERM COST ANALYSIS WORKSHEET

In this chapter, the economic analysis framework developed in chapter II is used to estimate first-year and long-term costs for various track maintenance scenarios. A variety of scenarios are developed to show how the track renewal method compares to selective maintenance on track of short, medium, and long average tie lives; with similar and dissimilar tie and rail lives; and comparing track renewal installed concrete ties to selectively maintained wood ties. Some other variables also are introduced. These variables include such factors as changes in average tie life induced by the track renewal method, the number of ties requiring replacement in the first year, and the inclusion or exclusion of ballast cleaning.

These scenarios do not provide an exhaustive analysis of all possible variables for a track renewal method evaluation. But they do provide an idea of what the potential magnitude of costs and benefits would be under a variety of real world conditions. The significant savings projected from the simulated conditions and assumptions of most of the scenarios indicates that the railroad industry in the United States should consider the track renewal method of maintenance.

1. Sample Track Maintenance Scenarios

Several different track maintenance scenarios were developed to provide a basis for comparison between conventional track maintenance and track renewal maintenance built around a Canron P-811. Each scenario describes a set of track maintenance requirements and corresponding long-term schedules of track maintenance operations for both types of maintenance.

Because a single scenario would be similar to just a few actual railroad situations, a range of scenarios was developed to provide more railroads with an idea of how track renewal economics would apply to their situations. The multiple scenarios also provide sufficient alternative situations so that track renewal economics can be evaluated to determine if some kinds of situations are more feasible for track renewal.

A. Development of Track Maintenance Requirements

The scenarios are presented as track maintenance requirements rather than as track physical and operating characteristics. These maintenance requirements, in tie and rail life expectancies, should be easy to relate to actual track maintenance requirements on many railroads.

The maintenance requirements for each scenario are defined by the following variable factors:

(1) Average tie life expectancy. Selective tie replacement cycles are built around average life expectancy and all of the scenarios follow this policy for the selective maintenance alternative. Some of the track renewal scenarios also follow the average tie life expectancy to determine the track renewal cycle length. In several scenarios, the track renewal method alternative is assumed to have extended average tie lives.

(2) Tie failure rate. The cumulative tie failures indicate when track should be renewed.

(3) Average rail life expectancy. The rail life dictates rail gang scheduling in every scenario and the track renewal cycle in most scenarios.

(4) Ballast surfacing and raising schedules. The cycle length between major surfacing operations is given. This is an approximate requirement which is used in every scenario. Two light surfacing operations are normally required between the major surface and raise operations. These light surfacing operations are not included in the scenario descriptions as they are assumed to be equal for selective maintenance and track renewal.

(5) Original track condition. The percentage of failed ties in the track in year 1 and the remaining service life of the rail are given. These two factors affect the scheduling of maintenance and the value of the used ties removed by the track renewal system.

(6) Maintenance policy. The minimum allowable FRA track classification is given. This limits the amount of deferred maintenance allowed, and also provides the basis for tie replacement requirements.

(7) Ballast maintenance method. The type of maintenance to be given to ballast is also shown. This includes complete undercutting and cleaning, or simple raising of the track line.

Other variables, such as gang makeup and production rates, inflation and discount rates, unit costs, etc., are not varied in the analysis presented here, although each one can have an impact on the results.

B. Scenario Descriptions

The scenarios developed for this study are presented in table 43. The track maintenance requirements for each alternative are shown. In each scenario, all ties in the renewal alternative are replaced and 25 percent of the ties are replaced in the selective maintenance alternatives in year 1, except scenario 2C in which 50 percent of the ties are replaced in the selective maintenance alternative.

Three sets of scenarios (1-, 2-, and 3-series) compare situations in which tie and rail life expectancies are approximately equal, as can be expected in tangent track. The 1-series of scenarios have an average tie life of 36 years, which is about the average for U.S. track. The 2-series assumes an average tie life of 25 years, which can be expected on heavily used main-line

TABLE 43

SCENARIO MAINTENANCE REQUIREMENTS
(All times given in years)

Scenario Number	Percent of Ties to Replace in Year 1	Selective Maintenance		Track Renewal Method				Average Rail Life	Year of First Rail Change	Ballast Maintenance		Surfacing Cycle
		Average Tie Life	Tie Gang Cycle	Average Tie Life	Cumulative Defective Year 25%	Cumulative Defective Year 50%	Year of Next Renewal			Undercut and Clean	Raise Only	
1A	25	36	9	36	29	34	35	35	1	X		9
1B	25	36	9	36	29	34	35	35	1		X	9
1C	25	36	9	45	36	42	36	35	1	X		9
2A	25	25	6+	25	20	24	25	24	1	X		6
2B	25	25	6+	30	24	28	25	24	1	X		6
2C	50	25	6+	30	24	28	25	24	1	X		6
3A	25	19	5-	19	15	18	16	17	1	X		5
3B	25	19	5-	22	17	21	18	17	1	X		5
4A	25	30	7-8	30	24	29	24	21	1	X		7-8
4B	25	30	7-8	30	24	29	22	21	1	X		7-8
4C	25	30	7-8	30	24	29	24	21	10	X		7-8
5	25	25	6+	25	20	24	20	10	1	X		6
6	25	25	6+	50*	40	--	41	24	1	X		6
7	25	19	5-	50*	40	--	41	17	1	X		5

*Concrete ties.

trackage. The 3-series assumes a 19-year tie life, which is found only on very heavily traveled main-line track. The heavy traffic that results in an average tie life of 19 years means that track maintenance time is very valuable and could tend to make full renewal methods especially attractive on heavy traffic lines because the track renewal method reduces track occupancy time.

The 4-series scenarios assume a tie life of 30 years with a rail life of 21 years. This can be expected on moderate curves. Similarly, the 5-series scenario assumes tie and rail lives of 25 and 10 years, respectively, based on fairly sharp main-line curves.

Scenarios 6 and 7 utilize information obtained from Amtrak to compare selectively maintained wood ties to concrete ties installed by a TRS.

The different tie and rail lives provide different life cycle lengths and different situations for use of the track renewal system. Thus, the effect of changing rails with the tie change can be studied. Some other conditions, such as ballast maintenance procedures, the proportion of defective ties in year 1, and the maximum allowable proportion of defective ties in the future, are also varied to make it possible to study effects of each type of condition on the economic feasibility of track renewal versus selective maintenance.

In some scenarios, it is necessary to replace 25 percent of the ties prior to the next track renewal cycle so that rail replacement coincides with the track renewal. The tie failure percentages over time are based on average tie life and the associated failure rates predicted by the Forest Products Laboratory, shown in figure 17 on page 58.

2. Sample Cash Flows

Discounted cash flows were calculated for each of the 14 scenarios described in table 43. An inflation rate of 5 percent and a discount rate of 10 percent were used in all scenarios. The long-term cash flows are shown in tables 44 to 68, on pages 62 through 70.

Scenario: *1A, 1C* | TABLE 44 | Alternative: *Selective*

Maintenance Gang \ Year	1	10	19	28
Tie Gang	18,315	18,315	18,315	18,315
Ballast Cleaning/Undercutting Gang	11,171		11,171	
Rail Gang	158,009			
Surfacing Gang	1,849	1,849	1,849	1,849
TRM Gang	—	—	—	—
Total Cost 1980 Constant $	189,344	20,164	31,335	20,164
Inflation Factor @ 5%	1.0000	1.5513	2.4066	3.7335
Inflated $	189,344	31,281	75,412	75,283
Discount Factor @ 10%	1.0000	0.4241	0.1799	0.0763
Discounted Cash Flow	189,344	13,266	13,566	5,744

Total Discounted Cash Flow: $221,920

Scenario: *1B* | TABLE 45 | Alternative: *Selective*

Maintenance Gang \ Year	1	10	19	28
Tie Gang	18,315	18,315	18,315	18,315
Ballast Cleaning/Undercutting Gang				
Rail Gang	158,009			
Surfacing Gang	1,849	1,849	1,849	1,849
TRM Gang	—	—	—	—
Total Cost 1980 Constant $	178,173	20,164	20,164	20,164
Inflation Factor @ 5%	1.0000	1.5513	2.4066	3.7335
Inflated $	178,173	31,281	48,527	75,283
Discount Factor @ 10%	1.0000	0.4241	0.1799	0.0763
Discounted Cash Flow	178,173	13,266	8,730	5,744

Total Discounted Cash Flow: $205,913

Scenario: *1A* | TABLE 46 | Alternative: *Track Renewal*

Maintenance Gang \ Year	1	10	19	30
Tie Gang				18,315
Ballast Cleaning/Undercutting Gang	9,437		11,171	
Rail Gang	—	—	—	—
Surfacing Gang		1,849	1,849	1,849
TRM Gang	202,468			
Total Cost 1980 Constant $	211,905	1,849	13,020	20,164
Inflation Factor @ 5%	1.0000	1.5513	2.4066	4.1161
Inflated $	211,905	2,868	31,334	82,997
Discount Factor @ 10%	1.0000	0.4241	0.1799	0.0630
Discounted Cash Flow	211,905	1,216	5,637	5,229

Subtotal: $223,987 Basic Maintenance: $1,851 Total Discounted Cash Flow: $225,838

Scenario: 1B TABLE 47 *Alternative: Track Renewal*

Maintenance Gang \ Year	1	10	19	30						
Tie Gang				18,315						
Ballast Cleaning/Undercutting Gang	—	—	—	—						
Rail Gang	—	—	—	—						
Surfacing Gang	1,849	1,849	1,849	1,849						
TRM Gang	202,468									
Total Cost 1980 Constant $	204,317	1,849	1,849	20,164						
Inflation Factor @ 5%	1.0000	1.5513	2.4066	4.1161						
Inflated $	204,317	2,868	4,450	82,997						
Discount Factor @ 10%	1.0000	0.4241	0.1799	0.0630						
Discounted Cash Flow	204,317	1,216	800	5,229						

Subtotal: $211,562 Basic Maintenance: $1,851 Total Discounted Cash Flow: $213,413

Scenario: 1C TABLE 48 *Alternative: Track Renewal*

Maintenance Gang \ Year	1	10	19	28						
Tie Gang	—	—	—	—						
Ballast Cleaning/Undercutting Gang	9,437		11,171							
Rail Gang	—	—	—	—						
Surfacing Gang		1,849	1,849	1,849						
TRM Gang	202,468									
Total Cost 1980 Constant $	211,905	1,849	13,020	1,849						
Inflation Factor @ 5%	1.0000	1.5513	2.4066	3.7335						
Inflated $	211,905	2,868	31,334	6,904						
Discount Factor @ 10%	1.0000	0.4241	0.1799	0.0763						
Discounted Cash Flow	211,905	1,216	5,637	527						

Subtotal: $219,285 Basic Maintenance: $896 Total Discounted Cash Flow: $220,181

Scenario: 2A, 2B TABLE 49 *Alternative: Selective*

Maintenance Gang \ Year	1	7	13	19						
Tie Gang	18,315	18,315	18,315	18,315						
Ballast Cleaning/Undercutting Gang	11,171									
Rail Gang	158,009									
Surfacing Gang	1,849	1,849	1,849	1,849						
TRM Gang	—	—	—	—						
Total Cost 1980 Constant $	189,344	20,164	20,164	20,164						
Inflation Factor @ 5%	1.0000	1.3401	1.7959	2.4066						
Inflated $	189,344	27,022	36,213	48,527						
Discount Factor @ 10%	1.0000	0.5645	0.3186	0.1799						
Discounted Cash Flow	189,344	15,254	11,537	8,730						

Total Discounted Cash Flow: $224,865

Scenario: 2C TABLE 50 *Alternative: Selective*

Maintenance Gang \ Year	1	7	13	19
Tie Gang	36,630	18,315	18,315	18,315
Ballast Cleaning/Undercutting Gang	11,171			
Rail Gang	158,009			
Surfacing Gang	1,849	1,849	1,849	1,849
TRM Gang	—	—	—	—
Total Cost 1980 Constant $	207,659	20,164	20,164	20,164
Inflation Factor @ 5%	1.0000	1.3401	1.7959	2.4066
Inflated $	207,659	27,022	36,213	48,527
Discount Factor @ 10%	1.0000	0.5645	0.3186	0.1799
Discounted Cash Flow	207,659	15,254	11,537	8,730

Total Discounted Cash Flow: $243,180

Scenario: 2A TABLE 51 *Alternative: Track Renewal*

Maintenance Gang \ Year	1	7	13	19	21
Tie Gang					18,315
Ballast Cleaning/Undercutting Gang	9,437				
Rail Gang	—	—	—	—	—
Surfacing Gang		1,849	1,849	1,849	
TRM Gang	202,468				
Total Cost 1980 Constant $	211,905	1,849	1,849	1,849	18,315
Inflation Factor @ 5%	1.0000	1.3401	1.7959	2.4066	2.6533
Inflated $	211,905	2,478	3,321	4,450	48,595
Discount Factor @ 10%	1.0000	0.5645	0.3186	0.1799	0.1486
Discounted Cash Flow	211,905	1,399	1,058	800	7,221

Subtotal: $222,383 Basic Maintenance: $2,756 Total Discounted Cash Flow: $225,139

Scenario: 2B, 2C TABLE 52 *Alternative: Track Renewal*

Maintenance Gang \ Year	1	7	13	19
Tie Gang	—	—	—	—
Ballast Cleaning/Undercutting Gang	9,437			
Rail Gang	—	—	—	—
Surfacing Gang		1,849	1,849	1,849
TRM Gang	202,468			
Total Cost 1980 Constant $	211,905	1,849	1,849	1,849
Inflation Factor @ 5%	1.0000	1.3401	1.7959	2.4066
Inflated $	211,905	2,478	3,321	4,450
Discount Factor @ 10%	1.0000	0.5645	0.3186	0.1799
Discounted Cash Flow	211,905	1,399	1,058	800

Subtotal: $215,162 Basic Maintenance: $1,626 Total Discounted Cash Flow: $216,788

Scenario: 3A

TABLE 53

Alternative: Selective

Maintenance Gang \ Year	1	6	11							
Tie Gang	18,315	18,315	18,315							
Ballast Cleaning/Undercutting Gang	11,171									
Rail Gang	158,009									
Surfacing Gang	1,849	1,849	1,849							
TRM Gang	—	—	—							
Total Cost 1980 Constant $	189,344	20,164	20,164							
Inflation Factor @ 5%	1.0000	1.2763	1.6289							
Inflated $	189,344	25,735	32,845							
Discount Factor @ 10%	1.0000	0.6209	0.3855							
Discounted Cash Flow	189,344	15,979	12,662							

Total Discounted Cash Flow: $217,985

Scenario: 3B

TABLE 54

Alternative: Selective

Maintenance Gang \ Year	1	6	11	16						
Tie Gang	18,315	18,315	18,315	18,315						
Ballast Cleaning/Undercutting Gang	11,171									
Rail Gang	158,009									
Surfacing Gang	1,849	1,849	1,849	1,849						
TRM Gang	—	—	—	—						
Total Cost 1980 Constant $	189,344	20,164	20,164	20,164						
Inflation Factor @ 5%	1.0000	1.2763	1.6289	2.0789						
Inflated $	189,344	25,735	32,845	41,919						
Discount Factor @ 10%	1.0000	0.6209	0.3855	0.2394						
Discounted Cash Flow	189,344	15,979	12,662	10,035						

Total Discounted Cash Flow: $228,020

Scenario: 3A

TABLE 55

Alternative: Track Renewal

Maintenance Gang \ Year	1	6	11							
Tie Gang	—	—	—							
Ballast Cleaning/Undercutting Gang	9,437									
Rail Gang	—	—	—							
Surfacing Gang		1,849	1,849							
TRM Gang	202,468									
Total Cost 1980 Constant $	211,905	1,849	1,849							
Inflation Factor @ 5%	1.0000	1.2763	1.6289							
Inflated $	211,905	2,460	3,012							
Discount Factor @ 10%	1.0000	0.6209	0.3855							
Discounted Cash Flow	211,905	1,465	1,161							

Subtotal: $214,531 Basic Maintenance: $1,908 Total Discounted Cash Flow: $216,439

Scenario: 3B TABLE 56 *Alternative: Track Renewal*

Maintenance Gang \ Year	1	6	11	16						
Tie Gang	—	—	—	—						
Ballast Cleaning/Undercutting Gang	9,437									
Rail Gang	—	—	—	—						
Surfacing Gang		1,849	1,849	1,849						
TRM Gang	202,468									
Total Cost 1980 Constant $	211,905	1,849	1,849	1,849						
Inflation Factor @ 5%	1.0000	1.2763	1.6289	2.0789						
Inflated $	211,905	2,460	3,012	3,844						
Discount Factor @ 10%	1.0000	0.6209	0.3855	0.2394						
Discounted Cash Flow	211,905	1,465	1,161	920						

Subtotal: $215,451 Basic Maintenance: $1,580 Total Discounted Cash Flow: $217,031

Scenario: 4A TABLE 57 *Alternative: Selective*

Maintenance Gang \ Year	1	9	16	22						
Tie Gang	18,315	18,315	18,315							
Ballast Cleaning/Undercutting Gang	11,171		11,171							
Rail Gang	158,009			158,009						
Surfacing Gang	1,849	1,849	1,849							
TRM Gang	—	—	—	—						
Total Cost 1980 Constant $	189,344	20,164	31,335	158,009						
Inflation Factor @ 5%	1.0000	1.4775	2.0789	2.7860						
Inflated $	189,344	29,792	65,143	440,212						
Discount Factor @ 10%	1.0000	0.4665	0.2394	0.1351						
Discounted Cash Flow	189,344	13,898	15,595	59,473						

Total Discounted Cash Flow: $278,310

Scenario: 4B TABLE 58 *Alternative: Selective*

Maintenance Gang \ Year	1	9	16							
Tie Gang	18,315	18,315	18,315							
Ballast Cleaning/Undercutting Gang	11,171		11,171							
Rail Gang	158,009									
Surfacing Gang	1,849	1,849	1,849							
TRM Gang	—	—	—							
Total Cost 1980 Constant $	189,344	20,164	31,335							
Inflation Factor @ 5%	1.0000	1.4775	2.0789							
Inflated $	189,344	29,792	65,143							
Discount Factor @ 10%	1.0000	0.4665	0.2394							
Discounted Cash Flow	189,344	13,898	15,595							

Total Discounted Cash Flow: $218,837

Scenario: 4C TABLE 59 *Alternative: Selective*

Maintenance Gang \ Year	1	9	10	16						
Tie Gang	18,315	18,315		18,315						
Ballast Cleaning/Undercutting Gang	11,171			11,171						
Rail Gang			158,009							
Surfacing Gang	1,849	1,849		1,849						
TRM Gang	—	—	—	—						
Total Cost 1980 Constant $	31,335	20,164	158,009	31,335						
Inflation Factor @ 5%	1.0000	1.4775	1.5513	2.0789						
Inflated $	31,335	29,792	245,119	65,143						
Discount Factor @ 10%	1.0000	0.4665	0.4241	0.2394						
Discounted Cash Flow	31,335	13,898	103,955	15,595						

Total Discounted Cash Flow: $164,763

Scenario: 4A TABLE 60 *Alternative: Track Renewal*

Maintenance Gang \ Year	1	9	16	22						
Tie Gang	—	—	—	—						
Ballast Cleaning/Undercutting Gang	9,437		11,171							
Rail Gang				158,009						
Surfacing Gang		1,849	1,849							
TRM Gang	202,468									
Total Cost 1980 Constant $	211,905	1,849	13,020	158,009						
Inflation Factor @ 5%	1.0000	1.4775	2.0789	2.7860						
Inflated $	211,905	2,732	27,068	440,212						
Discount Factor @ 10%	1.0000	0.4665	0.2394	0.1351						
Discounted Cash Flow	211,905	1,274	6,480	59,473						

Subtotal: $279,132 Basic Maintenance: $1,228 Total Discounted Cash Flow: $280,360

Scenario: 4B TABLE 61 *Alternative: Track Renewal*

Maintenance Gang \ Year	1	9	16							
Tie Gang	—	—	—							
Ballast Cleaning/Undercutting Gang	9,437		11,171							
Rail Gang	—	—	—							
Surfacing Gang		1,849	1,849							
TRM Gang	202,468									
Total Cost 1980 Constant $	211,905	1,849	13,020							
Inflation Factor @ 5%	1.0000	1.4775	2.0789							
Inflated $	211,905	2,732	27,068							
Discount Factor @ 10%	1.0000	0.4665	0.2394							
Discounted Cash Flow	211,905	1,274	6,480							

Subtotal: $219,659 Basic Maintenance: $532 Total Discounted Cash Flow: $220,191

Scenario: 4C TABLE 62 *Alternative: Track Renewal*

Maintenance Gang \ Year	1	9	10	16						
Tie Gang	—	—	—	—						
Ballast Cleaning/Undercutting Gang	9,437			11,171						
Rail Gang			158,009							
Surfacing Gang		1,849		1,849						
TRM Gang	60,319									
Total Cost 1980 Constant $	69,756	1,849	158,009	13,020						
Inflation Factor @ 5%	1.0000	1.4775	1.5513	2.0789						
Inflated $	69,756	2,732	245,119	27,068						
Discount Factor @ 10%	1.0000	0.4665	0.4241	0.2394						
Discounted Cash Flow	69,756	1,274	103,955	6,480						

Subtotal: $181,465 Basic Maintenance: $1,228 Total Discounted Cash Flow: $182,693

Scenario: 5 TABLE 63 *Alternative: Selective*

Maintenance Gang \ Year	1	7	11	14						
Tie Gang	18,315	18,315		18,315						
Ballast Cleaning/Undercutting Gang	11,171									
Rail Gang	158,009		158,009							
Surfacing Gang	1,849	1,849		1,849						
TRM Gang	—	—	—	—						
Total Cost 1980 Constant $	189,344	20,164	158,009	20,164						
Inflation Factor @ 5%	1.0000	1.3401	1.6289	1.8856						
Inflated $	189,344	27,022	257,380	38,021						
Discount Factor @ 10%	1.0000	0.5645	0.3855	0.2897						
Discounted Cash Flow	189,344	15,254	99,220	11,015						

Total Discounted Cash Flow: $314,833

Scenario: 5 TABLE 64 *Alternative: Track Renewal*

Maintenance Gang \ Year	1	7	11	14						
Tie Gang	—	—	—	—						
Ballast Cleaning/Undercutting Gang	9,437									
Rail Gang			158,009							
Surfacing Gang		1,849		1,849						
TRM Gang	202,468									
Total Cost 1980 Constant $	211,905	1,849	158,009	1,849						
Inflation Factor @ 5%	1.0000	1.3401	1.6289	1.8856						
Inflated $	211,905	2,478	257,380	3,487						
Discount Factor @ 10%	1.0000	0.5645	0.3855	0.2897						
Discounted Cash Flow	211,905	1,399	99,220	1,010						

Subtotal: $313,534 Basic Maintenance: $1,153 Total Discounted Cash Flow: $314,687

Scenario: 6

TABLE 65

Alternative: Selective

Year / Maintenance Gang	1	7	13	19	25	31	37			
Tie Gang	18,315	18,315	18,315	18,315	18,315	18,315	18,315			
Ballast Cleaning/Undercutting Gang	11,171				11,171					
Rail Gang	158,009				158,009					
Surfacing Gang	1,849	1,849	1,849	1,849	1,849	1,849	1,849			
TRM Gang	—	—	—	—	—	—	—			
Total Cost 1980 Constant $	189,344	20,164	20,164	20,164	189,344	20,164	20,164			
Inflation Factor @ 5%	1.0000	1.3401	1.7959	2.4066	3.2251	4.3219	5.7918			
Inflated $	189,344	27,022	36,213	48,527	610,652	87,147	116,786			
Discount Factor @ 10%	1.0000	0.5645	0.3186	0.1799	0.1015	0.0573	0.0323			
Discounted Cash Flow	189,344	15,254	11,537	8,730	61,981	4,994	3,772			

Total Discounted Cash Flow: $295,612

Scenario: 6

TABLE 66

Alternative: Track Renewal

Year / Maintenance Gang	1	7	13	19	25	31	37			
Tie Gang	—	—	—	—	—	—	—			
Ballast Cleaning/Undercutting Gang	9,437				11,176					
Rail Gang					158,009					
Surfacing Gang		1,849	1,849	1,849	1,849	1,849	1,849			
TRM Gang — Concrete	226,684									
Total Cost 1980 Constant $	236,121	1,849	1,849	1,849	171,029	1,849	1,849			
Inflation Factor @ 5%	1.0000	1.3401	1.7959	2.4066	3.2251	4.3219	5.7918			
Inflated $	236,121	2,478	3,321	4,450	551,584	7,992	10,709			
Discount Factor @ 10%	1.0000	0.5645	0.3186	0.1799	0.1015	0.0573	0.0323			
Discounted Cash Flow	236,121	1,399	1,058	800	55,986	458	346			

Subtotal: $296,168 Basic Maintenance: 0.00 Total Discounted Cash Flow: $296,168

Scenario: 7

TABLE 67

Alternative: Selective

Year / Maintenance Gang	1	6	11	16	18	20	25	30	35	39
Tie Gang	18,315	18,315	18,315	18,315		18,315	18,315	18,315	18,315	18,315
Ballast Cleaning/Undercutting Gang	11,171				11,171				11,171	
Rail Gang	158,009				158,009				158,009	
Surfacing Gang	1,849	1,849	1,849	1,849		1,849	1,849	1,849	1,849	1,849
TRM Gang	—	—	—	—	—	—	—	—	—	—
Total Cost 1980 Constant $	189,344	20,164	20,164	20,164	169,179	20,164	20,164	20,164	189,343	20,164
Inflation Factor @ 5%	1.0000	1.2763	1.6289	2.0789	2.2920	2.5270	3.2251	4.1161	5.2533	6.3855
Inflated $	189,344	25,735	32,845	41,919	387,759	50,954	65,031	82,997	994,678	128,757
Discount Factor @ 10%	1.0000	0.6209	0.3855	0.2394	0.1978	0.1635	0.1015	0.0630	0.0391	0.0267
Discounted Cash Flow	189,344	15,979	12,662	10,035	76,699	8,331	6,600	5,229	38,892	3,438

Total Discounted Cash Flow: $367,209

Scenario: 7　　　　TABLE 68　　　　*Alternative: Track Renewal*

Maintenance Gang \ Year	1	6	11	16	18	20	25	30	35	39
Tie Gang										
Ballast Cleaning/Undercutting Gang	9,437				11,171				11,171	
Rail Gang					158,009				158,009	
Surfacing Gang		1,849	1,849	1,849		1,849	1,849	1,849	1,849	1,849
TRM Gang	226,684									
Total Cost 1980 Constant $	236,121	1,849	1,849	1,849	169,180	1,849	1,849	1,849	171,029	1,849
Inflation Factor @ 5%	1.0000	1.2763	1.6289	2.0789	2.2920	2.5270	3.2251	4.1161	5.2533	6.3855
Inflated $	236,121	2,360	3,012	3,844	387,760	4,673	5,963	7,611	898,465	11,807
Discount Factor @ 10%	1.0000	0.6209	0.3855	0.2394	0.1978	0.1635	0.1015	0.0630	0.0391	0.0267
Discounted Cash Flow	236,121	1,465	1,161	920	76,699	764	605	480	35,130	315

Subtotal: $353,600　　　Basic Maintenance: 0.00　　　Total Discounted Cash Flow: $353,660

The first-year and long-term costs for each operation were taken from table 35, on page 44, as developed in chapter II and applied to specific years as indicated by the scenario descriptions. Each cost is inflated by 5 percent and discounted by 10 percent to obtain a discounted cash flow cost expressed in 1980 dollars. These costs are totaled for the comparative periods.

The track renewal alternatives of the wood tie scenarios have an additional cost added for replacing failed wood ties over the renewal cycle. The cost is different for each scenario because the tie failure and replacement rate was calculated statistically for each particular situation. The methodology for this calculation is described below.

Step 1: The total cumulative number of failed ties each year for the scenario was determined by using tie failure rates from the Forest Products Laboratory chart in figure 17, on page 58.

Step 2: The number of occurrences in which ties need to be replaced was determined from table 69, on page 71. FRA standards for Class V track prohibit having 2 ties in a row defective. Therefore, for every occurrence in which 2 or 3 ties in a row are defective, one tie must be replaced. For every occurrence of 4 or 5 in a row defective, 2 ties must be replaced. Table 69 is cumulative both vertically and horizontally, so that each row includes all of the ties shown in the row below it, and each column includes the ties in preceding columns. The number of occurrences of consecutive defective ties per mile shown in table 69 was determined by the formula: tP^r

where t = total number of ties per mile

P = proportion of the ties defective

r = number of ties in a row defective.

In determining the number of ties to replace in each year, differences between given totals should be calculated rather than direct use made of the total themselves.

Step 3: The number of ties requiring replacement in each year is multiplied by $26.08, which is the unit cost for replacing a tie by a basic maintenance gang as developed in chapter II. This cost could be reduced if the basic maintenance gang installs used ties instead of new ties to replace failed ties and if they use small tie replacement machines instead of manual labor.

Step 4: The annual costs are inflated by 5 percent and then discounted by 10 percent as is done in the discounted cash flow analysis.

Step 5: The discounted cash flows are totaled to produce the total discounted cost of manual tie replacement over the renewal cycle.

Steps 3, 4, and 5, above, are shown in tables 70 to 77, on pages 72 to 75. To coordinate with rail change, some scenarios have a selective tie gang to replace 25 percent of the ties in the year in which there are a cumulative 25-percent or more ties failed, with a full track renewal at a later year, usually the one in which 50 percent or more of the original ties would have failed. For these scenarios, steps 1 and 2 have to be done twice before steps 3, 4, and 5 are done.

3. Analysis of Sample Cash Flows

The results of the calculations for long-term discounted cash flow for the 14 scenarios are summarized in table 78 on page 75 and table 79 on page 76. Table 78 presents the difference in long-term costs between track renewal and selective maintenance with and without material credit on a per-mile basis. In addition, the calculated internal rates of return for the track renewal alternative in each scenario is shown. Table 79 shows the long-term cost differentials for a full year's track renewal production of 177 miles. Numbers in parentheses indicate a loss for the track renewal alternative while all other numbers represent projected savings due to track renewal.

TABLE 69

CUMULATIVE TIE FAILURE OCCURRENCES PER MILE BY OVERALL TIE FAILURE RATE*

Ties in a Row Defective	Percentage of Ties Defective																								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	33	65	98	130	163	195	228	260	293	325	358	390	423	455	488	520	553	585	618	650	683	715	748	780	813
2		1	3	5	8	12	16	21	26	33	39	47	55	64	73	83	94	105	117	130	143	157	172	187	203
3						1	1	2	2	3	4	6	7	9	11	13	16	19	22	26	30	35	40	45	51
4												1	1	1	2	2	2	3	4	5	6	8	9	11	13
5																		1	1	1	1	2	2	3	3
6																								1	1

*The number of occurrences of consecutive defective ties per mile = tP^r

where t = total number of ties per mile (3,250 used for this table)

P = decimal proportion of ties defective

r = number of ties in a row defective

Tables 80 and 81, on pages 76 and 77, show the effect on long-term costs if the production rate for the track renewal system is reduced to about 1,900 ties per day (table 80) or increased to about 3,900 ties per day (table 81). The differences between these tables and table 78 reflect changes in the year 1 cost per mile for the track renewal system and primarily result from spreading the seasonal cost for the operation over a different number of miles.

It should be noted that the present worth of savings or losses are not directly comparable between scenarios because the life over which the scenario is valid varies.

The following findings are apparent from the long-term cost differentials:

a. Costs, savings (or losses), and internal rates of return between track renewal and selective maintenance alternatives vary widely with application to specific scenarios.

b. If no material credit is taken, those scenarios with short average wood tie lives (3A, 3B, 7) have higher savings for track renewal than those with long tie lives (1A, 1B, 1C). But material credit is higher for scenarios with long tie lives because the average remaining life in the ties is longer, as developed in chapter II. This causes the long-term cost differentials of similar scenarios, such as 1A, 2A, 3A, 4A, and 5, to be very close ($17,200 to $18,700 per mile in table 78).

c. If the track renewal method of track maintenance extends average tie life, the long-term savings due to track renewal is increased considerably, as shown by scenarios 1C, 2B, and 3B when compared to 1A, 2A, and 3A, respectively.

d. If ballast cleaning is omitted, as is done in scenario 1B, the long-term savings due to track renewal is reduced, as compared to 1A. This indicates that ballast cleaning is more economically attractive when combined with track renewal than as part of the selective maintenance method.

e. Long-term cost savings are generally increased if a track must be upgraded, as shown by scenario 2C when compared with 2B. But the savings differential is small if material credit is taken.

f. Track renewal, without simultaneous rail change, is not very economically attractive. The scenario with rail change in a different year from track renewal, 4C, has the largest track renewal alternative loss without material credit and is the only scenario in which the savings with material credit is probably too small to justify the track renewal method.

g. The ratio of tie life to rail life can vary without much impact on the long-term savings. Scenarios 2A and 5 are similar except for much different rail lives. Scenario 5, with much shorter rail life, has only marginally higher savings for the track renewal method.

h. Changing the year in which the next full track renewal operation will take place may have a large impact at that future time but a small impact in the present worth costs as shown in scenarios 4A and 4B.

i. Concrete ties installed by a track renewal machine provide significant long-term savings when compared to selectively maintained wood ties, as shown in scenarios 6 and 7, but the savings must be realized over a long period of time

TABLE 70

BASIC MAINTENANCE COST PER YEAR - SCENARIOS 1A, 1B

Average Tie Life: 36 years

Tie Condition: 25% Bad in Year 29

Year	Ties Changed	1980 Cost	+5% Inflation	"Cash Flow" -10% Discount
17	1	26.08	56.93	12.39
18	0			
19	2	52.16	125.52	22.58
20	2	52.16	131.81	21.55
21	3	78.24	207.59	30.85
22	4	104.32	290.64	39.26
23	4	104.32	305.17	37.47
24	10	260.80	801.05	89.48
25	13	339.04	1,093.44	110.98
26	26	678.08	2,296.25	211.94
27	31	808.48	2,874.71	241.19
28	36	938.88	3,505.31	274.46
29	46	1,199.68	4,702.87	325.91
30	0			
31	0			
32	8	208.64	946.81	49.33
33	25	652.00	3,106.71	147.26
34	42	1,095.36	5,480.09	236.19
Totals	253			$1,850.84

TABLE 71

BASIC MAINTENANCE COST PER YEAR - SCENARIO 1C

Average Tie Life: 45 years

Tie Condition: 25% Bad in Year 35/36

Year	Ties Changed	1980 Cost	+5% Inflation	"Cash Flow" -10% Discount
22	1	26.08	72.66	9.82
23	0			
24	2	52.16	160.21	17.90
25	2	52.16	168.22	17.07
26	3	78.24	264.95	24.46
27	4	104.32	370.93	31.12
28	4	104.32	389.48	29.72
29	5	130.40	511.18	35.42
30	12	312.96	1,288.17	81.16
31	12	312.96	1,352.58	77.50
32	17	443.36	2,011.97	104.82
33	20	521.60	2,485.37	117.81
34	23	599.84	3,001.00	129.34
35	41	1,069.28	5,617.25	219.63
Totals	146			$895.77

TABLE 72

BASIC MAINTENANCE COST PER YEAR - SCENARIO 2A

Average Tie Life: 25 years

Tie Condition: 25% Bad in Year 21

Year	Ties Changed	1980 Cost	+5% Inflation	"Cash Flow" -10% Discount
12	1	26.08	44.60	15.63
13	2	52.16	93.67	29.84
14	2	52.16	98.35	28.49
15	3	78.24	154.92	40.79
16	8	208.64	433.74	103.84
17	17	443.36	967.81	210.60
18	23	599.86	11,374.88	271.95
19	40	1,043.20	2,510.57	451.65
20	67	1,747.36	4,415.58	721.95
21	0			
22	12	312.96	871.91	117.79
23	27	704.16	2,059.88	252.95
24	57	1,486.56	4,565.97	510.02
Totals	259			$2,755.50

TABLE 73

BASIC MAINTENANCE COST PER YEAR - SCENARIOS 2B, 2C

Average Tie Life: 30 years

Tie Condition: 25% Bad in Year 25

Year	Ties Changed	1980 Cost	+5% Inflation	"Cash Flow" -10% Discount
15	1	26.08	51.64	13.60
16	2	52.16	108.44	25.96
17	2	52.16	113,86	24.78
18	3	78.24	179.33	35.47
19	8	208.64	502.11	90.33
20	17	443.36	1,120.37	183.18
21	23	599.84	1,591.56	236.51
22	29	756.32	2,107.11	284.67
23	36	938.88	2,746.51	337.27
24	44	1,147.52	3,524.61	393.70
Totals	167			$1,625.47

TABLE 74

BASIC MAINTENANCE COST PER YEAR - SCENARIO 3A

Average Tie Life: 19 years

Tie Condition: 25% Bad in Year 15

Year	Ties Changed	1980 Cost	+5% Inflation	"Cash Flow" -10% Discount
9	0			
10	1	26.08	40.46	17.16
11	4	104.32	169.93	65.51
12	7	182.56	312.23	109.44
13	14	365.12	655.72	208.91
14	39	1,017.12	1,917.88	555.61
15	70	1,825.60	3,614.69	951.75
Totals	135			$1,908.38

TABLE 75

BASIC MAINTENANCE COST PER YEAR - SCENARIO 3B

Average Tie Life: 22 years

Tie Condition: 25% Bad in Year 17

Year	Ties Changed	1980 Cost	+5% Inflation	"Cash Flow" -10% Discount
10	1	26.08	40.46	17.16
11	2	52.16	84.96	32.75
12	2	52.16	89.21	31.27
13	3	78.24	140.51	44.77
14	8	208.64	393.41	113.97
15	17	443.36	877.85	231.14
16	32	834.56	1,734.97	415.35
17	56	1,460.48	3,188.08	693.73
Totals	121			$1,580.14

TABLE 76

BASIC MAINTENANCE COST PER YEAR - SCENARIOS 4A, 4B, 4C

Average Tie Life: 30 years

Tie Condition: 25% Bad in Year 24

Year	Ties Changed	1980 Cost	+5% Inflation	"Cash Flow" -10% Discount
15	1	26.08	51.64	13.60
16	2	52.16	108.44	25.96
17	2	52.16	113.86	24.78
18	7	182.56	418.43	82.76
19	9	234.72	564.88	101.62
20	12	312.96	790.85	129.30
21	15	391.20	1,037.97	154.24
22	27	704.16	1,961.79	265.04
23	46	1,199.68	3,509.42	430.96
4A, 4C Totals	121			$1,228.26
4B Total (Years 15 to 21)	48			$ 532.26

TABLE 77

BASIC MAINTENANCE COST PER YEAR - SCENARIO 5

Average Tie Life: 25 years

Tie Condition: 25% Bad in Year 20

Year	Ties Changed	1980 Cost	+5% Inflation	"Cash Flow" -10% Discount
12	1	26.08	44.60	15.63
13	2	52.16	93.67	29.84
14	2	52.16	98.35	28.49
15	3	78.24	154.92	40.79
16	8	208.64	443.74	103.84
17	17	443.36	967.81	210.60
18	23	599.86	1,374.88	271.95
19	40	1,043.20	2,510.57	451.65
Totals	96			$1,152.79

TABLE 78

LONG-TERM COST ANALYSIS SUMMARY
(All costs are complete per mile)

Scenario Number	Economic Life for Comparison (years)	Selective Maintenance Costs ($)	Track Renewal Costs ($)	Track Renewal Savings Without Material Credit ($)	Track Renewal Savings With Material Credit ($)	Internal Rate of Return on Track Investment (%)	
						Without Material Credit	With Material Credit
1A	34	221,900	225,800	(3,900)	18,700	7.3	*
1B	34	205,900	213,400	(7,500)	15,100	5.9	25.4
1C	36	221,900	220,200	1,700	24,300	9.9	*
2A	24	224,900	225,100	(200)	17,700	8.5	31.2
2B	24	224,900	216,800	8,100	26,000	12.1	31.8
2C	24	229,500	216,800	12,700	26,800	33.2	*
3A	15	218,000	216,400	1,600	17,200	9.6	29.3
3B	17	228,000	217,000	11,000	27,000	13.5	31.0
4A	23	278,300	280,400	(2,100)	18,400	8.2	35.2
4B	21	218,800	220,200	(1,400)	19,100	8.5	35.2
4C	23	164,800	182,700	(17,900)	2,600	3.3	10.4
5	19	314,800	314,700	100	18,000	9.4	30.4
6	40	295,600	296,200	(600)	17,300	9.3	12.6
7	40	367,200	353.700	13,500	29,500	11.0	14.1

*Rate of return cannot be calculated because of no extra cost in the first year (the rate of return is based on the differential cost incurred in the first year).

TABLE 79

POTENTIAL SAVINGS GENERATED BY TRACK RENEWAL FOR ONE SEASON'S WORK
(177 miles*)

Scenario Number	Economic Life (years)	Track Renewal Savings Without Material Credit	Track Renewal Savings With Material Credit **
1A	34	(690,300)	3,309,900
1B	34	(1,327,500)	2,672,700
1C	36	300,900	4,301,100
2A	24	(35,400)	3,132,900
2B	24	1,433,700	4,602,000
2C	24	2,247,900	4,743,600
3A	15	214,400	3,044,400
3B	17	1,947,000	4,779,000
4A	23	(371,700)	3,256,800
4B	21	(247,800)	3,380,700
4C	23	(3,168,300	460,200
5	19	17,700	3,186,000
6	40	(106,200)	3,062,100
7	40	2,389,500	5,221,500

*One season's assumed production.
**Total savings for one season's production.

TABLE 80

LONG-TERM COST ANALYSIS SUMMARY
LOW TRM PRODUCTION RATE (1,920 TIES/DAY*)
(All costs are complete per mile)

Scenario Number	Economic Life for Comparison (years)	Selective Maintenance Costs ($)	Track Renewal Costs ($)	Track Renewal Savings Without Material Credit ($)	Track Renewal Savings With Material Credit ($)
1A	34	221,900	231,600	(9,700)	12,900
1B	34	205,900	219,200	(13,300)	9,300
1C	36	221,900	225,900	(4,000)	18,600
2A	24	224,900	230,900	(6,000)	11,900
2B	24	224,900	222,500	2,400	20,300
2C	24	229,500	222,500	7,000	21,100
3A	15	218,000	222,200	(4,200)	11,800
3B	17	228,000	222,800	5,200	21,200
4A	23	278,300	286,100	(7,800)	12,700
4B	21	218,800	225,900	(7,100)	13,400
4C	23	164,800	188,500	(23,700)	(3,200)
5	19	314,800	320,400	(5,600)	12,300
6*	40	295,600	300,900	(5,300)	12,600
7*	40	367,200	358,400	8,800	24,800

*1,890 ties per day for installing concrete ties in scenarios 6 and 7.

TABLE 81

LONG-TERM COST ANALYSIS SUMMARY
HIGH TRM PRODUCTION RATE (3,840 TIES/DAY*)
(All costs are complete per mile)

Scenario Number	Economic Life for Comparison (years)	Selective Maintenance Costs ($)	Track Renewal Costs ($)	Track Renewal Savings Without Material Credit ($)	Track Renewal Savings With Material Credit ($)
1A	34	221,900	223,000	(1,100)	21,500
1B	34	205,900	210,500	(4,600)	18,000
1C	36	221,900	217,300	4,600	27,200
2A	24	224,900	222,300	2,600	20,500
2B	24	224,900	213,900	11,000	28,900
2C	24	229,500	213,900	15,600	29,700
3A	15	218,000	213,600	4,400	20,400
3B	17	228,000	214,200	13,800	29,800
4A	23	278,300	277,500	800	21,300
4B	21	218,800	217,300	1,500	22,000
4C	23	164,800	179,800	(15,000)	5,500
5	19	314,800	311,800	3,000	20,900
6*	40	295,600	293,800	1,800	19,700
7*	40	367,200	351,200	16,000	32,000

*3,990 ties per day for installing concrete ties in scenarios 6 and 7.

as indicated by the low internal rates of return for these two scenarios. This is because concrete ties cost more than wood ties, increasing the first-year cost of the track renewal alternative.

j. In comparing concrete ties that are installed by a track renewal machine to selectively maintained ties, concrete ties are more economically attractive if replacing wood ties with very short average life expectancies, like the 19-year average wood tie life in scenario 7.

k. The average production rate of the track renewal system has a major impact on long-term savings due to the track renewal method. The wood tie scenarios lose about $5,800 in savings with daily production cut one-third and gain about $2,900 with a 25-percent increase in production. The concrete tie scenarios (6 and 7) show slightly smaller losses and gains with similar changes in production. With a low production rate, the projected savings due to the track renewal method are still significant for all scenarios (except 4C) if full material credit is realized. These savings are all in the first year.

The largest portion of the long-term costs in most scenarios is the cost in the first year. The total costs for each alternative, material credits for the renewal alternative, and cost differentials are summarized in table 82, on page 78. The following findings are apparent from these first-year costs:

a. In most situations, track renewal costs more in the first year than selective maintenance, even with material credit. Without material credit, the differential is $22,600 per mile if 25 percent of the ties need to be replaced, both rails changed, and the ballast cleaned.

b. If 50 percent of the ties must be replaced, along with rail replacement, track renewal becomes more competitive in the first year, as shown by scenario 2C. Figure 19, on page 78, shows the breakeven point for first-year costs with respect to tie replacement requirements when the average tie life is 24 years and wood ties are being installed. If no material credit is taken by the track renewal alternative, track renewal and selective maintenance break even at about 56 percent tie replacement in the first year. If material credit is realized, the breakeven point is approximately 32 percent tie replacement. Figure 20, on page 79, shows the first-year breakeven point if concrete ties are installed by the track renewal method to replace wood ties with an average life of 24 years. Without material credit the breakeven point is about 90 percent replacement and with material credit it is 75 percent replacement in the first year.

c. If the average tie life of the track being renewed is long (such as the 36-year life of scenario 1A), the differential between alternatives is less than if the average tie life is short (such as the 19-year-life of scenario 3A)

TABLE 82

FIRST-YEAR COST SUMMARY
(All costs are complete per mile)

Scenario Number	Total Selective Maintenance Cost ($)	Total Track Renewal Cost ($)	Track Renewal Cost Minus Material Credit	Net Cost to Renew Track
1A	189,300	211,900	189,300	0
1B	178,200	204,300	181,700	3,500
1C	189,300	211,900	189,300	0
2A	189,300	211,900	194,000	4,700
2B	189,300	211,900	194,000	4,700
2C	207,700	211,900	197,800	(9,900)
3A	189,300	211,900	195,900	6,600
3B	189,300	211,900	195,900	6,600
4A	189,300	211,900	191,400	2,100
4B	189,300	211,900	191,400	2,100
4C	31,300	69,800	49,300	18,000
5	189,300	211,900	194,000	4,700
6	189,300	236,100	218,200	28,900
7	189,300	236,100	220,100	30,800

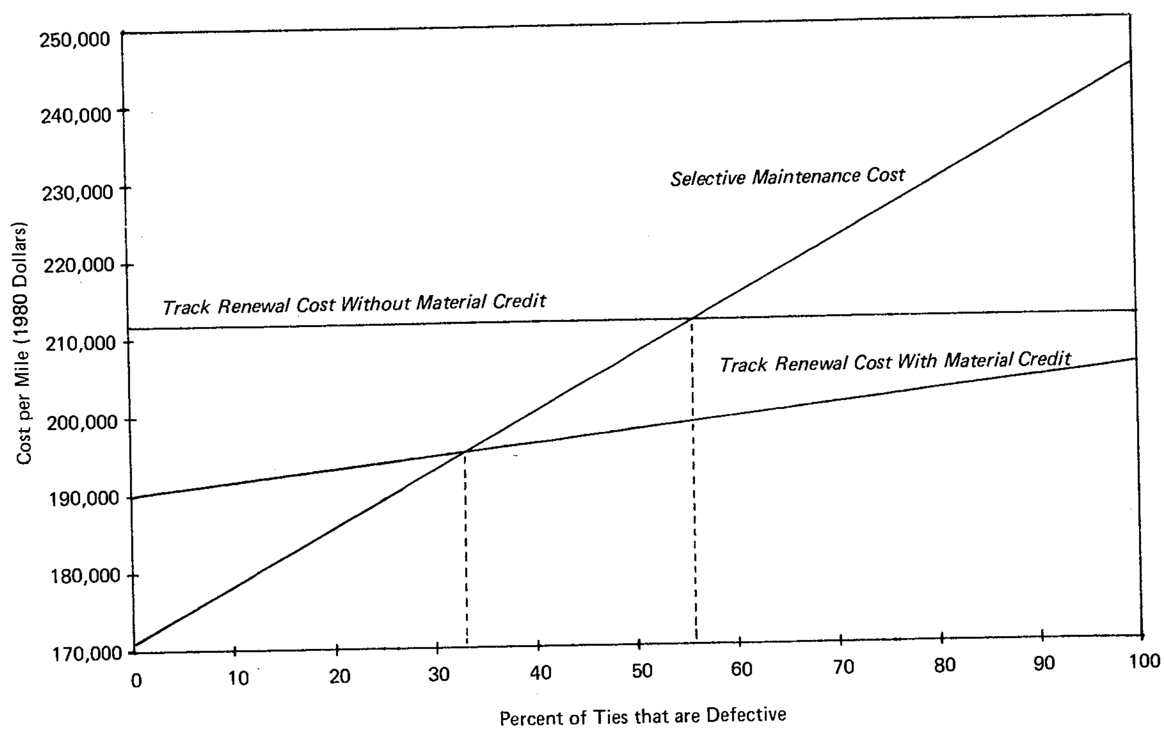


FIGURE 19. FIRST-YEAR BREAKEVEN ANALYSIS: INSTALLING WOOD TIES
(24-year average tie life)

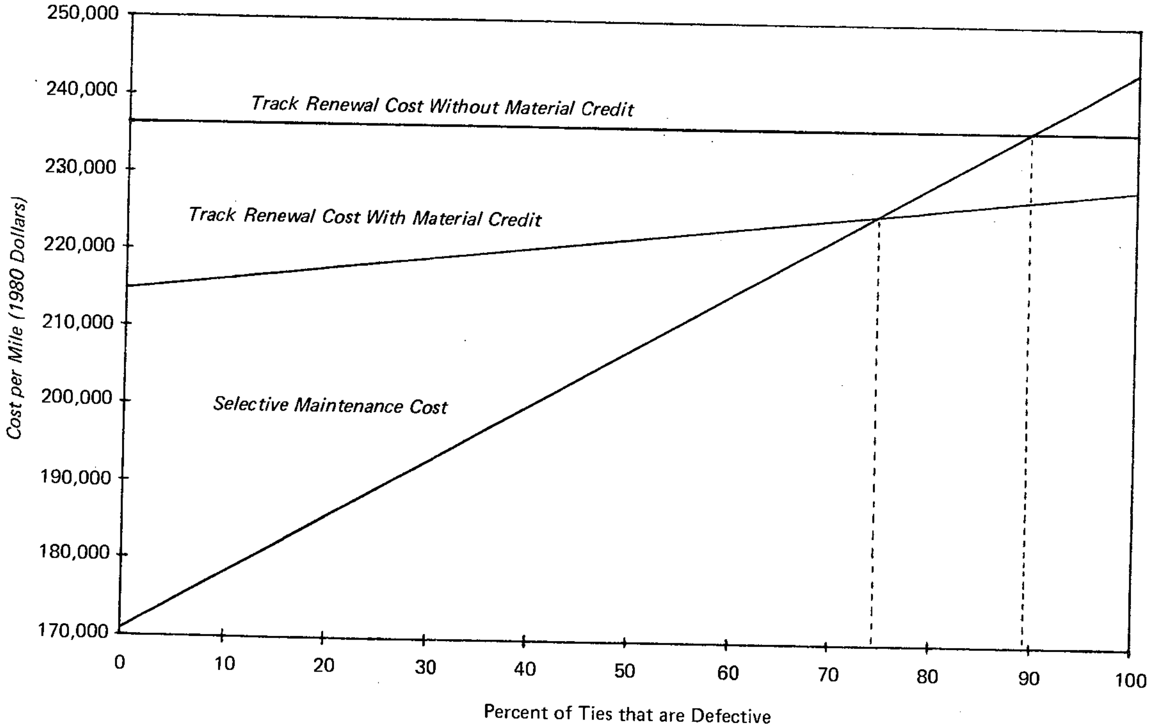


FIGURE 20. FIRST-YEAR BREAKEVEN ANALYSIS:
INSTALLING CONCRETE TIES VERSUS SELECTIVELY MAINTAINED WOOD TIES

because of the higher material credit from the reused ties. It should be noted though that this material credit will not be fully earned during the first year.

d. Ballast cleaning is cheaper when performed with track renewal than when done separately by selective maintenance, as shown in chapter II. The per-mile costs are about $13,000 for selective maintenance and $9,400 for track renewal with surfacing included, or about a 28-percent savings for track renewal ballast cleaning.

e. Installing concrete ties costs considerably more in the first year than selective maintenance, as shown in scenarios 6 and 7, even with full material credit, because of the high unit cost of the ties. Concrete ties require many years of service to pay for themselves through maintenance cost savings.

Breaking down the combined first-year costs for all operations in each alternative by type of cost provides an interesting comparison as shown below:

	Selective Maintenance	Track Renewal to Wood	Track Renewal to Concrete
Labor	$ 23,100	$ 11,200	$ 9,500
Transportation	$ 1,200	$ 4,100	$ 7,600
Capital Recovery Cost	$ 4,400	$ 5,200	$ 4,500
Equipment Maintenance	$ 6,700	$ 5,900	$ 5,500
Materials	$153,900	$185,500	$209,000
Totals	$189,300	$211,900	$236,100

As can be seen, labor costs are significantly lower for track renewal in the first year. This is due to a decrease from 218.4 man-days per mile to 98.9 man-days per mile. Material costs and transportation costs are much higher than for selective maintenance, while equipment costs (capital recovery and equipment maintenance) are approximately equal.

A separate finding of the analysis of the data is the fact that the track occupancy time required for track maintenance is reduced by the track renewal method. When the 6.5 hours per day occupancy time assumed for this study is divided by the production rates for each operation shown in chapter II, the track occupancy per mile of track is obtained. These times are totaled for a typical first year for the selective maintenance alternative below:

Operation	Production Rate (Miles per 6.5 Hours)	Occupancy Time (Hours per Mile)
Rail Gang	0.54	12.0
Tie Gang	1.00	6.5
Surface and Line	1.23	5.3
Ballast Cleaning	0.615	10.6
Total		34.4

This compares with 7.3 hours per mile for the track renewal system based on 0.886 mile per day installing wood ties. (Support gangs distributing and picking up materials are assumed to be on adjacent miles of track and therefore not adding to the track occupancy requirements.) In a direct comparison, track renewal results in a savings of 27.1 hours of track occupancy in the first year, which is a 79 percent reduction from the 34.4 hours required for the selective maintenance operations.

In scenario 2A, the selective maintenance method requires tie gangs and surface and lining gangs in years 7, 13, and 19. This would require a total of 35.4 hours of future track occupancy time per mile. The track renewal method would require surface and lining gangs in years 7, 13, and 19 (15.9 hours) and a tie gang in year 21 (6.5 hours), for a total of 22.4 hours. Therefore, the track renewal method results in an additional savings of 13.0 hours in future years and a total of 40.1 hours over the renewal cycle. Scenarios in which the track renewal method does not need a mechanized tie gang during the renewal cycle would experience larger long-term savings in occupancy time.

Several factors that would affect overall costs to the railroad were not considered in this analysis, primarily because they are difficult to quantify. These factors include the following:

a. No absenteeism costs were included in the study. With a smaller labor requirement than the selective maintenance operations it would replace, a track renewal system may provide overall savings in this area.

b. A track renewal system can operate effectively at night. The Canadian National TRS frequently works at night to utilize the most advantageous window in train operations.

c. With enclosed operator stations, some TRM's can work during inclement weather, thereby being able to improve their overall seasonal production.

IV. TRACK RENEWAL MACHINE TECHNOLOGY AND APPLICATIONS

As of mid-1980, there are 600 to 650 track renewal machines (TRM's) currently operational throughout the world. Most of them are being used to renew track in European countries. Only five of them are being used in North America -- one by Amtrak in the Northeast Corridor, one by Canadian National Railways, and three by the National Railways of Mexico.

To understand the full potential of the track renewal concept in North America, it is useful to consider TRM design and application on a worldwide basis. Accordingly, this chapter presents summary information on the major designs, principal applications, and future trends in track renewal machine technology worldwide, as viewed from a North American perspective.

1. Track Renewal Machine Designs

The 600 to 650 TRM's now in use represent more than 30 different models, each of which is derived from one of seven basic designs. The following brief descriptions cover these seven basic designs.

A. Single Machine - Rail-Mounted

The single machine is a large unit (often referred to as a train) that rides on the track with the renewal equipment suspended from a support beam that is supported by a power car at one end and a tie exchange car at the other end.

The front of the machine (tie exchange car) rides on the old track while the rear of the machine (the power car) rides on the new track. An example of this type of machine is the Canron P-811 machine which was developed by an Italian track renewal contractor, Valditerra Construction Company, in conjunction with the Matisa Corporation, a subsidiary of Canron. The P-811 is shown in figure 21. Coupled to the tie exchange car of the P-811 is a group of special-purpose flat cars which are used for holding and transporting new and old ties. These tie cars are outfitted with side rails which support a portal gantry crane which picks up groups of ties and moves them from the tie cars to the tie exchange car and moves groups of used ties from the tie exchange car back to the tie cars. Connecting rails between the tie cars allow the gantry to travel the full length of the tie cars. The tie exchange car contains conveyor belts for transporting new ties to the tie laying device and transporting old ties from the tie pickup device to an accumulator where they can be handled by the gantry crane.

Attached to the machine's supporting beam are roller guides for both the old and new rail. The old rail is guided off of the old ties in front of the tie pickup mechanism and is left beside the track. The ties are picked up by a rotating drum mechanism. The drum has teeth at intervals of about 90 degrees which hook each tie and push it against a curved guide so that the tie moves over the top of the drum and falls onto the conveyor belt, where it is carried up to the accumulator for pickup by the gantry.

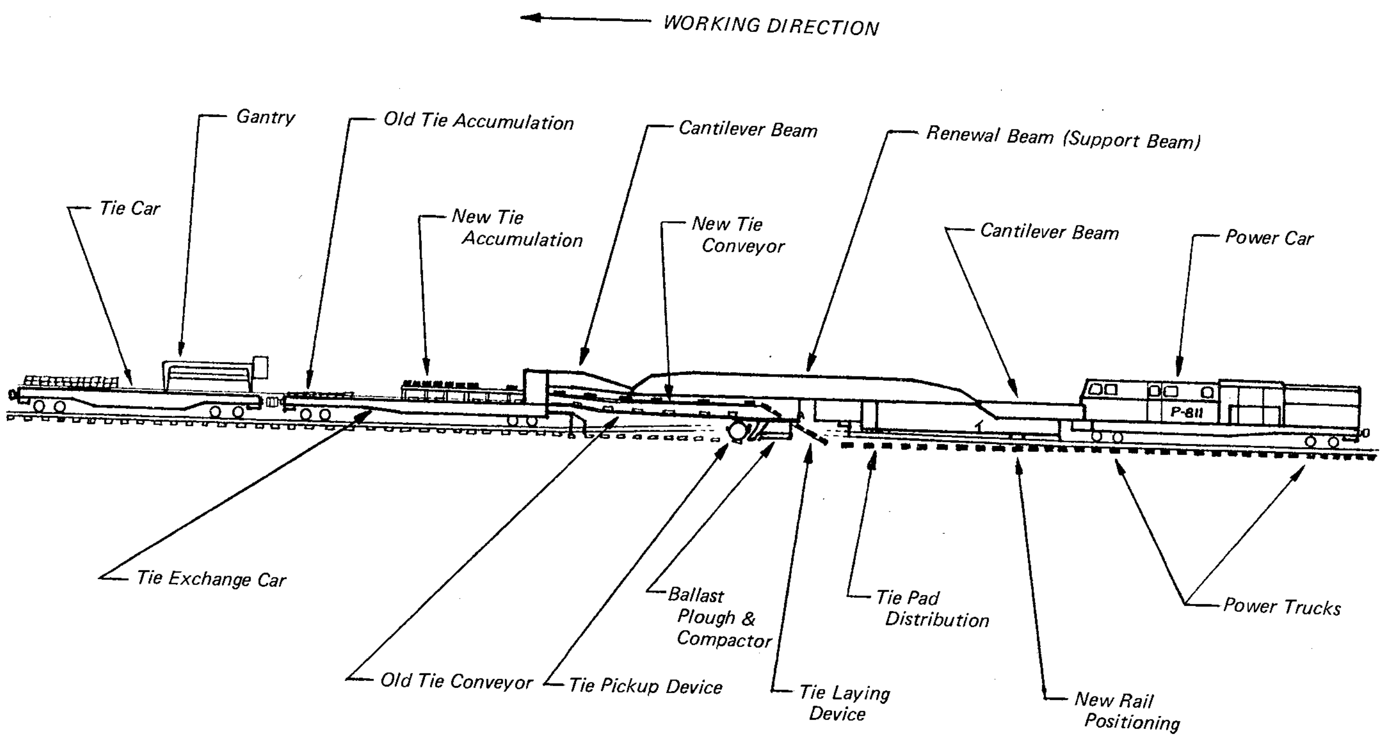


FIGURE 21. CANRON P-811 TRACK RENEWAL MACHINE

After the old ties are removed, the ballast is plowed and compacted and the new ties are laid in place. A mechanism automatically releases the new ties, one at a time, onto the roadbed at any spacing set by the machine operator.

The new rail, having previously been laid beside the track is guided onto the track so that it is placed on the new ties behind a work station where tie pads or plates are manually laid on the new ties. If new rail is not required, the old rail can be replaced.

The power car is equipped with a diesel engine to provide power to the unit and contains controls and monitoring instruments for operating the train. Other controls are located at various work stations along the machine in order to stop the operation in response to any special problems encountered, such as a cross-tie becoming jammed in the pickup mechanism.

The P-811 is self-propelled by two hydrostatically driven trucks. It has a maximum working speed of 1,000 meters per hour. For travel to and from the job site, the work stations suspended from the beam are raised and the train can either move at low speed under its own power or can be pulled at higher speeds by a locomotive. The P-811 costs approximately $1.9 million.

Another single train machine is the Plasser & Theurer SUM 1000 track renewal machine, shown in figure 22. This machine is similar to the Canron P-811 in form and function. The main difference is in the tie pickup mechanism and in the tie placement technique. Whereas the P-811 uses a rotating drum machine to pick up old ties, the SUM 1000 uses a two-pronged forklift which is inserted beneath the tie and lifts it up onto the conveyor belt for transport to the gantry. Similarly, this Plasser & Theurer machine uses another forklift mechanism to place the new ties on the roadbed. The first machine of this type is under construction for the Tanzania Zambia Railway. This machine currently costs approximately $1.5 million.

B. Single Machine - Combined Rail Crawler

This type of machine is similar to the single machine - rail-mounted, except that either one end or the middle of the machine is supported by a crawler while the machine is in operation. These machines travel to the work site on two-axle trucks. After the first ties are removed, either the end or the middle of the machine is supported by a crawler traveling on the ballast. At the present time there are five types of machines in this category.

The Plasser & Theurer SUZ 500LS removes the old rail and ties, levels the ballast, and installs new ties. The new rail or, if desired, the old rail is placed on the ties by means of a separate rail threading machine.

The Plasser & Theurer SUZ 500J is similar to the SUZ 500LS, except the old track is removed in 20-meter-long panels. The panel method has an advantage in track removal speed, but is satisfactory only for track with positive fastenings or in relatively good condition with nonstaggered joints. Rollers at the rear end of the train direct the new rail into the tie plate of the new ties.

The Plasser & Theurer SVZ 800 machine is similar to the 500-series, except that it is designed for laying new track only. The SUZ 500LS, SUZ 500J, and SVZ 800 are shown in schematic form in figure 23 on the following page.

The Plasser & Theurer SMD 80, the latest model machine in this category, removes the old rail and ties separately. The new ties are laid and the new rail or, if desired, used rail is placed on the tie plates by a separate threading machine.

The Canron P-811S is, in principle, similar to the P-811 except that the need for the cantilever arrangement has been eliminated by the supporting of the equipment support beam by a skid that rides on top of the tie plates. This has shortened the machine considerably and has permitted a reduction in operating manpower and reduced setup and cleanup time, as well as permitting rebuilding of curved track as sharp as 11 degrees.

These machines currently cost $1.5 to $2.5 million each.

C. Double Train Machine

Another concept of track renewal machine is embodied in the double train system, the only existing design being the Plasser & Theurer SUZ 350, shown in figure 24. This machine was developed from the first continuous production machine, the SUZ 2000, built for the German Federal Railway in 1968. The SUZ 2000 has since been scrapped. In this case, the operation of

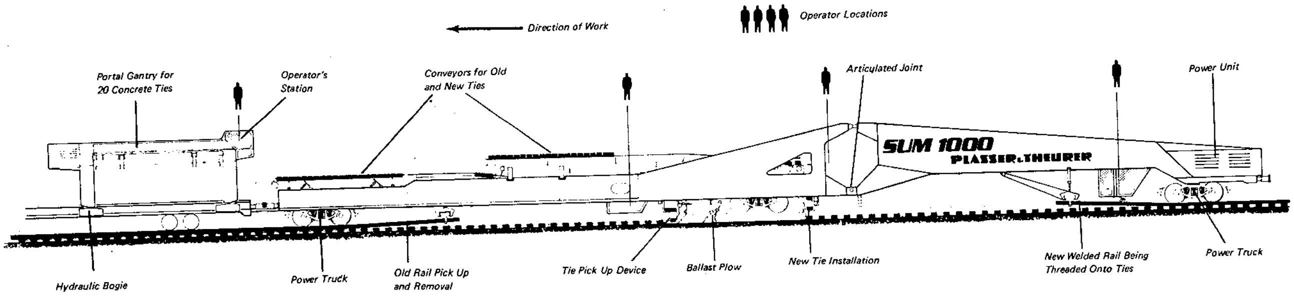


FIGURE 22. PLASSER & THEURER SUM 1000

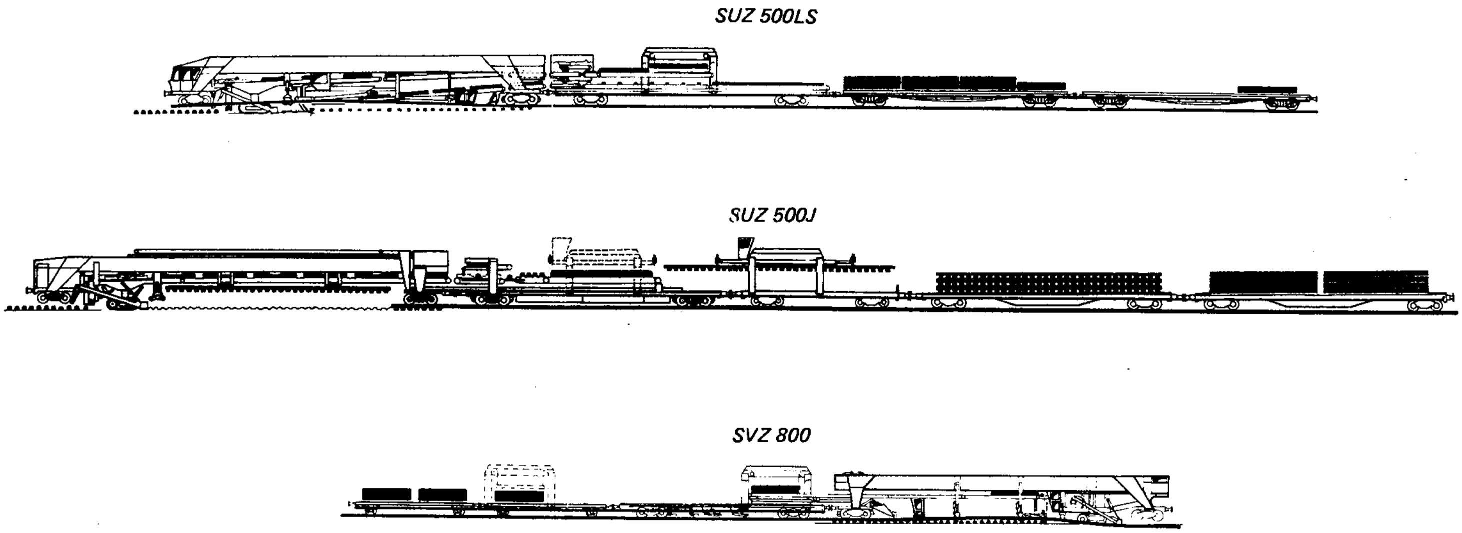


FIGURE 23. PLASSER & THEURER SUZ 500LS, SUZ 500J, AND SVZ 800

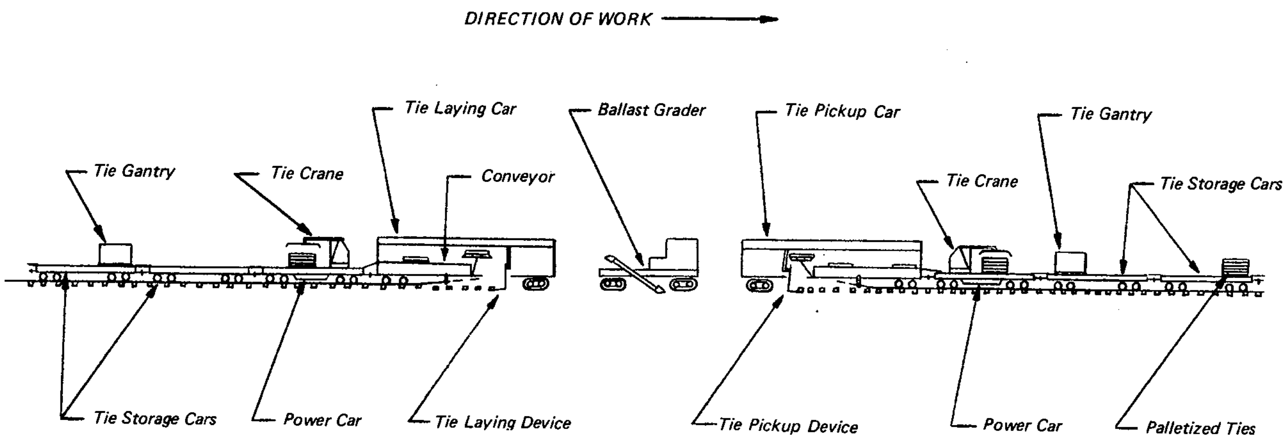


FIGURE 24. PLASSER & THEURER SUZ 350

picking up old rail and ties is separated from the operation of installing new ties and rail. Instead of each entire machine being supported on the rails, one end of each machine rides on crawlers. In between the two machines a ballast grader prepares the roadbed for the placement of the new ties. The grader follows the tie removal unit at a distance of 5 to 20 meters.

The tie pickup mechanism and the tie placement mechanism are both forklift type mechanisms like those of the SUZ 500 and SUM 1000. The old and new rails are exchanged through a system of roller guides similar to those on the P-811. However, on the SUZ 350, the old rail is guided to rest between the rails on the new track.

The SUZ 350 also incorporates a work station in the track removal section for the pickup of old fasteners (which are loosened separately in front of the train) and a work station in the track laying section for the applying and tightening of new fasteners. The work stations are located beneath the machines so that the workers can remain comfortably seated while working in all kinds of weather.

Since it is two separate machines, the SUZ 350 is capable of also removing track or significantly changing track alignment by using each unit separately. In addition, since the two machines can be separated by any distance, complete rebuilding of the roadbed, rather than simple grading, can be carried out between the machines. This machine currently costs approximately $2.5 million.

D. Gantry Crane System (Auxiliary Rails)

The most common system at this time is the gantry crane system. There are some 200 to 300 gantries presently being used in various parts of the world. The method was originally developed in the 1920's. With the gantry system (a typical gantry system is shown in figure 25), new rail is laid beside the old track. The ballast shoulder is then plowed level to permit the rail positioning machine to set the new rail to a gage of 10 feet, 9 inches, on the shoulder. This gage varies somewhat, depending on machine design and usage. Small adjustments in alignment are possible by moving the new rail alignment relative to the track. The gantry is used to pick up the old track in

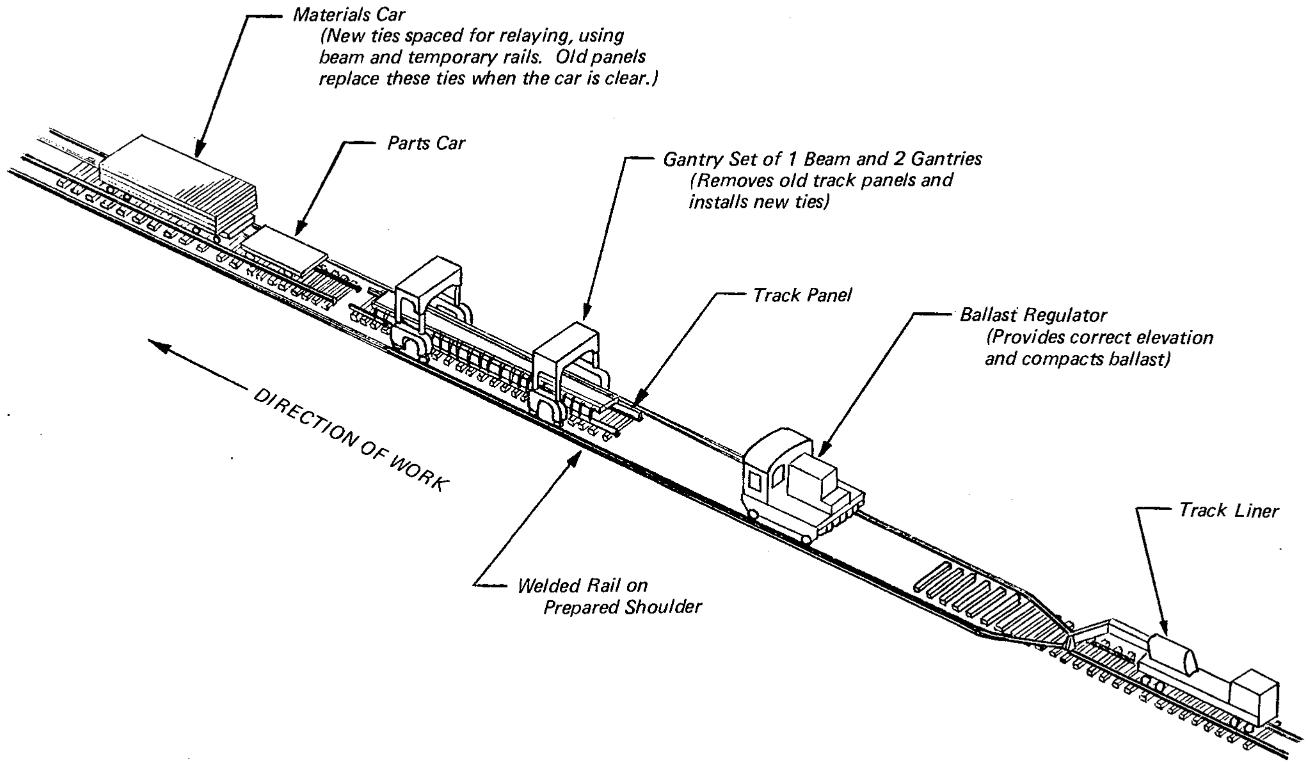


FIGURE 25. RMC/SECMAFER GANTRY SET

panels up to 20 meters long and place them on a flat car for transportation to a track panel facility. In Europe, most jointed rail is built so that joints are located opposite each other and the track is already in convenient panels. For welded rail, or rail with staggered joints, the track must be cut to create panels. The panel is picked up by clamping either the rails or the ties, depending on the design of the machine.

After the old track has been removed, a ballast regulator, which rides on the same rails as the gantries, smooths and dresses the roadbed. After the regulator vacates the work area, the gantry crane picks up a new panel of track or ties from the storage cars and places it in position on the roadbed. Depending on the design of the machine, the gantry may pick up the ties as a unit by grasping the ends of each tie, by clasping the tie plates or, in a few cases, the ties may be held together by rails which are clamped by the gantry. If the gantry lays ties, the new rails (the gantry rails) are positioned on the tie plates by a rail threader. If the new track is laid in panels, it is usual to later replace the rail with new welded rail. Production rates range from 300 to 400 feet per hour, although production can be increased 40 to 50 percent by using two gantries in tandem.

At least 10 different manufacturers produce this type of machine. Among the machines, there are minor variations in the method of operating the system. For example, the Polish State Railways (PKR) use a system of gantry cranes moving along the track on the new rails positioned aside the existing track with a gage of 3,020 millimeters. Flat cars with rails of the same gage are connected to the new rails by a 1:42 ramp. Gantries pick up one panel and carry it onto the flat car. These gantries lay single ties.

Due to their restricted clearance diagram, the Swiss Railways have developed a hybrid gantry system called the Puma system. It avoids outside rails by having the gantry cranes run on rails atop the flat cars. One special car permits the picking up of panels through a 19-meter-long open gap in its deck. Individual ties are laid through the gap, while the rear end of the special car rests on the preplaced rails on the ballast shoulder, which afterwards becomes the running rails.

The gantry system is simpler and costs less to purchase than the single and double train systems, but it also requires more operations; such as rail cutting. Also, it is normally used only on track that either has positive fastenings or is in relatively good condition. The gantry cranes currently cost between $250,000 and $750,000 each.

E. Gantry Crane System (Track-Mounted)

A concept similar to the gantry crane system described above, but much smaller, is a method developed in the 1950's by the Swedish State Railways. The shoulder ballast is first leveled to create an even work surface. Then long panels, 120 to 400 feet long, are lifted approximately 2 feet by a number of small track lifters as shown in figure 26. Light rail auxiliary track is then pulled under the lifted panel. A number of small trollies are rolled under the panel and the panel is then lowered onto them. The panel is then towed to a temporary dismantling location. The hydraulic lifters are then placed on a panel of new track and by means of the small trollies, the new panel is towed to the site. The panel is lifted, the trollies and auxiliary track are removed, and the panel is installed.

While there are few equipment requirements for this method of track renewal, the need for an on-track assembly and disassembly area limits its use to tight clearance locations such as tunnels, stations, and yard approaches.

There are three manufacturers of this type of equipment. However, the Geismar equipment is primarily designed to replace switches and has the ability to move laterally to the track. The panel track gantry cranes of this type cost between $200,000 and $900,000.

F. Panel Track System

The principle of operation of the panel track system has been known for years; machines utilizing this principle were used to build track in the United States in the late 1800's. In the late 1950's the Soviet Railways used the same principle to develop what is now called the Platov track panel laying machine.

The system consists of two identical trains. These trains consist of a number of special flat cars for the transportation of track panels (usually 6 per car) and an engine car to provide power for winching the track panels to and from the panel crane, which is shown in figure 27.

The worn track is cut into panels, picked up by the crane, and stacked on the car behind. When the maximum number of panels is accumulated, the panels are winched back along the series of flat cars. Similarly, for installing new track, the stack of panels is pulled beneath the crane and removed one by one and placed on the roadbed.

If continuously welded rail is desired, the panel rails must be removed and continuously welded rail relaid on the ties. The rail panels can be welded together by an in-track welding machine, but this method is generally

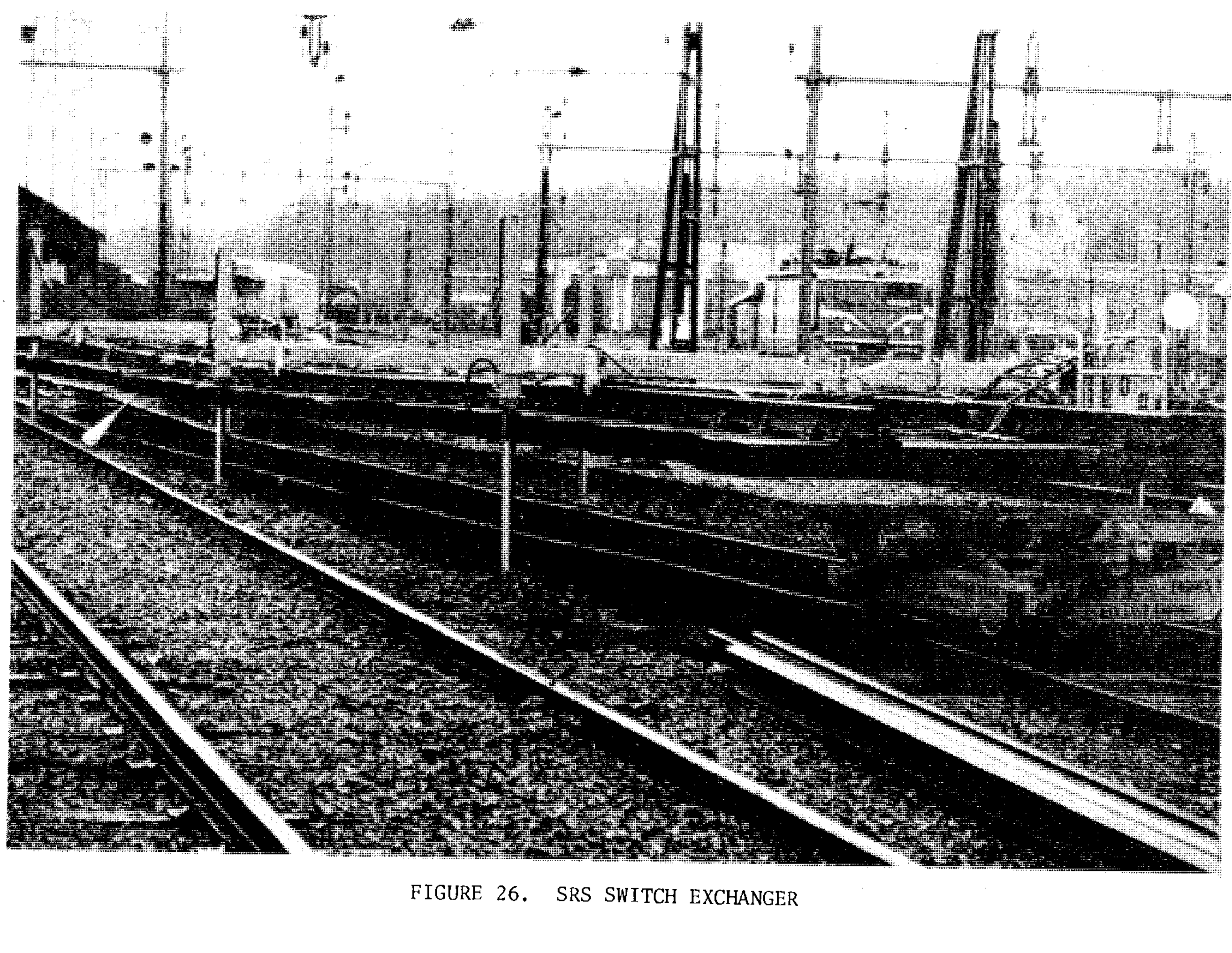


FIGURE 26. SRS SWITCH EXCHANGER

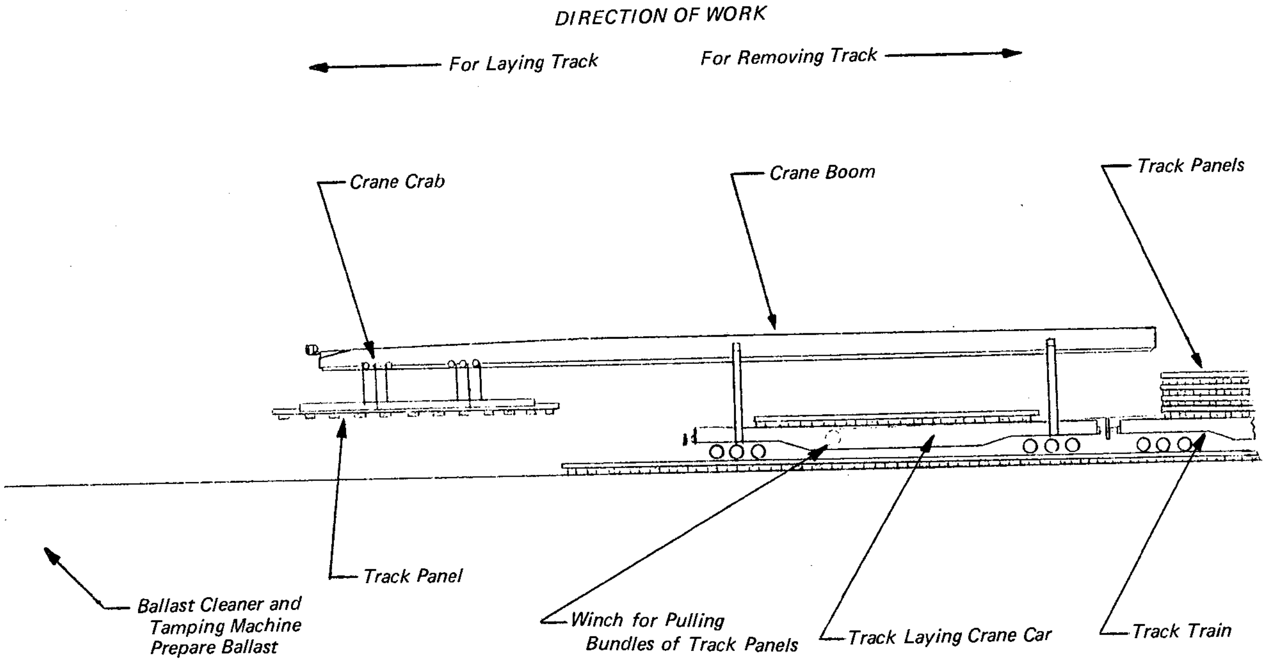


FIGURE 27. PLATOV TRACK PANEL LAYING MACHINE

used only on track in relatively light service. The space between the track removal and the track placement machines is available for roadbed operations, such as ballast cleaning, grading, as required.

There are at least six separate types of machines of this design from three different manufacturers presently in use. The Niemag machine was developed in the 1930's and used by the German Federal Railway extensively until the early 1970's when it was considered too slow. In addition to machines for rebuilding primary tracks, Plasser manufactures a panel laying system that includes a flash butt welding machine and is used for constructing new low-density track. Platov offers at least three models suited to different track conditions. A complete panel track system currently costs $1-1.5 million.

G. Twin Boom Crane System

In multi-track territory, when the track renewal operation can utilize two tracks, the simplest mechanized method is possible. The twin boom crane is essentially a rail-mounted crane having two booms or jibs, as shown in figure 28. A locomotive-hauled train of an empty flat car and cars with new panel track is stationed on the track to be renewed while the twin boom crane, operating from the adjacent track, removes and replaces the track in panels. As with any panel method of track removal, it is primarily suited to positive fastening track or spiked tie track in relatively good condition.

This method is possible under very tight clearance restrictions and utilizes equipment that can be used for other track maintenance purposes. For these reasons, this method is very popular on British Railways.

This method of track renewal is actually possible with single boom rail-mounted cranes, but is simplified with the use of twin boom cranes. At present there are at least seven manufacturers of these cranes worldwide. The cranes can also be used for other track maintenance purposes such as bridge repair and switch replacement. A twin boom crane currently costs approximately $1 million.

A summary of track renewal machines currently in use or under construction is shown in table 83, on pages 88 and 89. It shows the manufacturer, number in use and where used, possible applications, crew size, and production capacity.

2. Track Renewal Machine Applications

Track renewal machines and support equipment are capable of removing ties, rails, and OTM from the roadbed and installing new or reconditioned ties, rails, and OTM on the roadbed. This study has focused on the use of TRM's as tools for the long-term maintenance of track. However, there are also specialized applications for which some TRM's are suitable. Each track renewal machine design shown in the equipment summary in table 83 shows the possible applications discussed below.

The two principal specialized applications are as follows:

a. Abandon track. Several types of TRM's are well-suited for track abandonment in that they normally operate in such a way that they remove the ties, rails, and OTM quite independently from laying track. A few other machines remove and install track continuously, but do not have to lay track as they proceed. Several thousand miles of track are abandoned in the United States each

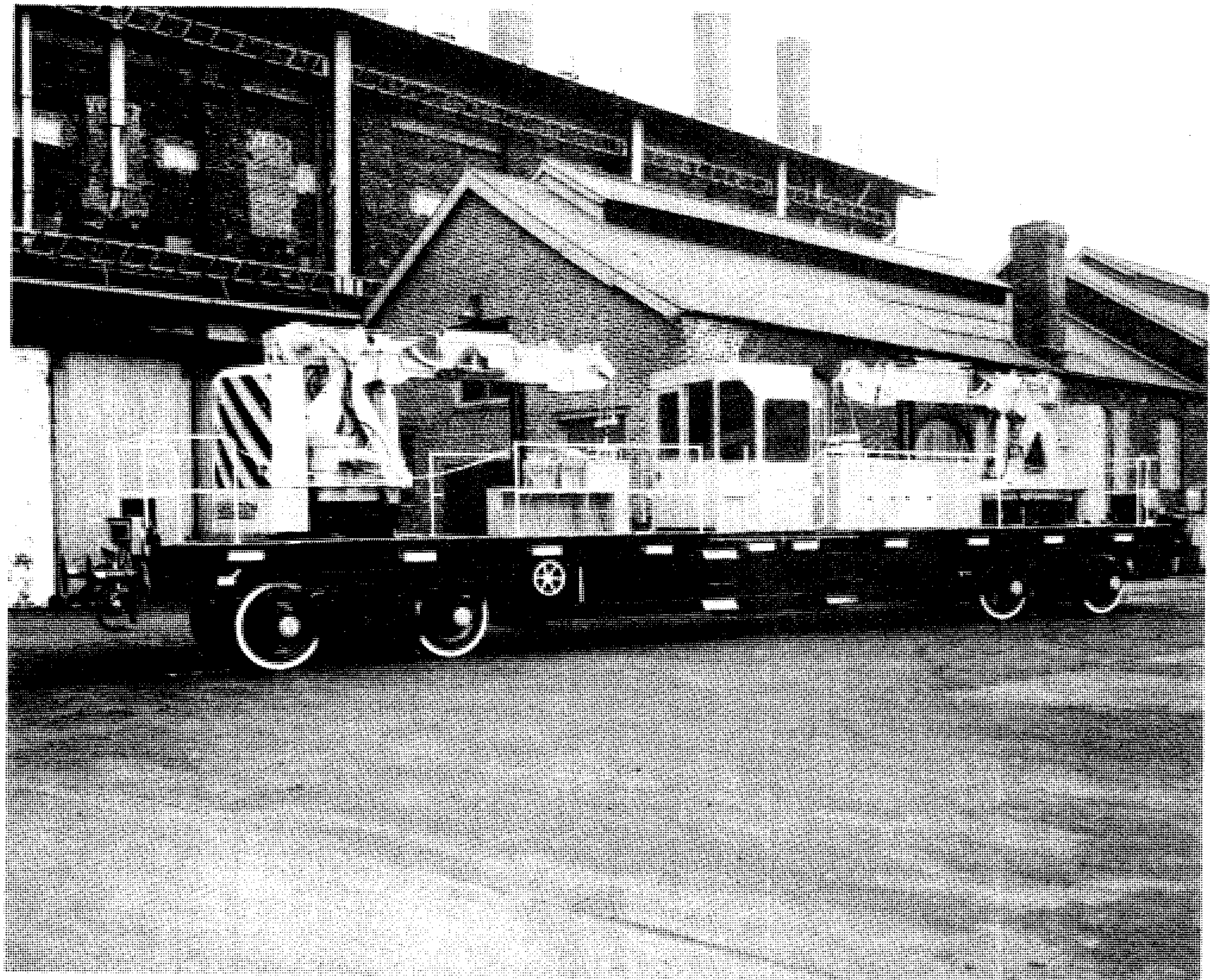


FIGURE 28. COWAN-SHELDON TWIN BOOM CRANE

year, thereby providing a significant potential market for TRM's.

b. Construct new track. Several types of TRM's are capable of building new track, with some models designed specifically for new construction. With the limited amount of new track construction in the United States (mostly in coal fields and new rapid transit lines), the U.S. demand for this application is likely to be limited.

Side benefits from the 100-percent track renewal process include the feasibility of changing one or more specific characteristics of the existing track structure in one pass. In some cases, the need for these changes would make use of the track renewal machine very attractive, irrespective of the economics of track renewal. These side benefit applications are discussed in the following paragraphs.

a. Major realignment of track. Most of the TRM's can change the track alignment several inches laterally and/or vertically while performing the renewal operation. Some designs can act in combined track abandonment--new track construction, which describes major track realignments that may range from as little as 5 feet to completely different routings and grades.

b. Conversion from wood to concrete ties. The first and only TRM application to date in North America has been for this purpose and is discussed in detail in other parts of this report.

c. Change in track class or design. A railroad that varies tie spacing for different classes of track may find a need to convert the spacing if the traffic pattern changes dramatically, as it would if unit coal trains began to be routed over a branch line previously used to serve small agricultural shippers. In the same context, major upgrading of a track is possible in one pass. Because the full renewal process can replace the entire track structure, it is feasible to change rail weight, tie type or size, tie plate and fastener type, ballast type, or any combination of these components.

3. Future Trends in TRM Technology

The panel replacement method of track renewal has progressed over the years to a variety of efficient machines designed for specific applications. The more recent continuous renewal method began with the separate track removal and track laying machines of the Plasser & Theurer SUZ 350 and has evolved into smaller, faster, and more efficient single machines designs. It appears that the panel

TABLE 83

A SURVEY OF TRACK RENEWAL EQUIPMENT

Machine Type	Manufacturer	Model Designation	Number in Use	Where Used*	Applications	Approximate Crew Size** Machine	System	Production Range*** (track feet per hour)
Single Machine — Rail-Mounted	Canron (Matisa)	P-811	9	AMTK, CNR, FS, HIR, SNCB, WAR	Replaces all ties and rail (if required).	7	50–120	600–2,000
	Plasser & Theurer	SUM 1000	1	TZR	Replaces all ties and rail (if required).	4	Not Available	1,000–2,000
Single Machine — Combined Rail Crawler	Plasser & Theurer	SUZ 500LS	2	SNCF	Replaces all ties and rail (if required). Can be used to abandon track.	6	60–150	1,400–1,600
	Plasser & Theurer	SUZ 500J	3	DB	Removes track in panels and replaces ties and rail.	5	60–150	600–1,400
	Plasser & Theurer	SVZ 800	0	----	Lays new track only.	4	Not Available	Up to 2,000
	Plasser & Theurer	SMD 80	1	SNCF	Replaces all ties. New or original rail reinstalled by separate machine.	6	150	Up to 2,000
	Canron (Matisa)	P-811S	1	FS	Replaces all ties and rail (if required).	5	50	800–2,000
Two Train System	Plasser & Theurer	SUZ 350	4	DB, OBB	Replaces all ties and rail (if required). Can be used to abandon track; lay new track; or rebuild track to totally new alignment. Permits work on ballast and subgrade.	25	60–120	800–1,600
Gantry Crane System (Auxiliary Rails) Note: When two machines are used in tandem, production is increased 40 to 50 percent.	Arneke	---	5	BR, OBB	Removes and replaces track in panels.	Not Available		Not Available
	Donnelli	---	?	DB, FS, NS, SNCF	Removes track in panels. New track replaced in panels or ties only.	Not Available		Up to 250
	Geismar	MD 10	200 to 300	BR, NS, SBB, SNCF	Removes track in panels. New track replaced in panels or ties only.	4	100	350–900
	Matisa	---	?	DB, SNCF	Removes track in panels. New track replaced in panels or ties only.	Not Available		Up to 250
	Plasser & Theurer	SUZ 20001	6	IR	Removes track in panels. Ties laid singly by separate machine.	30	40	Up to 400
	Pluto	---	?	SNCF	Removes track in panels. New track replaced in panels or ties only.	Not Available		650– 950
	Not Available	---	?	PKP	Removes and replaces track in panels.	Not Available	65	Up to 400

TABLE 83 (Continued)

Machine Type	Manufacturer	Model Designation	Number in Use	Where Used*	Applications	Approximate Crew Size** Machine	System	Production Range*** (track feet per hour)
Gantry Crane System (Auxiliary Rails) – Continued	Not Available	Puma	?	SBB	Removes and replaces track in panels under severe clearance restrictions.	—	—	Not Available
	Robel	48.32	3	DB, PR	Removes track in panels. New track replaced in panels or ties only.	4	Not Available	Up to 350
	Secmafer	M6, M8, M9	?	BR, FcNM, SNCB, SNCF	Removes track in panels. New track replaced in panels or ties only.	—	—	Not Available
Gantry Crane System (Track-Mounted)	Karlsruhe	—	?	DB, NS	Removal and replacement of up to 400-foot panels.	10	92	260–300
	Swedish Rail System	—	?	AMTK, SJ	Removes and replaces switches or other track in panels of up to 150-foot lengths.	19	49	Not Available
	Geismar	—	?	AMTK, DB, SNCF	Removes and replaces switches in panels of up to 400-foot lengths.	7	30	4 to 8 hours per switch
Panel Track System	Niemag	—	?	DB	Removes or lays track in panels.	3	60	Up to 250
	Plasser & Theurer	JVK 1200	1	BKV	Removes or lays track in panels.	3	50–70	Up to 200
	Plasser & Theurer	JVK 1802	?	—	Removes or lays track in panels.	6	Not Available	Up to 800
	Plasser & Theurer	WAPS	1	—	Lays track in panels. Panels welded with flash butt welder.	5	Not Available	Up to 250
	Platov	YK 25, YK 25/9 YK 25/21	350+ ****	CSD, DR, FcNC, MAV, SZD	Removes or lays track in panels.	6	30–160	Up to 1,300
Twin Boom Crane System (Double Track Required)	Plasser & Theurer	TJC 60	?	—	Removes and replaces track in panels.	—	—	Not Available
	Cowan-Sheldon, Thomas Smith, and others		46	BR	Removes and replaces track in panels.	—	—	Not Available

*Railroad Code: AMTK – Amtrak; BKV – Budapest Transportation System; BR – British Rail; CNR – Canadian National Railways; CSD – Czechoslovak State Railways; DB – German Federal Railway; DR – German State Railways; FcNC – Cuban National Railways; FcNM – National Railways of Mexico; FS – Italian State Railways; HIR – Hammersley Railways; IR – Indian Government Railways; MAV – Hungarian State Railways; NS – Netherland State Railway; OBB – Austrian Federal Railway; PKP – Polish State Railways; PR – Pakistan Railway; SBB – Swiss Federal Railway; SJ – Swedish State Railways; SCNB – Belgian National Railways; SCNF – French National Railways; SZD – Soviet Railways; TZR – Tanzania Zambia Railway

**Crew size varies with track condition and location, safety requirements, mechanization of support operations, and other factors.

***Production rate is affected by track condition and location, possession time, crew size and experience, planning effectiveness, and other factors.

****These machines usually work in pairs for track renewal.

and continuous methods will both continue to improve with faster and more efficient machines. But the currently faster continuous machines will probably have the most improvements.

None of the track renewal machines presently in use are designed specifically for the North American market. North American applications allow a larger clearance diagram and higher permissible axle loads, which can lead to simplification of the required operations, as well as allow more operations to be performed by the track renewal machine itself. Simplification would improve machine availability and reduce the crew size.

The major manufacturers have begun designing machine components for installing wood ties with cut spike fastenings. Most of the technology required already exists on other machines, such as the Canron rail changeout machine and the Plasser automatic power wrench. An efficient North American continuous track renewal machine, capable of removing and installing all track components with minimal support, is possible within 5 years or less according to the major manufacturers. The systems will have a maximum production capacity of approximately 3,000 feet per hour (1,846 wood ties installed at 19.5-inch centers) and should be able to average about 2,000 feet per hour (1,230 wood ties installed) during operating times. The Canron P-811 owned by Canadian National Railways operated at 2,640 feet per hour during a short test in 1979. While that machine could not sustain such a pace for more than an hour, it showed that a high production rate should be attainable.

The on-track equipment and labor, as well as support operations, for an Americanized track renewal system built around a continuous renewal single machine installing wood ties with cut spike fastenings, is shown in figure 29. It should be noted that the total crew required is approximately 50 percent of the crew shown for the Canron P-811 based system as shown in chapter II.

The system shown in figure 29 has only one ballast undercutter-cleaner to keep up with a TRM rebuilding track at 2,000 feet per hour. At the present time, the largest ballast undercutter-cleaners are capable of 1,200 feet per hour production rates, undercutting to a depth of 10 inches. Research is currently going into the development of higher capacity machines. It is possible to use two ballast cleaners to achieve a higher production level to keep up with a high-speed TRM.

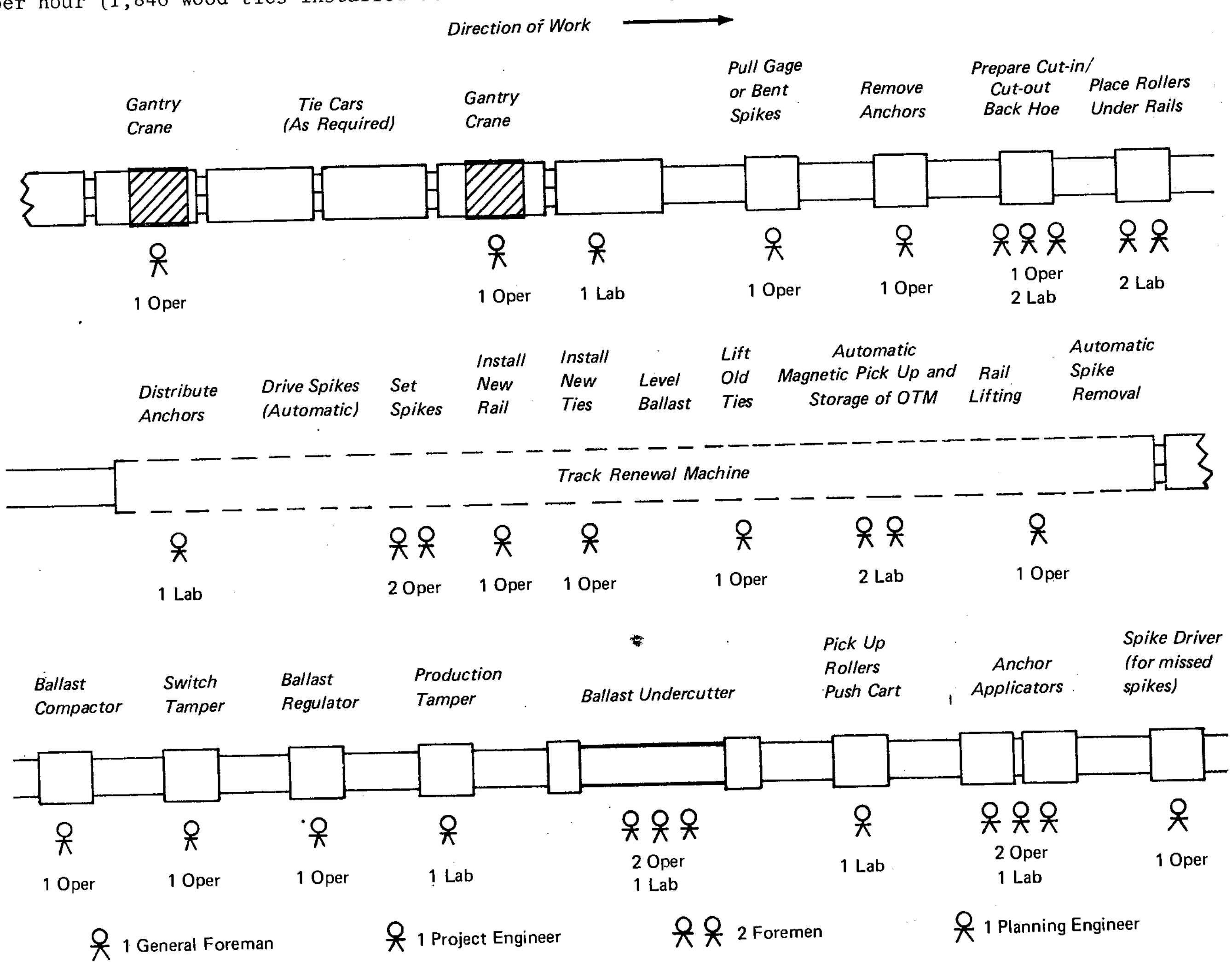


FIGURE 29. FUTURE TRACK RENEWAL GANG INSTALLING WOOD TIES
(Average production rate 2,000 feet per hour)

V. TRACK RENEWAL MACHINE OWNERSHIP ALTERNATIVES

In preceding chapters, this report has explored the operation and economic implications of the track renewal method with respect to railroad ownership and operation. There are two other alternatives which will be discussed in this chapter: railroad leasing and operation and contractor ownership and operation of the equipment.

In the event that the track renewal method of track maintenance catches on in the United States, or track renewal machines are used to rebuild much of the track in need of major rehabilitation, there would be a large potential market for these machines. Railroad track maintenance consultant David R. Burns has estimated that a total potential North American market of approximately 50 track renewal machines would exist with full conversion to the track renewal method. About 40 of these machines could be operated by those individual railroads that are large enough (about 4,000 to 6,000 miles of track) to keep such machines busy over the machines' useful lifetimes. The remaining market would be for renewing trackage owned by smaller railroads and would require joint ownership, leasing, or contractor operation. Since some of the large railroads may prefer to use contractor services instead of their own machines, the possible market for contractors is more than 10 machines.

The difference between potential and actual demand will be affected by both the level of acceptance of the track renewal method for track maintenance and the economics for each railroad.

Ownership alternatives are discussed, with advantages and disadvantages, in the following sections.

1. Railroad Ownership and Operation

The major railroads have traditionally owned, or leased from banks and other investors, nearly all track maintenance equipment and operated this equipment with their own personnel. This approach is natural for equipment that will be fully utilized by a single railroad over the machine's life. Long-term equipment costs are less with outright ownership than by leasing for short periods. The railroad that owns track renewal equipment has full control over the scheduling of track renewal and can modify the equipment to fit specific needs.

As shown in chapter III, a railroad can save several million dollars a year by owning and operating track renewal machines to replace selective maintenance operations under a variety of conditions. But to realize such savings requires a long-term commitment to the track renewal method. Such a commitment entails some risk in that the method is new to North American conditions and the equipment is not yet tailored for cut spike track and American ballast conditions. Further, the life of the track structure under renewal conditions has not been studied.

The high turnover rate of track maintenance personnel and the difficulty in moving a trained force of supervisors, mechanics, and operators over a rail system would tend to keep a railroad track renewal system crew in a constant learning state that would keep down productivity. However, the track renewal method of track maintenance requires a smaller crew than the selective maintenance methods it would replace and the railroad could afford to pay premium wages to the 10 to 15 key operating personnel needed to keep the system operating properly.

Railroads with short work seasons and small railroads cannot utilize track renewal machines fully. Even if they can afford to purchase a machine and can justify it economically, some other alternative may be preferable.

2. Railroad Lease and Operation

A railroad that cannot fully utilize a track renewal machine but which can justify the track renewal method may prefer to lease a machine for a short term. Such an arrangement would allow northern railroads and short line railroads to use the method without having to justify the full equipment cost. The arrangement could be made by a northern railroad owning a machine and leasing it to a southern railroad during the winter season. Or the machine could be owned by a third party in a manner similar to private rail freight car ownership and leasing.

The risk to the railroad leasing the equipment would be minimized in that it does not have any money tied up in the expensive track renewal machine. The support equipment in the track renewal system, with the exception of a ballast undercutter-cleaner, is all standard track maintenance machinery that can be returned to selective maintenance at any time. The ballast cleaner can also be leased, as Amtrak and Canadian National have done in their concrete tie installation programs in past years.

A railroad that could justify buying a track renewal machine could avoid the long-term commitment that ownership implies by leasing a machine for part or all of just one season for a specific task. It could then evaluate the ramifications of track renewal without having a major investment in equipment influencing the decision.

Leasing a track renewal machine means that the railroad may finish using the machine before its personnel have learned how to use it efficiently. Also, the equipment probably could not be modified to fit local requirements and may not be available at the specific time desired by the railroad. Leasing charges would certainly be higher than capital recovery and maintenance costs if the equipment is owned, but these costs are a small portion of the total cost of track renewal.

3. Contractor Ownership and Operation

An ownership area in which interest has been growing is contractor ownership and operation of track renewal machines and perhaps entire track renewal systems. There is precedent for this in Europe, where contractors perform the entire renewal process for several major railroads. At least one of these European contractors is currently studying the possibility of offering his track renewal services in the United States. The subject was also discussed in a paper presented to the General Contractors Association.*

A contractor owned and operated track renewal machine or system could move around the country to fully utilize the equipment, and the contractor would train a crew that would stay with the machine or system. Such a crew should be able to sustain a consistantly high production rate that would get the job done on a predictable schedule. It is difficult to say whether or not the cost to the railroad would be comparable to railroad ownership or lease and operation.

Small railroads already use contractors for some or all track maintenance. Most large railroads use contractors for rail grinding, rail inspection, bridge construction, and other specialized work. The small railroads could certainly use contractors for track renewal. Larger railroads that do not want to commit themselves to long-term track renewal, or simply find contractor economics advantageous, may have some difficulty with their labor agreements, especially if they wish to contract for an entire track renewal system.

Contractor operation of track renewal reduces the railroad's control over its operations in that the contractor will want minimum track occupancy times guaranteed and must be supplied with sufficient materials to perform each day's work. Considerable coordination must be maintained, especially if the railroad supplies the support equipment and manpower in the system. These requirements are somewhat offset by the railroad's ability to require minimum production levels and track quality standards.

*Presented by Mr. David S. Gedney, Associate Director, Office of Engineering, Northeast Corridor Project, Federal Railroad Administration, in February 1980, in Washington, D.C.

VI. CONCLUSIONS

This chapter summarizes the major findings of the analysis of track renewal systems and wood tie reuse and also identifies some areas for further study.

1. Summary of Findings

The principal findings of this study are summarized below:

a. Under certain conditions, the track renewal method offers significant long-term cost savings in track maintenance over the selective maintenance method.

b. The first-year costs of track renewal are likely to be higher than those for selective maintenance. With track renewal, however, the result of first-year activities is a completely rebuilt track. Furthermore, if at least one-third of the ties have to be replaced, first-year track renewal costs will be either equal to or less than those for selective maintenance.

c. Wood tie reuse is technically practical and economically feasible when combined with track renewal operations. This reuse, combined with the sale of scrap ties, provides a net material credit that has a significant impact on the cost savings associated with track renewal.

d. Track renewal reduces the amount of track occupancy time needed to perform maintenance work.

e. Completely renewed track has a better overall track structure over the life cycle of the track than selectively maintained track.

f. Track renewal technology has been advancing at a rapid rate in recent years, and this trend appears likely to continue such that future TRM's will achieve higher production rates with less labor and fewer support machines.

g. Although track renewal can produce large savings in labor and equipment costs, it does require a major planning effort and a commitment from management to operate successfully. A shortage of any material or a breakdown by any one of several key machines could have a serious impact upon the efficiency and cost-effectiveness of track renewal applications.

h. Based on the detailed economic framework and the sample analysis, it is evident that the framework itself should be a useful research tool for the U.S. railroad community to use for comparing the track renewal and selective maintenance methods. Given all the variables and options that exist in track maintenance procedures and real world applications, each railroad needs to consider the potential of track renewal from its own perspective.

2. Areas for Further Study

Track renewal and large-scale wood tie reuse have only recently begun in the United States and Canada. There is still very little direct experience to draw upon for determining the appropriate procedures, equipment designs, crew sizes, production rates, or planning requirements. Although some of these elements can be ascertained only through implementation, there are other areas of study that can be undertaken in the meantime that would help make the economic framework more precise and useful. The major areas are discussed below:

a. In this study, tie life was varied in several scenarios to see the economic effect that tie life has on the overall economics. Depending on the current average tie life, the long-term costs can be reduced by as much as $6,000 to $10,000 per mile if track renewal increases average tie life by about 20 percent. This increase, however, is an assumption, in that there is only a limited amount of data currently available on the service life of wood ties installed by the out-of-face method in North America. Accordingly, it is important to be able to answer the following questions: Will track renewal (as compared to selective maintenance) increase the service life of wood ties and, if so, under what conditions and for how long? In addition, what is the likely pattern of individual tie failures in renewed track over the life cycle?

b. It is essential to determine the optimal method of handling and processing wood ties removed under track renewal and scheduled to be reused in track such that their remaining service life can be maximized. Improper handling and processing can reduce the remaining life of used ties. The cost of studying alternative methods and developing reuse guidelines would probably pay for itself very quickly in added tie life.

c. What are the alternatives for profitably disposing of wood ties removed under track renewal but not destined to be reused in track? In the present study, a flat rate value of $2 per tie was assumed to be obtainable for each used wood tie not reused in track. A market study of used ties would be useful in itself if it could help railroads to develop more profitable markets for disposing of used wood ties.

d. What are the intermittent selective maintenance requirements likely to be under track renewal? It was assumed in the framework that some wood ties would be replaced, the track resurfaced, and little else done during the long-term renewal cycle. The optimal maintenance schedule over the cycle should be determined so that long-term costs can be predicted more accurately.

e. What are the likely costs and benefits to be derived from certain factors that have been identified but not quantified in this study? These factors include (1) the value of track occupancy time to railroad operating departments as well as engineering departments, (2) the value of reduced energy consumption (if any) owing to more even track quality under track renewal, and (3) the value of reduced equipment and lading damage (if any) owing to more even track quality. It should be noted that each of these factors also can be applied to other study areas and, in addition, should be of interest to the railroad industry irrespective of the track renewal application.

f. What are the U.S. railroad community's preferences for performance, design, and safety specifications for future track renewal machines? All of the existing TRM designs have been created for track renewal operations outside of North America. The few North American machines are all modified European machines. An industry-wide survey of desired performance, design, and safety specifications should be conducted, followed by the development of a set of U.S. or North American specifications that could be presented to manufacturers interested in or willing to develop new markets.

g. Given the hypothetical nature of the economic framework developed in this study, the framework should be tested by one or several railroads. The results should be used to strengthen the framework's value as a research tool and should be shared with the railroad community.

h. The economic framework is designed for comparing the track renewal and selective maintenance methods for maintaining existing track. Comparable research tools should be developed for determining the costs and benefits of using track renewal systems for abandoning track and for rebuilding badly deteriorated track.

i. Similarly, additional study is needed on the economic impact of TRM leasing (rather than ownership) by the railroads, as well as of the railroads contracting for track renewal services from nonrailroad TRM owner-operators.

j. The present framework is based on the assumed use of a particular TRM, the Canron P-811. Depending upon the development of such interest in the railroad community, it may be appropriate to further modify the framework to reflect the potential use of other designs.

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