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ECONOMICS OF CONCRETE AND WOOD TIE TRACK STRUCTURES

ECONOMICS OF CONCRETE AND WOOD TIE TRACK STRUCTURES

AUGUST 1978

INTERIM REPORT

Prepared for

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16. Abstract

This report presents results from an evaluation of the economic benefits of concrete- versus wood-tie track. The analysis includes the life-cycle capital, maintenance, and renewal costs for concrete- and wood-tie track for four specific test cases and traffic ranges from 15 to 40 annual million gross tons (MGT). The sensitivity of the justifiable first cost of concrete ties as a function of parametric changes in service and maintenance variables has also been determined.

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PREFACE

This report was prepared by Bechtel Incorporated and Battelle's Columbus Laboratories (BCL) under Contract DOT-TSC-1044 as part of the Improved Track Structures Research Program managed by the U. S. Department of Transportation, Transportation Systems Center (TSC). This program is sponsored by the Office of Rail Safety Research, Improved Track Structures Research Division, of the Federal Railroad Administration, Washington DC.

The overall objective of this program is to improve the safety and serviceability of cross-tie track. Work on this contract includes an evaluation of the economic feasibility of using synthetic cross ties and rail-fastener assemblies to obtain improved component life-time and long-term performance. The economic study includes the life-cycle cost estimates to construct, renew, and maintain both concrete- and wood-tie track structures on a per-track-mile basis. Also included are estimated time intervals and costs for each of nine major track maintenance and renewal operations, a review of the equipment requirements, and a discussion of environmental and material availability considerations for concrete- and wood-tie track.

This is the fourth interim report for this contract. The first was a planning document for a track-measurement program. The second covered the review and selection of track-analysis models for predicting track response and included a statistical description of concrete-tie track loads from measurements made on the Florida East Coast Railway. The third included a parametric study which presented a unified assessment of the effect of variations in tie size and spacing and ballast depth on track response. Also included were discussions of maintenance criteria for track surface deterioration and track lateral strength requirements for wood and concrete tie track.

Dr. Andrew Kish and Mr. Donald McConnell of the Transportation Systems Center were the technical monitor and alternate technical monitor, respectively. Their cooperation and suggestions are gratefully acknowledged.

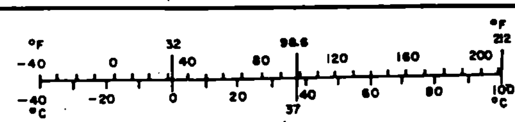
METRIC CONVERSION FACTORS

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

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
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1. INTRODUCTION AND CONCLUSIONS

1.1 INTRODUCTION

The primary objectives of this economic study of concrete and wood tie track structures were:

a. Develop a general methodology and sufficient cost data to evaluate the economic benefits of concrete versus wood ties for typical railroad operation.

b. Evaluate 50-year life cycle capital, maintenance and renewal costs for concrete and wood tie track systems for four specific test cases over the traffic range of 15 to 40 annual million gross tons (MGT) of typical North American freight service.

c. Compute the justifiable cost* of concrete ties as a function of selected service and maintenance variables.

The report consists of the following major elements:

a. Estimation of costs to construct, renew, and maintain both wood and concrete tie track structures on a per track mile basis. Renewal and maintenance costs are estimated for nine separate operations.

b. Estimation of time intervals between each of the nine maintenance and renewal operations for both wood and concrete ties. Time intervals are computed as a function of selected service variables.

c. Review of the major equipment required to construct and maintain wood and concrete tie track.

d. Discussion of significant environmental considerations as they affect the supply of track materials, track construction and maintenance, and material disposal.

e. Presentation of results of the 50-year life cycle economic study. A discussion of various sensitivity analyses performed and their impact on life-cycle costs is also included.

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*Justifiable cost of a concrete tie includes the purchase price of the tie and fastening hardware, delivery, and sales tax. The justifiable cost is derived by equalizing the life cycle costs for wood and concrete tie track structures.

For the purpose of this study, wood and concrete tie track structures were analyzed using the Battelle MULTA Computer Program [1]* to develop baseline track designs which are estimated to have approximately equal surfacing and lining requirements. Baseline track structure designs were selected which have the same maximum deviator stress at the ballast/subgrade interface, as computed by the program, on the assumption that equal maximum deviator stress results in equal settlement or "plastic deformation" of the track structures and therefore equal maintenance frequency for both track structures.

In order to limit the magnitude of the analytical effort, life cycle costs computations for wood and concrete tie track structures were performed for four test cases, each of which represents a fundamentally different application of concrete ties. The four test cases were:

I. Replace wood ties with concrete ties in an existing single or double track railroad. This represents the greatest potential use of concrete ties.

II. Use concrete ties to construct a new single or double track railroad.

III. Replace wood ties with concrete ties in an interior track** on an existing electrified railroad. This case is similar, but not identical, to portions of the Northeast Corridor track owned by Amtrak.

IV. Replace wood ties with concrete ties only on sharp curves in an existing single or double track railroad. Data for 4-degree curves were used for evaluating costs.

A baseline economic analysis and various sensitivity analyses were performed for each test case. Each case was evaluated over the range of 15 to 40 million gross tons (MGT) annual traffic, except Test Case III which was evaluated at 40 MGT only.

It should be clearly understood that the economic advantage or disadvantage of concrete ties is strongly coupled to existing track conditions; required maintenance frequency; costs of labor, equipment and materials; and

*Numbers in brackets denote references listed in Reference section.

**Interior track is defined as a track which has paralleling, adjacent tracks on both sides in the same right of way. The purpose of this test case is to show the sensitivity to the difficulties associated with performing maintenance operations between two or more in-service tracks.

productivity of maintenance gangs. If the conditions vary significantly from those used in this study for a particular track under evaluation, the economic advantage of concrete ties may differ substantially from what is reported here. However, the results presented in the following sections provide an indication of those conditions which affect decisions regarding concrete ties.

1.2 ECONOMIC FRAMEWORK

This economic evaluation of concrete ties was based on 50-year life cycle costing considering significant differentiating costs between the wood and concrete tie track. Fifty years was selected because it represents a period long enough to take full advantage of those systems components with the longest useful service lives. The present worth method of analysis was used.

An average annual inflation rate of four percent was applied to all costs over the 50 year period. This value was based on the average compound annual increase in building costs over the past 60 years. A sensitivity analysis was also performed for an average annual inflation rate of six percent on labor costs. Common labor costs have escalated at an average annual rate of 6.3 percent over the past 60 years.

Zero, 7, and 10 percent discounting rates were used in the analyses to discount the annual cash flows over the 50 year period. Deducting the 4 percent average inflation rate, this would result in approximately an actual 3 percent and 6 percent return on investment before taxes for the 7 and 10 percent discount rates respectively.

Residual values at the end of the 50-year life cycle were computed by multiplying the fraction of remaining useful life of a component or operation by the replacement cost. This method corrects for the distortions inherent in this type of analysis where major expenditures may be made just prior to the scraping or redesign of the system, a situation that would be avoided in real life.

Federal tax laws were reviewed to determine their cost impact [1-2]. The Tax Reform Act of 1976, Section 263-G of the code, specifies that concrete ties are not a betterment to the track structure and therefore costs incurred must be expensed in the year installed (in existing track). The other major applicable tax law is the investment tax credit, which, in Section 48-A9 of the same code, allows the investment tax credit to be applied to all costs incurred for building or maintaining railroad track. This law applies equally to wood and concrete tie track, therefore, concrete ties do not presently receive any specific tax benefits over wood ties.

State and local taxes were not examined in this study, however, a four percent state sales tax on all materials was included in the life cycle costing. The impact of local property taxes and state taxes should be addressed on a site specific basis when analyzing the economics of concrete ties.

This economic study addresses life-cycle costs before income taxes. Clearly, the after tax return on investment for concrete ties must consider the overall financial position of the railroad including revenues, other railroad expenses, and the sources of funds to finance an investment in concrete ties.

1.3 CONCLUSIONS

This economic study of wood and concrete tie track structures revealed the following factors as those having the most significant impact on the economic benefits of concrete ties:

a. annual tonnage on track

b. cost to install concrete ties

c. frequency of surfacing and lining required on wood versus concrete tie tracks

d. life of rail in curves on wood versus concrete tie track

e. life of wood ties

f. train fuel savings on concrete tie track

g. future cost of wood ties

h. future cost of labor.

The following is a summary of the results of the baseline economic study. Most of the costs shown here can be found in the summary tables in Section 6.

a. The cost estimates for installing concrete ties developed in the study were based on use of a track-laying system (TLS). One TLS is estimated to cost between 1.5 and 2.0 million dollars. In this study, a lease cost of $2500 per day was used. The TLS was estimated to lay an average of one mile of ties per day.

b. The type and cost of track equipment required for routine maintenance of concrete tie track does not differ significantly from the equipment required to maintain wood tie track.

c. For an equal number of derailments, the average annual cost in 1977 dollars to repair track is estimated to be approximately $730 per track mile for concrete tie track and $140 for wood tie track for 40 annual MGT.

d. The justifiable purchase cost per concrete tie, including hardware, transportation, and sales tax, for installing concrete ties in an existing single or double track railroad carrying 40 MGT per year is approximately $28 at the 10 percent discount rate. At 15 MGT per year the justifiable purchase price is reduced to only $18 per tie. Concrete-tie track will provide a cost savings only if ties can actually be purchased for less than the predicted justifiable cost.

e. For new track construction, the justifiable cost per concrete tie is approximately $46 at 40 annual MGT and $39 at 15 annual MGT at the 10 percent discount rate.

f. For refurbishing an existing well-maintained, electrified railroad, the justifiable cost per concrete tie is $21 at 40 annual MGT at the 10 percent discount rate.

g. For installation of concrete ties on only sharp curves in existing track, the justifiable cost of a concrete tie is approximately $80 at the 10 percent discount rate and 40 annual MGT and $40 at 15 annual MGT.

h. The average annual savings in 1977 dollars for track maintenance and component renewal costs for concrete versus wood tie track maintained to Class 5 track standards is approximately $3000 to $4000 per track mile for 40 annual MGT and $1500 to $2300 per mile for 15 annual MGT. This is the estimated annual savings after the concrete ties are installed.

i. On 4-degree curves, the average annual savings in track maintenance and component renewal costs for concrete ties is estimated to be $12,500 per track mile at 40 annual MGT and $4,900 per track mile at 15 annual MGT.

This report is intended to indicate those conditions under which concrete ties may be an attractive investment. It is recommended that when analyzing the economics of concrete ties for candidate rail lines, very site-specific cost data should be collected. Furthermore, those candidate lines should be identified and studied as early as possible in order to carefully plan the maintenance program on the track up to the time concrete ties are installed. This may mean delaying major tie renewal, rail renewal, surfacing or ballast cleaning. Additionally, a second-hand use or outside market should be found for the wood ties, other track materials (OTM) and possibly rail that will be removed when concrete ties are installed.

2. COST ESTIMATES

2.1 INTRODUCTION

Costs estimates were developed for construction and maintenance operations for which there is a significant differential cost between wood and concrete tie track, as a result of either the differing labor, material and equipment costs or frequency of the operation. The cost estimates were prepared to serve two primary objectives. First, they serve as the basis for the life cycle costing of wood and concrete tie track systems for each of the four test cases previously described. Second, it is anticipated they can serve as base estimates, modified as required, to evaluate life cycle costs for wood and concrete tie track for any site-specific case. Sufficient explanation of all estimated costs is provided to readily permit modification based on any railroad's data. Thus the estimating methodology has a general use.

The literature is rich with cost data for various track maintenance or renewal operations on wood tie track. Unfortunately, these estimates could not be used directly in this study because, typically, the estimating methodology is either not defined, or lacks a common basis for comparing maintenance operations (e.g., lay new rail versus renew ties). Additionally, the cost differential is small for some maintenance and renewal operations for wood versus concrete tie track structures. To evaluate the effect of these smaller differentials, accurate cost estimates - particularly on a relative basis between wood and concrete tie structures - are essential.

For these reasons, detailed cost estimates were prepared specifically for this study. Maximum use was made of available literature for guidance in establishing productivity rates for the various operations. Detailed documentation of all cost estimates is included in this report to allow modification of the estimates for site specific use or to permit use of railroad historical maintenance data.

It is acknowledged that there is very limited North American experience constructing or maintaining concrete tie track. The cost estimates for concrete tie track, therefore, were based on discussions with persons who have experience with concrete tie track, information from the literature and suppliers, and discussions with persons knowledgeable with railroad track maintenance operations in general.

A strong word of caution is necessary regarding the unit costs, productivity rates, and total costs of the various construction and maintenance operations estimated. An attempt was made in this study to use values which were considered representative of "normal" or "average" conditions. It is recognized that costs actually vary widely with geography, condition of existing physical plant, present equipment position, and other factors. Therefore, any attempt to apply this study to a particular line should use site specific data wherever possible.

2.2 UNIT COSTS

Unit costs for labor, equipment and materials were established for use in all construction and maintenance cost estimates.

Labor rates on an hourly basis for straight time and overtime are shown in Table 2-1. The labor rates are based on April 1976 Burlington Northern Railroad rates, escalated by 5 percent to adjust for mid-1977 [2-1]. Labor rates for other railroads may vary from Burlington Northern's by as much as 10 percent.

Equipment costs on a daily and hourly basis are summarized in Table 2-2. The costs are based on railroad ownership of all equipment with the exception of the track renewal machine*, for which a lease cost was estimated. The methodology used in the cost determinations was:

a. Capital cost: equal annual payments based on an eight percent loan for the original purchase and delivery price (including 4 percent sales tax). Salvage credit included for major equipment.

b. Property tax: 1.5 percent of depreciated value (straight line) annually.

c. Annual maintenance and supply costs: estimated as 15 percent of original purchase price for most pieces of equipment. Does not include allowance to cover a field mechanic.

d. Daily rate: sum of items above divided by 220 days. This rate is based on four hours of track time use per day for major track equipment.

e. Hourly rate: daily rate divided by four.

*For the purposes of this study it was assumed that a track laying machine would be available on a lease basis. In 1978, two such machines will be in operation in North America. One is being purchased by the Canadian National Railroad and the other by Amtrak.

TABLE 2-1 HOURLY LABOR RATES - 1977[1]

Classification	Straight Time[2]	Overtime
Supervisor	$14.65	$19.59
Foreman	12.66	16.93
Assistant Foreman	11.36	15.19
Operator		
Large Equipment	11.61	15.53
Small Equipment	10.43	13.95
Laborer	9.63	12.88
Mechanic	11.48	15.35
Truck Driver		
Large Truck	10.38	13.88
Small Truck	10.04	13.43
Welder	11.32	15.14
Cook	10.04	13.43
Train Crew	44.00	59.00
One Engineer,		
One Conductor		
Two Brakemen		

Notes:

(1) Based on Burlington Northern Railroad rates[2-1].
(2) Base plus 40% fringe benefits, 10% administrative and accounting, 6% workmens compensation, 2% taxes, 6% small tools and supplies.

TABLE 2-2 EQUIPMENT COST SUMMARY - 1977

Equipment	Daily Rate	Hourly Rate
Rolling Stock		
Diesel Locomotive	$ 450	$113
Ballast Car	23	6
Caboose	33	8
50C.Y. Air Dump Car	45	11
Flat car	19	5
Tie Car	19	5
CWR Train - 36 cars	756	190
CWR Threader Car	235	59
Track Equipment		
175 CFM Compressor, Hi-Rail	53	13
Anchor Applicator	18	5
Ballast Cribber	14	4
Gauger	38	10
Portable Rail Grinder	2	0.50
Rail Heater	38	10
Rail Puller/Expander	3	0.75
Spike Puller (Hydraulic)	7	2
Tie Adzer	23	6
Creosote Machine	7	2
Speed Swing	122	31
Abrasive Rail Saw	20	5
Rail Drill	2	0.50
Dual Spike Setter/Driver	77	19
Rail Lifter	8	2
Tiebed scarifier/inserter	47	12
Tie Crane	31	8
Tie Pusher	22	6
Ballast Regulator	75	19
Production Tamper/liner	174	44
Hydraulic Spike Driver	15	4
Winch Cart	64	16
Tie plug Inserter	15	4
Tie Drills	10	2
Spike Cart	15	4
Scrap Loader	37	9
Tie End Sweeper	28	7
Wide Gauge Threader	124	31
Multiple Cribber	140	35
Adzer Creosoter	140	35
Gauge Threader & Line Spiker	146	37
Gauger Spiker	126	32
Crane w/magnet	168	42
Spot Tamper	83	21
Ballast Undercutter	1089	272

TABLE 2-2 (Continued)

Equipment	Daily Rate	Hourly Rate
Track Equipment (Continued)		
Track Laying Machine	$2500	$511
Tie Shear	69	17
Dual Spike Puller	20	5
Auto Sled	400	100
Off Track Equipment		
5 ton Hi-Rail Crane	58	15
20 ton Hi-Rail Crane	124	31
Motor Grader	73	18
4CY End Loader	105	26
Pick-up Truck	14	4
Mechanics Truck (or Welders)	22	5
Crew Truck	23	6
40 Passenger Bus	34	8
Low Boy Truck	58	14
Dump Truck 5CY-Hi-Rail	37	9
Dump Truck 5CY	30	7
House Trailers	11	--
Kitchen Trailer	18	--

Note:

Cost of equipment computed as follows:

Annual

Borrow money for equipment purchase at 8% interest paid back in equal annual payments over the useful life of the equipment

Annual property taxes and insurance in the amount of 1.5% of equipment value

Annual maintenance cost included (except field maintenance)

Daily Cost

Annual cost divided by 220 days/year

Hourly Cost

Daily cost divided by 4 hours/day

Material prices are shown in Table 2-3. The purchase prices are based on supplier quotations. Estimated delivery cost is included but sales taxes are not.

Ballast was priced at $4 per cubic yard plus $2.50 per cubic yard for transportation (an allowance of fifteen percent for shrinkage and waste was used in costing). This price is an average of many quotations received for high quality ballast. The transportation cost was based on a 155 mile on-line haul, an average reported in a recent AREA bulletin. Obviously, the delivered price of ballast varies widely with location. The impact of ballast cost on the life cycle costs between wood and concrete ties is not significant, however, unless the existing ballast has to be removed, and new ballast placed under the concrete ties to provide better support.

Credit for residual material value was included in the life cycle analysis, both for materials removed when concrete ties are initially installed, as well as normal renewals for wood and concrete tie track. The equation used to compute residual value is:

$$RV = \left[\frac{(A - B)\ (C)}{D - 1}\right] \times E + (BxC) - T$$

Where: RV = Residual value

A = Ratio of value at end of first year to original cost

B = Salvage value/original cost

C = Original cost

D = Total useful life in years

E = Remaining years of useful life

T = Transportation cost.

2.3 MAINTENANCE, RENEWAL, AND CONSTRUCTION OPERATIONS AND COSTS

The life-cycle cost analysis was based on those construction and maintenance operations for which there is a significant cost differential between the wood and concrete tie structures. The cost estimates are based on some common as well as specific assumptions. An attempt was made to make the assumptions as representative of average conditions as possible, but it is understood that actual conditions vary widely. The assumptions common to all estimates (except as noted) are shown in Table 2-4 [2-2].

TABLE 2-3 MATERIAL UNIT COSTS - 1977[1]

Item	Unit	Cost
135 RE Rail	Ton	$338[2]
Field Weld	Each	132
Track Spikes	Each	0.25
Hold Down Spikes	Each	0.45
Rail Anchors	Each	0.93
Tie Plates		
7 3/4" x 14"	Each	3.78
8 1/2" x 16"	Each	5.73
Rail Fastener Clip	Each	1.30
Insulator	Each	0.25
Tie Pad	Each	0.55
Wood Ties		
7" x 9" x 8'-6"	Each	15.00
Concrete Ties		
11" width x 9'-0"	Each	30.00[3]
Ballast	CY	6.50

Notes:

(1) Includes transportation cost of approximately $12/ton ($2.50/CY for ballast). Does not include sales tax.
(2) Includes shop welds.
(3) Used for concrete tie replacement.

TABLE 2-4 CONCRETE- AND WOOD-TIE TRACK STRUCTURES - DESCRIPTION AND PRODUCTIVITY ASSUMPTIONS

I. Track Design

	Wood Tie Track	Concrete Tie Track
a.	ties at 19.5" spacing	ties at 24" spacing
b.	8" clean ballast under ties	8" clean ballast under ties, and 2-1/2-inches greater total ballast depth than for wood ties
c.	136 RE rail	136 RE rail
d.	7" x 9" x 8'-6" ties	11" wide x 9' long ties
e.	7-3/4" x 14" tie plates	Fastener clip, insulator, and tie pad

II. Physical Description of Track

a. 70% tangent track, 30%(1) two degree curvature

b. 1% grade

c. 1 turnout every three track miles

d. all sidings and special track work(2) supported by wood ties

III. Factors affecting construction and maintenance productivity are:

a. track is returned to service every night

b. one hour travel time per day

c. continuous use of track during working time

d. "average" weather conditions for non-winter.

(1) For Test Case IV, 100% 4 degree curvature.

(2) Special trackwork includes all switches, frogs, guard rails, derails and other track structures and fittings, other than plain unguarded track, that are fabricated before laying.

During installation of concrete ties for refurbishing existing track, a cost will be incurred for raising the elevation of grade crossings and turnouts as a result of increasing the ballast depth. Clearly, if the grade crossing or turnout is replaced and the subgrade work done when concrete ties are installed, this represents a betterment for the special trackwork and the cost of that betterment should not be charged to the concrete tie installation. If the grade crossing or turnout were only raised to allow installation of the concrete ties, the cost of raising should not be greater than the cost incurred during normal surfacing, the cost of which is included in the installation of concrete ties. The routine maintenance for sidings and special trackwork should not be significantly greater for concrete versus wood tie track. For these reasons, the concrete tie case was not penalized for construction or maintenance costs associated with special trackwork.

Detailed cost estimates were prepared for 15 separate maintenance, renewal, and construction operations for wood and concrete tie track structures. These are:

<u>Maintenance and Renewal</u>

1) Lay new rail
2) Tie replacement
3) Surface and line track
4) Clean ballast and surface and line track
5) Regauge track
6) Transpose rail
7) Spot surfacing
8) Derailment repairs
9) Grind rail
10) Replacement of concrete ties, 100-percent renewal.

<u>Construction</u>

11) Clean ballast and replace existing rail and wood ties with new CWR and concrete ties
12) Replace ballast and replace existing rail and wood ties with new CWR and concrete ties.
13) Clean ballast and replace existing wood ties with concrete ties
14) Replace ballast and replace existing wood ties with concrete ties.
15) Construct new track.

The rates at which the various machines and crews perform individual work functions were determined by averaging production figures obtained from several railroads and equipment suppliers. Table 2-5 is a list of the major operations and the productivity rates used for each. The development of these rates and the sources used are detailed in Appendix A.

Detailed costs for each of the 15 operations were estimated for a single or double track, non-electrified railroad. In order to evaluate all the test cases, however, costs for the above operations on interior tracks in electrified territory and on isolated sections of 4-degree curved track were also required. To obtain these costs, factors were developed to adjust the base cost estimates for labor and equipment (material costs do not change) for each of the 15 operations based on Long Island Railroad estimates[2-3] and the best judgment of experienced maintenance-of-way engineers. They are shown in Table 2-6. While a detailed explanation of each of the cost factors contained in the table would be impractical if not impossible, it must be recognized that they represent an attempt to assess a decrease in productivity. Such decreased productivity is the result of performing maintenance and construction operations in a confined area, i.e., interior track with rail traffic on adjacent tracks or with restricted overhead clearance due to a catenary. A decrease in productivity is also realized where work is performed only on curves when equipment must be continually set up and dismantled between work sites. In many cases, specifically for concrete ties, the factors are purely judgmental as little historical North American railroad data exist.

A summary of costs for labor, equipment, new materials, and salvage credits for each of the maintenance, renewal, and construction operations is shown in Table 2-7. These estimates are based on the unit costs and estimating assumptions previously described. They include direct costs and field supervision. Overhead costs were not included because they were not considered to represent a significant differentiating cost between wood and concrete tie track ownership and maintenance. Presumably, however, the expected lower maintenance requirements for concrete tie track would be reflected, to some degree, in reduced overhead expenses. For a detailed list of the basis used to estimate the cost of each operation, see Appendix B.

TABLE 2-5 PRODUCTIVITY RATES FOR MAJOR TRACK CONSTRUCTION, MAINTENANCE, AND RENEWAL OPERATIONS(1)

Item	Crew Size	Daily Production (Track Miles)	Rate Used
Rail Laying-W (2)	61	1/2	12 Hrs/Mile
Rail Laying Equipment-C(2)	49	1/2	12 Hrs/Mile
Tie Replacement-W	34	2.5	125 Ties/Hr
Tie Replacement-C	24	0.75	40 Ties/Hr
Surfacing and Lining-W	8	1	1400 Ft/Hr
Surfacing and Lining-C	7	1.3	1700 Ft/Hr
Ballast Cleaning-W	16	1/3	429 Ft/Hr
Ballast Cleaning-C	11	1/2	1000 Ft/Hr
Track Sledding with plow-W	18	0.91	1220 Ft/Hr
Track Sledding with plow-C	11	1	2000 Ft/Hr
Track Relaying-W to C	32	1.25	1500 Ft/Hr
New Track Construction-W	80	1	700 Ft/Hr
New Track Construction-C	72	1	700 Ft/Hr

(1) See Appendix A for references and greater detail
(2) W-wood ties; C-concrete ties

TABLE 2-6 ESTIMATED LABOR AND EQUIPMENT COST FACTORS FOR VARIOUS TYPES OF TRACK MAINTENANCE AND RENEWAL OPERATIONS(1)

Operation	Interior Track		Electrified		Four-Degree Curve Only	
	Wood	Concrete	Wood	Concrete	Wood	Concrete
Maintenance or Renewal						
1. Lay new rail	1.02	1.02	1.05	1.05	1.30	1.30
2. Tie replacement	1.20	1.30	1.10	1.20	1.20	1.10
3. Surface and line	1.00	1.00	1.00	1.00	1.10	1.10
4. Clean ballast and surface	1.50	1.50	1.20	1.20	--	--
5. Regauge track	1.00	1.00	1.00	1.00	1.10	1.10
6. Transpose rail	1.02	1.02	1.00	1.00	1.00	1.00
7. Spot work	1.00	1.00	1.00	1.00	1.00	1.00
8. Repair derailment	1.20	1.30	1.05	1.05	1.00	1.00
9. Grind rail	1.00	1.00	1.00	1.00	1.20	1.20
10. 100% replacement concrete ties	--	1.40	--	1.20	--	1.60
Construction						
11. Replace rail, ties and clean ballast	--	1.40	--	1.30	--	1.60
12. Replace rail, ties and ballast	--	--	--	1.30	--	1.60
13. Replace ties, & clean ballast	--	1.40	--	1.20	--	1.60
14. Replace ties and ballast	--	--	--	1.20	--	1.60
15. Build new track	0.98	0.98	1.00	1.00	--	--

(1) Baseline costs are represented by the factor 1.0. The baseline is for non-electrified single or double mainline track.

TABLE 2-7 SUMMARY OF MAINTENANCE, RENEWAL, AND CONSTRUCTION COST ESTIMATES

(Cost Per Mile in Thousands of Dollars - 1977)

Operation	Labor		Equipment		New Material	Material Credit	Total	
	Electrified	Non-Electrified	Electrified	Non-Electrified			Electrified	Non-Electrified
1. Lay Rail - Wood tie track:								
Base case	10.7	10.2	6.3	6.0	94.5	-16.8	94.7	93.9
Interior Track	10.9	10.4	6.4	6.1	94.5	-16.8	95.0	94.2
Curve Only	13.9	13.3	8.1	7.9	94.5	-16.8	99.7	98.8
Lay Rail - Concrete Tie Track:								
Base Case	7.1	6.8	3.9	3.7	100.9	-16.8	95.1	94.6
Interior Track	7.2	6.9	4.0	3.8	100.9	-16.8	95.3	94.8
Curve Only	9.2	8.8	5.1	4.8	100.9	-16.8	98.4	97.7
2. Tie Replacement - Wood Tie Track: 25 percent replacement								
Base Case	3.6	3.3	2.2	2.0	13.2	-0-	19.0	18.5
Interior Track	4.4	4.0	2.7	2.4	13.2	-0-	20.3	19.6
Curve Only	4.4	4.0	2.7	2.4	13.2	-0-	20.3	19.6
Tie Replacement - Concrete Tie Track: 3.8 percent replacement								
Base Case	1.7	1.4	1.0	0.8	3.9	-0-	6.6	6.1
Interior Track	2.2	1.8	1.2	1.0	3.9	-0-	7.3	6.7
Curve Only	1.9	1.6	1.1	0.9	3.9	-0-	6.9	6.4
3. Surface and Line - Wood Tie Track: Base Case and Interior Track -3" raise	1.1	1.1	1.3	1.3	7.0	-0-	9.4	9.4
Surface and Line - Concrete Tie Track: Base Case and Interior Track 3" raise	0.8	0.8	1.2	1.2	6.5	-0-	8.5	8.5
4. Clean Ballast and Surface and Line - Wood Tie Track: Base Case 8" depth	8.3	7.0	7.5	6.3	6.7	-0-	22.5	20.0
Interior Track	12.5	10.4	11.3	9.4	6.7	-0-	30.5	26.5
Clean Ballast and Surface and Line - Concrete Tie Track: Base Case 8" depth	6.7	5.6	6.0	5.0	3.8	-0-	16.5	14.4
Interior Track	10.0	8.3	9.0	7.5	3.8	-0-	22.8	19.6
5. Regauge Track - Wood Tie Track: Curve Only	2.1	2.1	0.2	0.2	0.7	-0-	3.0	3.0
6. Transpose Rail - Wood Tie Track:								
Base Case and Curve Only	12.0	12.0	4.4	4.4	3.2	-0-	19.6	19.6
Interior Track	12.3	12.3	4.5	4.5	3.2	-0-	20.0	20.0
Transpose Rail - Concrete Tie Track:								
Base Case and Curve Only	8.8	8.8	2.6	2.6	3.2	-0-	14.6	14.6
Interior Track	8.9	8.9	2.6	2.6	3.2	-0-	14.7	14.7
7. Spot Work - Wood Tie Track: (per mile per 12 MGT) Base Case, Interior Track and Curve Only	0.35	0.35	0.11	0.11	-0-	-0-	0.46	0.46
Spot Work - Concrete Tie Track: (per mile per 12 MGT) Base Case, Interior track, and Curve Only	0.28	0.28	0.08	0.08	-0-	-0-	0.36	0.36

TABLE 2-7 (Continued)

Operations[1]	Labor		Equipment		New Material	Material Credit	Total	
	Electrified	Non-Electrified	Electrified	Non-Electrified			Electrified	Non-Electrified
8. Repair Derailment - Wood Tie Track:								
Base Case and Curve Only	2.8	2.7	0.1	0.1	3.3	-0-	6.2	6.1
Interior Track	3.3	3.2	0.1	0.1	3.3	-0-	6.7	6.6
Repair Derailment - Concrete Tie Track:								
Base Case and Curve only	5.6	5.4	0.8	0.7	24.5	-0-	30.9	30.6
Interior Track	7.3	7.0	1.0	1.0	24.5	-0-	32.8	32.5
9. Grind Rail - Subcontract plus provide work train							0.94	0.94
10. 100 Percent Replacement of Concrete Ties -								
Base Case	6.5	5.4	7.5	6.3	108.1	-0-	122.1	119.8
Interior Track	9.1	7.6	10.5	8.8	108.1	-0-	127.7	124.5
Curves Only	10.4	8.7	12.0	10.0	108.1	-0-	130.5	126.8
11. Install new rail, concrete ties, clean ballast								
Base Case	9.7	7.5	15.2	12.1	98.6	-73.9	49.6	44.3
Interior Track (Tie cost not incl.)	13.6	10.4	20.4	16.2	98.6	-73.9	58.7	51.3
Curves Only (Tie cost not incl.)	15.5	11.9	23.1	18.2	98.6	-73.9	63.3	54.8
12. Install new rail, concrete ties, replace ballast:								
Base Case (Tie cost not incl.)	8.9	6.8	15.9	12.7	111.8	-73.9	62.7	57.4
Curves Only (Tie cost not incl.)	14.2	10.9	24.2	19.1	111.8	-73.9	76.3	67.9
13. Install concrete ties, clean ballast								
Base Case (Tie cost not incl.)	6.7	5.6	11.3	9.7	10.6	-32.2	-3.6	-6.3
Interior Track (Tie cost not incl.)	9.4	7.9	15.0	12.8	10.6	-32.2	2.8	-0.9
Curves Only (Tie cost not incl.)	10.8	9.0	16.8	14.4	10.6	-32.2	6.0	1.8
14. Install concrete ties, replace ballast								
Base Case (Tie cost not incl.)	5.8	4.8	11.0	9.5	23.8	-32.2	8.4	5.9
Curves Only (Tie cost not incl.)	9.3	7.7	16.3	13.9	23.8	-32.2	17.2	13.2
15. Construct New Track - Wood Tie Track:								
Base Case (Include wood ties)	7.3	7.3	9.3	9.3	194.3	-0-	210.9	210.9
Interior Track (Include wood ties)	7.1	7.1	9.1	9.1	194.3	-0-	210.5	210.5
Construct New Track - Concrete Tie Track:								
Base Case (Tie cost not incl.)	7.0	7.0	9.1	9.1	111.8	-0-	127.9	127.9
Interior Track (Tie cost not incl.)	6.9	6.9	8.9	8.9	111.8	-0-	127.6	127.6

(1)Purchase cost of concrete ties and hardware not included in operations 11, 12, 13, 14 and 15.

Notes:

See Appendix B for detailed description of items.
Costs include direct costs and field supervision. Overhead costs are not included.
Material credits include transportation and handling costs. The material credit for items 11 and 12 includes credit for rail with 50 percent useful life remaining at the time of removal.

3. TRACK MAINTENANCE AND RENEWAL REQUIREMENTS

Four test cases representing fundamentally different applications of concrete ties were selected for detailed evaluation of life cycle costs. In order to limit the number of variables for evaluation, however, certain physical track characteristics and train service assumptions common to all four cases were made, some of which have been described previously. It is important to recognize that significant differences may exist between these assumptions and the actual conditions for a specific track under evaluation.

3.1 TEST CASE DESCRIPTIONS

I: Replace wood ties with concrete ties in an existing single or double track railroad. This is the most important case, as it represents the greatest potential use of concrete ties.

II: Construct a new single or double track railroad. Costs evaluated in this case were for the wood and concrete tie track structures, including ballast, above the finished subgrade.

III: Replace wood ties with concrete ties in an interior track of an existing, electrified railroad. This case is similar to that in portions of the Northeast Corridor which is owned by Amtrak.

IV: Replace wood ties with concrete ties on all sharp curves, in an existing single or double track railroad. Cost factors were based on curves averaging 4 degrees.

Each of these cases was evaluated over 50 years, for annual traffic ranging from 15 to 40 MGT. Life cycle cost sensitivities for changes in selected variables were performed and are discussed in Section 4.

3.2 FREQUENCY OF MAINTENANCE AND RENEWAL OPERATIONS

Central to the life-cycle costing analysis is the need for accurate estimates of the frequency of the various maintenance and renewal operations over the 50 year system life. Maintenance frequencies can vary widely depending primarily upon weather, subgrade, and traffic conditions. However, much information is available on "average" maintenance requirements on wood tie track as a function of these variables. Much less information is available for estimating concrete tie track maintenance. The primary references used in estimating maintenance frequencies in this study were: Procedures For Analyzing the Economic Costs of Railroad Roadway For Pricing Purposes by TOPS On-Line Services, Inc., 1976[3-1]; conversations with Bob Hudson, Chief Engineer, Florida East Coast Railway Co.; and AREA committee reports. Other references will be noted in the ensuing discussion.

The frequency of the maintenance and renewal operations included in this study were derived for each of the 10 operations described in Section 2. In each case frequencies have been computed for 15 and 40 annual MGT except for the electrified track which was evaluated for 40 annual MGT only. Table 3-1 is a summary of the vehicle characteristics and tonnage breakdown for each vehicle type which was used in computing the maintenance and renewal requirements.

3.2.1 Lay Rail. Reference [3-1] was the primary reference used to analyze the economics of tangent and two-degree curvature track. The equation used for computing rail life on wood tie track is:

$$T = KWD^{0.565}$$

where

T = rail life in MGT

K = factor corresponding to track design and type of traffic (1.14 tangent, 1.0 for 2-degree curve)

W = weight of rail in pounds per yard

D = annual traffic in million gross tons.

This equation was used to compute rail life for 136 RE rail for Test Cases I, II, and III. There is no evidence to date that rail life on tangent track is increased for concrete tie track versus wood tie track. On curves, however, the Canadian National Railroad has found that rail life in curves may be double for concrete tie track versus wood tie track. More information on the precise relationship of rail life on wood and concrete tie track structures should be forthcoming from the Facility for Accelerated Service Testing (FAST) at TTC. Because these data are not yet available, a more conservative increase in rail life on concrete tie track was used in this study. On two-degree curves on wood-tie track, rail is estimated to last

TABLE 3-1 DESCRIPTION OF TRAFFIC AND TRACK USED IN ESTIMATING TRACK MAINTENANCE REQUIREMENTS

Vehicle Type	Static Wheel Load - Kips	Tonnage Breakdown[1]	
		Test Cases I, II, IV	Test Case III
Locomotive	33	20%	6%
Freight Cars			
90 Ton Hoppers	30	15%	4%
Other Loaded Cars	24	50%	43%
Empties	7	10%	7%
Passenger Cars	14	5%	40%
Total		100%	100%
Linear Weighted Average of Static Wheel Loads		24.5 Kips	19.6 Kips

(1)

	Average	FRA Track Classification
Test Cases I and II	50 mph	5
Test Case III	80 mph	6
Test Case IV	30 mph	4

approximately 88 percent as long as on tangent track. This 12 percent differential was split in half and 94 percent was used for rail life on concrete tie track in this study. Using the above equation for Test Cases I, II, and III, the results are:

Track Description	Rail Life Estimates 15 Annual MGT	40 Annual MGT
Tangent - wood or concrete ties	718 MGT	1250 MGT
Two degree curves - wood tie	632 MGT	1100 MGT
- concrete ties	675 MGT	1175 MGT
Weighted average[(1)] - wood ties	693 MGT	1205 MGT
- concrete ties	705 MGT	1228 MGT
Life in years - wood ties	46 years	30 years
- concrete ties	47 years	31 years

For Test Case IV, curves averaging 4 degrees exclusively, rail life on wood tie track[(2)] was estimated at 250 MGT, and 50 percent greater, or 375 MGT, on concrete tie track regardless of annual tonnages. This gives a life on curves of:

	15 Annual MGT	40 Annual MGT
Wood tie track	16.7 years	6.25 years
Concrete tie track	25 years	9.4 years

3.2.2 Tie Replacement. Estimated wood tie life was also computed from Reference [3-1]. The life of wood ties reported in this reference corresponds well with AREA committee reports, Canadian National Railroad, and representatives of the Railway Tie Association. The equation for computing wood tie life is:

$$L = K\left(e^{(4.5881 - 0.060770\,\alpha)}\right) 1.181D^{0.60825}$$

where

L = Tie life in MGT

K = Factor corresponding to track design and type of traffic (0.68)

α = Degree of curvature

D = annual traffic in million gross tons

e = 2.718 (base of natural logarithms).

(1) Seventy-percent tangent track, 30 percent 2-degree curvature.
(2) Longer life of rail in absolute terms favors the wood tie case.

The life of 7" x 9" x 8'-6" hardwood ties using this equation is:

	15 Annual MGT	40 Annual MGT
Tangent	411 MGT	769 MGT
Curves - 2°	364	661
Weighted average for Test Cases I, II, III		
MGT	397	736
Years	26.4	18.4
Test Case IV - 4° curves		
MGT	315	560
Years	21	14

These are the baseline estimates for wood-tie life. A life cycle cost sensitivity analysis was made by varying these lives by plus and minus 5 years.

There is a very limited data base with which to compute concrete tie life. Concrete ties have been in service for 40 years in Great Britain and a minimum 50 year life is projected. Therefore, a 50 year life was used in this study for the baseline analysis. A sensitivity analysis was performed by setting concrete tie life equal to double wood tie life, but not to exceed 50 years.

Traditionally, only a portion of the wood ties in a track are replaced at one time. This study is based on renewal of 25 percent of all wood ties using traditional methods at time periods equal to one quarter of the projected wood tie service life.* This renewal practice is similar to that of most North American railroads. A fundamentally different practice, and one that has not been tried in North America, is to renew all wood ties at one time with the track laying system. The ties removed from track would be classified, with some replaced in the same track; some placed in lesser used lines, sidings, or yard tracks; and, some disposed of. Primary considerations in evaluating the cost effectiveness of this approach would be condition of the existing track and the potential for reuse or sale of ties removed from track. Under certain conditions, this method of wood tie renewal could result in cost savings over the traditional method which was evaluated in this study.**

*No spot replacement of wood ties was included.
**See the article written by David R. Burns in the March 1977 issue of Railway Track and Structures magazine for more information on this subject.

Initial installation or total renewal of concrete ties in existing or new track was estimated using a track laying system. Additionally, an estimated spot replacement of 3.8 percent of all concrete ties (100 ties per mile) 5 years after installation was included. * This should be a conservative amount, as only 0.11 percent of the concrete ties were replaced after 4 years of service in the Canadian National Railroad's Jasper test section [3-2].** A spot replacement of 0.5 percent (13 ties per mile) of concrete ties was included in the analysis at 7 year intervals for 15 annual MGT and 5 year intervals for 40 annual MGT.

3.2.3 Surface and Line Track. Battelle Columbus Laboratories' MULTA track analysis computer program [3-3] was used to establish the track structure designs for both wood and concrete tie track used in this study. The track structure designs were selected for wood and concrete track that have the same maximum deviator stress at the ballast/subgrade interface, using equal track loadings. For each test case, the frequency of surfacing and lining maintenance was assumed to be approximately equal for wood and concrete tie track structure when the maximum deviator stress is equal, because this is one of the most important factors for track settlement. Thus, frequency of surface and lining for both track structures was set equal in this economic study.

The actual frequency of surfacing and lining***was computed using the equation developed by TOPS [3-1]. The equation is:

$$L = K(D^{-0.36302})\,(e^{3.2451})$$

where

L = cycle length in years

K = factor corresponding to track design and type of traffic

D = annual traffic in million gross tons

e = 2.718 (Base of natural logarithms).

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*It is expected that a small number of ties will fail initially due to manufacturing defects, damage in transportation and installation and uneven track conditions which will require some spot replacement of concrete ties.

**Total of 10,000 ties installed in 1972 [3-2].

***For additional information on surfacing and lining requirements and rail life, see the Northeast Corridor High-Speed Rail Passenger Service Improvement Program-Task 19-Support Services: Dynamics and Computer Program Development, July 1976 by Bechtel, Inc.

The time interval between surfacing and lining track based on this equation is:

	K	15 Annual MGT	40 Annual MGT
Test Cases I, II, and IV	0.53	5.1 years	3.6 years
Test Case III	0.30	--	2.0

There are indications that the required interval between each surfacing and lining operation is longer for concrete tie track than for wood tie track based on the experience of the Florida East Coast Railway and the Canadian National Railroad. However, a statistically significant empirical data base did not exist when this study was conducted to permit quantification. An economic sensitivity analysis was made to quantify the cost savings if the time between each surfacing and lining for concrete tie track is twice as long as that for wood tie track.

3.2.4 Clean Ballast and Surface and Line Track. The requirement for ballast shoulder cleaning is dependent on the type of ballast, weather conditions, and subgrade soil conditions. For the purpose of this study, ballast shoulder cleaning during every third surfacing and lining cycle was included.

3.2.5 Regage Track. Regaging track on curves is expensive and it has the adverse side effect of spike killing wood ties. In this study, regaging wood tie track on curves was estimated at the following intervals:

(a) once between the time new rail is laid and the rail is transposed

(b) once between the time the rail is transposed and the rail is removed.

Regaging of concrete tie track is not necessary because the rail seat spacing is fixed.

3.2.6 Transpose Rail. To maximize the useful life of rail on curves, rail on both wood and concrete tie track was transposed once between laying and removal.

3.2.7 Spot Surfacing. It was estimated that, for wood tie track, one full-time spotting gang could cover 200 track miles for 15 annual MGT and 77 miles of track for 40 annual MGT. Concrete tie track was estimated to have 25 percent lower costs. The cost of spot surfacing does not represent a significant differentiating cost between wood and concrete tie track, providing both structures do not experience abnormal maintenance problems.

3.2.8 Derailment Repairs. Time constraints limited an in-depth study of potential derailment frequency and repair costs in this study. Utilizing information contained in a study entitled Economics of Short Trains [3-4], however, an average of one derailment for every 3.4 MGT over 500 miles of track was assumed. The nature of the derailment was estimated to be a derailed truck traveling a distance of 2000 feet.* The frequency of derailments on wood and concrete tie track were considered equal.

3.2.9 Rail Grinding. Equal rail grinding for wood and concrete tie track after every 160 MGT was used in the baseline analysis. Table 3-2 contains

Table 3-2 contains a summary of the maintenance or renewal frequencies for 15 and 40 annual MGT for each of the nine operations just described. The life cycle costing described later in this report is based on these maintenance and renewal frequencies.

*See Appendix B for details.

TABLE 3-2 FREQUENCY OF MAINTENANCE OPERATIONS FOR THE BASELINE ANALYSIS

(Cycle Length In Years)

Maintenance Operation	Test Case 1 Existing Track				Test Case 2 New Track				Test Case 3 Electrified		Test Case 4 Curves Only			
	15 Annual MGT		40 Annual MGT		15 Annual MGT		40 Annual MGT		40 Annual MGT		15 Annual MGT		40 Annual MGT	
	Wood	Concrete	Wood	Concrete	Wood	Concrete	Wood	Concrete	Wood	Concrete	Wood	Concrete	Wood	Concrete
1. Lay rail - 136 RE	46	47	30	31	46	47	30	31	30	31	16.7	25	6.25	9.4
2. Tie replacement	6.6[1]	7[2]	4.6[1]	5[2]	6.6[1]	7[2]	4.6[1]	5[2]	4.6[1]	.5[2]	5.25[1]	7[2]	3.5[1]	5[2]
3. Surface and line track	5.1	5.1	3.6	3.6	5.1	5.1	3.6	3.6	2.0	2.0	5.1	5.1	3.6	3.6
4. Clean ballast and[3] surface and line track	15.3	15.3	10.8	10.8	15.3	15.3	10.8	10.8	6.0	6.0	15.3	15.3	10.8	10.8
5. Regage rail[4]	21	--	13.8	--	21	--	13.8	--	13.8	--	9.5	--	3.12	--
6. Transpose rail[5] (on curves only)	42	44.8	27.6	29.4	42.0	44.8	27.6	29.4	22.6	29.4	16.7	25.0	6.25	9.4
7. Spot work	0.8	0.8	0.3	0.3	0.8	0.8	0.3	0.3	0.3	0.3	0.8	0.8	0.3	0.3
8. Repair derailment per track mile	112	112	42	42	112	112	42	42	42	42	112	112	42	42
9. Grind rail	10.7	10.7	4.0	4.0	10.7	10.7	4.0	4.0	4.0	4.0	10.7	10.7	4.0	4.0

(1) This represents a 25 percent tie replacement.
(2) A 3.8 percent replacement 5 years after installation, and a 0.5 percent replacement at the interval shown.
(3) Every third surface and lining cycle includes ballast cleaning.
(4) Regaging of rail on wood tie track between rail laying or removal and transposition.
(5) Transpose between laying and removing rail.

4. MAJOR EQUIPMENT REQUIREMENTS

This section contains a discussion and summary of the major track equipment used to install and maintain wood and concrete tie track. The primary purpose is to identify the different equipment requirements for each type of track.

Installing Concrete Ties in Existing Track

The least expensive method of installing concrete ties in existing track, under most conditions, is with the track laying system.* The track laying system has been used in Europe and is just being introduced into North America. The cost of the system is reported to be $1.5 to $2 million.

The apparatus threads the rail out beyond the end of the ties, picks up the old ties, moves them by conveyor belt to flat cars for transport and replaces them with new (concrete) ties at the correct spacing. Either new CWR or the old rail is then threaded back onto the new ties. Behind this machine the track is usually undercut to lower it to the original grade and additional ballast added and the track surfaced.

In this study, the cost estimate for original installation of concrete ties is based on use of a track laying system. The track laying system could be used for wood tie replacement, if 100 percent replacement of wood ties was an economical alternative. This alternative, which represents a fundamental difference in maintenance philosophy over that traditionally used by railroads today, was not evaluated in this study.

New Track Construction

Much of the equipment used in new construction of wood tie track is also used for construction of concrete tie track. Whereas spike drivers are used with wood ties, a machine of approximately equal cost would be needed for applying fasteners to concrete ties. Both types of ties must be distributed by truck or by rail if available. Wood ties can be spaced by hand, but a special

*The minimum number of track miles required to justify using a track laying system will vary widely depending upon equipment availability and cost, the physical layout and design of the railroad, and the track availability.

machine or small crane is needed for concrete ties since they weigh over 600 pounds each. Distribution of ballast and raising, lining and tamping the ties require the same equipment for both types of tracks.

Rail Renewal

Relaying CWR on concrete ties requires substantially less equipment than relaying CWR on wood ties. A comparison of the equipment typically used is shown in Table 4-1.

Tie Renewal

There is very little experience with renewal of concrete ties in North America, therefore, there is no specialized equipment presently in the United States for removal and installation of concrete ties. For wood tie track, there are several types of equipment designed for removing and installing large numbers of ties, with minimum damage to the rest of the existing track structure, some of which could possibly be modified to handle concrete ties.

The equipment required for a typical tie gang is shown in Table 4-2.

Surfacing and Lining Track

For surfacing and lining, essentially the same type of equipment can be used on both wood and concrete tie track.

Other Maintenance

The equipment required for other maintenance operations is much the same for both wood and concrete ties. Ballast cleaning, spot surfacing and rail grinding utilize the same equipment. Equipment used in transposing and regaging rail is similar to that required in rail laying.

TABLE 4-1 EQUIPMENT FOR RAIL RELAY

Item	Approx. Purchase Price(1) (1000s)	Wood Ties	Concrete Ties
Spike Puller	13	X	
Speed Swing	90	X	X(2)
Ballast Cribber	8	X	X(2)
Tie Adzer	13	X	
Creosote Machine	4	X	
Gager	25	X	
Compressor, Hi-Rail	35	X	
Spike Drivers	9	X	
Anchor Applicator	12	X	
Rail Heater	22	X	X
Machine to remove and install fasteners	25		X

Notes

(1) Does not include sales tax or delivery costs
(2) Heavier duty required for concrete ties.

TABLE 4-2 EQUIPMENT FOR TIE RENEWAL

Item	Approx. Purchase Price(1) (1000s)	Wood(2) Ties	Concrete(3) Ties
Dual Spike Puller	13	X	
Tie Shear	51	X	
Tie Crane	22	X	X(4)
Tie Bed Scarifier/Inserter	35	X	X
Rail Lifter	4.5	X	X
Dual Spike Setter/Driver	50	X	
Anchor Applicator	12	X	
Spot Tamper	60	X	X
Ballast Regulator	55	X	X
Machine to remove and install fasteners	25		X(5)
Machine to remove tie and install concrete ties	100		X

Notes

(1) Does not include sales tax or delivery costs.
(2) Example of equipment for replacing 600-1000 ties per mile.
(3) Equipment used for replacement of 60-160 ties per mile. (Study assumes that 100% of concrete ties are replaced by Track Laying System at end of useful life.)
(4) Machine of this type needed but would have to be heavier duty than that used for wood ties.
(5) Probably used only for 100% replacement of concrete ties.

5. ENVIRONMENTAL CONSIDERATIONS

The primary environmental considerations for wood and concrete tie track structures are:

a. availability of materials: cement, stone aggregates, steel, and lumber,

b. disposal of ties removed from track, and

c. total energy consumed building, maintaining, and operating trains on the track.

5.1 AVAILABILITY OF MATERIALS

The present and future availability of cement, stone aggregates, and steel were not formally addressed in this study. There are indications, however, that as a result of tougher environmental constraints on cement and steel manufacturers and quarrying activities, the price of concrete tie materials will be increasing.

A review of the future availability of hardwood cross ties was undertaken in this study which, unfortunately, revealed a lack of sufficient data to project future availability or prices with any degree of certainty. This is largely due to the unpredictable demand for wood products and the costs involved in retrieving logs of sufficient dimensions for cross ties. Following is a brief summary of the findings of the investigation.

The demand for wood ties has varied widely in the United States. Installations were 47 million ties in 1937, 12 million in 1961, and 20 million in 1973. For the existing railroad system, however, future annual replacements of 30 million ties per year are projected [5-1]. Construction of new lines and abandonment of old lines will alter this demand slightly.

The most comprehensive review of timber availability and future demand for all wood products is the Outlook for Timber in the United States performed by USDA in 1974 [5-1]. The following quotation from this report summarizes the USDA's findings on hardwood supply and future prices in the U.S.

> "Supplies of hardwood timber are increasing although industrial use is limited by problems of quality and availability.
>
> The outlook for hardwoods is somewhat mixed in spite of the fact that removals, of all sizes and species of hardwood

timber in 1970 was some 25 percent less than total net growth.

Projections of available supplies of hardwood sawtimber over the next few decades - assuming 1970 levels of forest management and specified cutting rates - increase 66-percent, from an actual harvest of 12.3 billion board feet in 1970 to over 20 billion board feet by 2000. This approximates the projection of demand associated with 1970 prices.

Projected supplies of hardwood products, in cubic feet, under these same assumptions materially exceed potential demands at 1970 prices.

While these projections imply little or no increase in hardwood prices, there are practical limitations on amounts of timber available for sale and industrial use at any given time. To many owners of hardwood timberland use of the forest for recreation or other nontimber objectives is of primary importance. Problems of quality also are of special significance. Much of the growth and available supply of hardwoods are in small tree sizes or species for which markets are limited; whereas the larger sizes of preferred species are in short supply in most areas. Other factors that could produce a tighter supply situation and higher prices include possible substitution of hardwoods for softwoods in production of woodpulp and certain other timber items."

USDA is not projecting a shortage of hardwoods, but they are projecting a potential shortage of hardwoods of sufficient size and quality for railroad ties. Additionally, discussions with H. R. Josephson, a consultant to the Railway Tie Association, revealed that other demands for softwoods might reduce their availability for ties, thus increasing the demand for hardwood ties. USDA made projections of future consumption of "new non-residential construction" lumber of which railroad ties are included. Three levels were projected, based on alternative assumptions for growth in population and economic activity, and land management policy. The projections indicate future consumption of this lumber group will grow at a compound annual growth rate of 1 percent for the low projection, 1-1/2 percent for the medium projection, and 2 percent for the high projection. Correspondingly, supply of hardwood between 1980 and 2000 is not projected to grow significantly, but the net growth is expected to exceed supply until the year 2000, as shown in Figure 5-1.

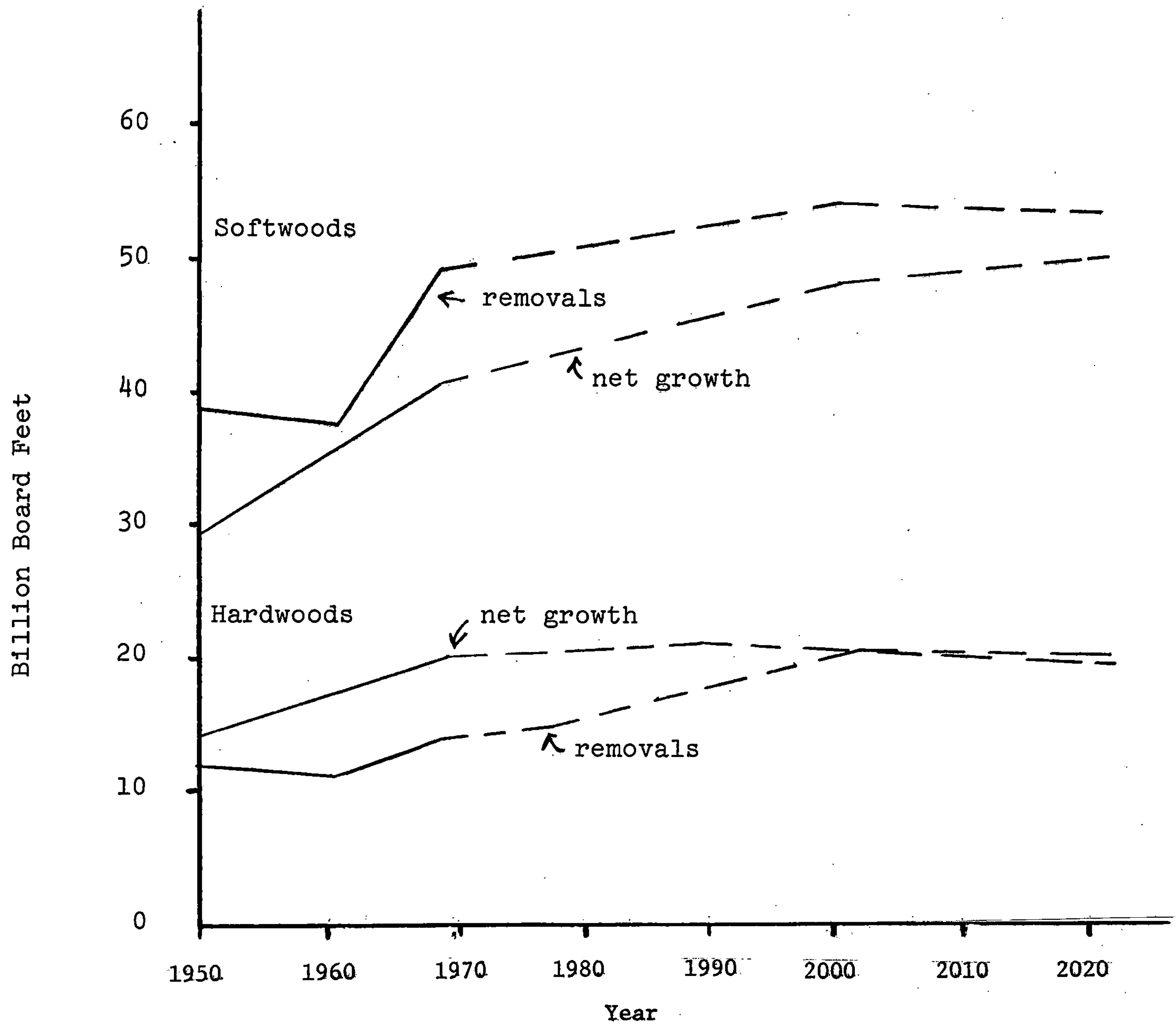

FIGURE 5-1 NET GROWTH AND REMOVALS OF SAW TIMBER IN THE UNITED STATES [5-1]

The USDA study does not include projections of future tie costs, but assuming good timber management and moderately increasing demand nationwide, the supply of hardwoods for tie manufacture is projected to be sufficient through the year 2000. This would represent the lowest cost for wood ties - stable tie prices measured in constant dollars. Therefore, in order not to unjustifiably bias the economic attractiveness of concrete ties, the baseline economic analysis was based on no escalation of wood tie prices (above the average 4 percent general inflation rate) over the 50 year life cycle. A life cycle cost sensitivity analysis was performed on each test case using a 1.5 percent inflation rate for wood ties in addition to the 4 percent general inflation rate. In 1977 dollars, a 1.5 percent annual inflation rate yields a $31 tie cost in 50 years, based on $15 per tie in 1977. It is understood, however, that both these cost estimates are average only. The cost of wood ties - including transportation costs - vary widely from region to region. Therefore, it is necessary that a railroad quantify as best they can the future availability and cost of wood ties for the specific line on which concrete versus wood tie economy is being studied.

Reconstituted and dowel-laminated ties were not reviewed in depth in this study. However, it is not anticipated that either of these ties will result in production costs lower than existing wood tie costs. The potential introduction of this or other new ties was an additional reason for not escalating the price of wood ties higher than the 4 percent average inflation rate.

5.2 DISPOSAL OF TIES

Wood ties removed from track may be disposed of in a variety of ways including:

- Reuse in other track
- Cribbing of railroad track, roads, etc.
- Sold for other uses (e.g., landscaping)
- Pulverized for manufacture of reconstituted ties
- Chopped into chips
- Burned as fuel
- Buried in ground
- Left in right-of-way, either whole or in pieces.

As a result of increasingly stringent environmental constraints, the last two alternatives are becoming much harder for the railroads to use. Therefore, for deteriorated wood ties, the railroads are going to be faced with increased disposal costs unless some alternative uses are forthcoming. In this study, wood tie disposal was based on cutting the ties into 3 pieces, removing from track, and hauling to a nearby dumping site. Although cutting the ties is expensive, increased production of the tie renewal operation using this method results in a low cost alternative as compared with most of the other methods traditionally used.

There is no significant secondhand use of concrete ties established because few have been removed from track. Trnasportation costs will be high, necessitating a local market. In this study, concrete ties would be removed out of face by the track laying system. It was estimated that the cost of transporting the concrete ties to a market would equal the credit from sales or value to the railroad for use in cribbing, etc., and therefore a net salvage credit of zero was included.

5.3 TOTAL ENERGY CONSUMED

An investigation and quantification of the energy required to produce, maintain, and dispose of wood and concrete tie track systems components was beyond the scope of this study. Table 5-1 is a list of major items that require quantification in order to comprehensively evaluate energy consumed for both track structures.

TABLE 5-1 TOTAL ENERGY CONSUMPTION FOR WOOD- AND CONCRETE-TIE TRACK STRUCTURES - ITEMS FOR QUANTIFICATION

Wood Ties	Concrete Ties
saw timber	manufacture cement
haul logs to mill	manufacture steel
saw logs into ties	mine and process aggregate
ship to treatment plant	haul materials to concrete tie plant
treat ties	manufacture ties
store ties	manufacture OTM
haul to track	store ties
manufacture and deliver other track material (OTM)	haul to track
install ties	install ties
renew rails as required	renew rail as required
surface and line track	surface and line track
gage rail	transpose rail
transpose rail	repair derailments
repair derailments	grind rail
grind rail	train fuel consumption
train fuel consumption	remove ties
remove ties	dispose of ties
dispose of ties	

6. RESULTS OF ECONOMIC STUDY

This section includes a review and summary of the 50 year life cycle economic analysis performed for both wood and concrete tie track structures for the four test cases. The analysis is based on the economic framework described in Section 1, the cost estimates set out in Section 2, and the maintenance and renewal requirements described in Section 3. Summarized herein are the justifiable cost of concrete ties and the overall economy of wood and concrete tie track structures for the baseline analysis, the sensitivity of life cycle costs to changes in selected cost and service variables, and a description of the methodology used to compute life cycle costs over the 50 year period.

In addition to the costs and maintenance and renewal frequencies described in the previous sections, an additional $3000 per track mile was added to the cost of installing concrete ties to cover train operating delay costs incurred as a result of the track time required to install the concrete ties. The $3000 was based on three hours track time per mile at an estimated value of $1000 per hour. The actual value of track time varies widely as a function of many variables. The time of three hours per track mile was that additional time allocated solely to the concrete tie placement activity.

6.1 RESULTS OF BASELINE LIFE-CYCLE COST ANALYSIS

The numerical results for all test cases are summarized in Table 6-1. The justifiable cost of concrete ties* and the life cycle savings or loss for concrete tie track over wood tie track** evaluated at 15 and 40 annual MGT and 0, 7, and 10 percent discount rates are shown in the table. The percent savings shown in Table 6-1 are based on the following nine maintenance and renewal operations (labor, equipment and materials):

1) Lay new rail
2) Tie replacement

*Justifiable cost of a concrete tie includes the purchase price of the tie, fastening hardware, delivery, and sales tax. The justifiable cost is derived by setting equal the life cycle costs for wood and concrete tie track structures.

**Using $38.80 as the cost of a concrete tie. This cost was estimated based on $30 for concrete tie purchase and delivery, $5.20 for rail clips, $1.10 for pads, $1.00 for insulators and 4 percent sales tax. See foot notes in Table 6-1 for the internal rate of return for each of the four test cases based on $38.80.

TABLE 6-1 JUSTIFIABLE COST PER CONCRETE TIE BASED ON 50-YEAR LIFE-CYCLE COSTS

Test Case Description	40 Annual MGT - Class 5 Track						15 Annual MGT - Class 5 Track					
	0 Percent Discount Rate		7 Percent Discount Rate		10 Percent Discount Rate		0 Percent Discount Rate		7 Percent Discount Rate		10 Percent Discount Rate	
	Justifiable Cost of Ties	Percent(1) Savings	Justifiable Cost of Ties	Percent(1) Savings	Justifiable Cost of Ties	Percent(1) Savings	Justifiable Cost of Ties	Percent(1) Savings	Justifiable Cost of Ties	Percent(1) Savings	Justifiable Cost of Ties	Percent(1) Savings
<u>Test Case I - Install Concrete Ties in Existing Track</u>												
<u>Baseline</u> (2)												
<u>Lay New Rail</u> (3)	$167.90	+25.0	$38.50	-0.2	$ 21.30	-21.7	$ 76.10	+15.2	$ 23.40	-20.2	$ 9.30	-60.2
Relay existing rail	154.00	+22.3	41.60	+2.4	27.80	-13.7	83.30	+18.1	27.30	-15.1	18.50	-41.4
<u>Sensitivities</u>												
Concrete tie life 37 years at 40 MGT	--		-8.40		-4.10		--		--		--	
Grind rail on concrete tie track twice as often	-13.80		-2.40		-1.50		-5.20		-0.90		-0.60	
Replace ballast	-4.90		-4.90		-4.90		-4.90		-4.90		-4.90	
Wood tie life +5 years 23.4 years at 40 MGT 31.4 years at 15 MGT	-48.40		-8.40		-5.30		-25.40		-4.40		-2.80	
Wood tie life -5 years 13.4 years at 40 MGT 21.4 years at 15 MGT	+87.60		+15.30		+9.60		+37.50		+6.40		+4.10	
Surface concrete tie track 1/2 as often as wood	+68.00		+11.80		+7.50		+48.10		+8.40		+5.30	
Wood tie costs inflate at 1.5% greater than average inflation annually	+101.00		+17.60		+11.10		+73.00		+12.70		+8.00	
Labor costs escalate 2% greater than average inflation annually	+46.50		+8.10		+5.10		+32.80		+5.70		+3.60	
1% energy savings on concrete tie track	+16.10		+2.80		+1.80		+6.10		+1.10		+0.70	
<u>Test Case II - New Track</u>												
<u>Baseline</u> (4)	178.00	+24.8	59.60	+11.9	46.40	+5.6	98.60	+19.0	46.20	+5.7	38.60	-0.3
<u>Sensitivities</u>												
Concrete tie life 37 years at 40 MGT	--		-8.40		-4.10		--		--		--	
Grind rail on concrete tie track twice as often	-13.80		-2.40		-1.50		-5.20		-0.90		-0.60	
Ballast $4.50 vs. $6.50 per cubic yard	-2.30		-2.30		-2.30		-2.30		-2.30		-2.30	
Wood tie life + 5 years 23.4 years at 40 MGT 31.4 years at 15 MGT	-49.60		-8.60		-4.80		--		-3.50		-2.10	
Wood tie life - 5 years 13.4 years at 40 MGT 21.4 years at 15 MGT	+85.50		+15.50		+10.00		--		+7.20		+4.10	
Surface concrete tie track 1/2 as often as wood	+68.00		+11.80		+7.50		+48.10		+8.40		+5.30	
Wood tie costs inflate at 1.5% greater than average inflation annually	+26.40		+7.00		+3.60		+16.60		+9.80		+0.40	
Labor costs escalate 2% greater than average inflation annually	+15.60		+2.10		+0.90		+8.30		+0.50		+0.20	
1% energy savings on concrete tie track	+16.10		+2.80		+1.80		+6.00		+1.10		+0.70	

(1) Estimated percent savings for concrete ties over wood ties over the 50 year life-cycle based on $38.80 cost for concrete ties. See Introduction to Section 6 for costs included.

(2) Based on a cost of $38.80 for concrete ties, the internal rate of return is approximately: Lay new rail 7% for 40 MGT; 5% for 15 MGT, Relay existing rail 8% for 40 MGT; 5-1/2% for 15 MGT.

(3) Removed rail has 50% of useful life remaining.

(4) Based on cost of $38.80 for concrete ties, the internal rate of return is approximately: Lay new rail 14% for 40 MGT; 10% for 15 MGT.

TABLE 6-1 (Continued)

Test Case Description	40 Annual MGT - Class 6 Track					
	0 Percent Discount Rate		7 Percent Discount Rate		10 Percent Discount Rate	
	Justifiable Cost of Ties	Percent(1) Savings	Justifiable Cost of Ties	Percent(1) Savings	Justifiable Cost of Ties	Percent(1) Savings
Test Case III - Install Concrete Ties in Existing Electrified Interior Track						
Baseline - Lay New Rail (2) (3)	$229.00	+23.7	$ 42.50	+2.1	$ 20.80	-16.3
Sensitivities						
Concrete tie life 37 years	-25.50		-9.10		-4.40	
Grind rail on concrete tie track twice as often	-13.80		-2.40		-1.50	
Wood tie life + 5 years 23.4 years at 40 MGT 13.4 years at 40 MGT	-53.60		-9.30		-5.90	
Wood tie life - 5 years 13.4 years at 40 MGT 21.4 years at 15 MGT	+95.70		+16.70		+10.50	
Surface concrete tie track 1/2 as often as wood	+122.00		+21.30		+13.50	
Wood Tie costs inflate at 1.5% greater than average inflation annually	+101.00		+17.60		+11.10	
Labor costs escalate 2% greater than average inflation annually	+58.60		+10.20		+6.40	
1% energy savings on concrete tie track	+16.10		+2.80		+1.80	

Test Case Description	40 Annual MGT - Class 5 Track						15 Annual MGT - Class 5 Track					
	0 Percent Discount Rate		7 Percent Discount Rate		10 Percent Discount Rate		0 Percent Discount Rate		7 Percent Discount Rate		10 Percent Discount Rate	
	Justifiable Cost of Ties	Percent(1) Savings	Justifiable Cost of Ties	Percent(1) Savings	Justifiable Cost of Ties	Percent(1) Savings	Justifiable Cost of Ties	Percent(1) Savings	Justifiable Cost of Ties	Percent(1) Savings	Justifiable Cost of Ties	Percent(1) Savings
Test Case IV - Install Concrete Ties Only in Sharp Curves (> 4 degrees)												
Baseline - Relay Existing Rail (4)	$666.00	+41.0	$128.00	+29.7	$ 80.80	+21.8	$291.00	+42.4	$ 62.50	+17.5	$ 39.70	+1.0
Sensitivities												
Concrete tie life: 37 years at 40 MGT	--		-8.90		-4.30		--		--		--	
Grind rail on concrete tie track twice as often	-13.80		-2.40		-1.50		-5.20		-0.90		-0.60	
Replace ballast	-4.90		-4.90		-4.90		-4.90		-4.90		-4.90	
Wood tie life + 5 years 19.0 years at 40 MGT 26 years at 15 MGT	-85.00		-14.90		-9.40		-41.50		-7.20		-4.60	
Wood tie life - 5 years 9 years at 40 MGT 16 years at 15 MGT	+179.00		+31.10		+19.60		+67.40		+11.70		+7.40	
Surface concrete tie track 1/2 as often as wood	+68.00		+11.80		+7.50		+48.10		+8.40		5.30	
Wood tie costs inflate at 1.5% greater than average inflation annually	+143.00		+24.80		+15.66		+97.20		+16.90		+10.60	
Labor costs escalate 2% greater than average inflation annually	+78.00		+13.60		+8.50		+35.60		+6.20		+3.90	
1% energy savings on concrete tie track	+16.10		+2.80		+1.80		+6.10		+1.10		+0.70	

(1) Estimated percent savings for concrete ties over wood ties over the 50 year life-cycle based on $38.80 cost for concrete ties. See introduction to Section 6 for costs included.

(2) Removed rail has 50% of useful life remaining.

(3) Based on a cost of $38.80 for concrete ties, the internal rate of return is approximately: Lay new rail 7.5% for 40 MGT.

(4) Based on a cost of $38.80 for concrete ties, the internal rate of return is approximately: Lay new rail 16% for 40 MGT; 10% for 15 MGT.

3) Surface and line track
4) Clean ballast and surface and line track
5) Regage track
6) Transpose rail
7) Spot surfacing
8) Derailment repairs
9) Grind rail.

Major cost items common to both wood and concrete ties such as track inspection, ditching, weed control, special track work maintenance, and bridge maintenance are not included.

Table 6-2 is a summary of the cost to install concrete ties and the average annual maintenance and renewal cost for concrete and wood tie track structures for each test case for constant 1977 dollars and costs discounted at 7 and 10 percent. The costs include the nine maintenance and renewal operations described in the preceding paragraph.

Firgures 6-1 and 6-2 display graphically the economy of concrete ties over the range of 15 to 40 annual MGT. These graphs were developed by connecting the points on the graph for 15 and 40 annual MGT, which were specifically evaluated in the study. Although this linear approximation is not exactly correct, it is within the range of accuracy of this economic study. Figure 6-1 is a plot of the justifiable cost of concrete ties for test cases I and II at the 7 and 10 percent discount rates. Figure 6-2 shows the average annual maintenance and renewal savings per track mile for concrete tie track over wood tie track. These savings are measured in constant 1977 dollars for the 50-year life cycle.

6.1.1 Test Case I: Installation of Concrete Ties in Existing Track. Two separate analyses were made for this case. The first involved laying new rail when the concrete ties are installed. The removed rail was considered to have 50 percent of its service life remaining, with the appropriate residual value credited in the cost analysis. The second analysis involved relaying the existing rail (also 50 percent rail life remaining) when the concrete ties are installed. Relaying existing rail is more cost effective when costs are

TABLE 6-2 CONSTRUCTION AND AVERAGE ANNUAL MAINTENANCE COSTS PER TRACK MILE(1)

(thousands of 1977 dollars escalated at 4% annually)

Baseline Analysis	Cost to Install(2) Concrete Ties	Annual Maintenance & Renewal Cost		Discounted Annual Maintenance and Renewal Cost(3)			
		Constant 1977 Dollars		7 Percent Discount Rate		10 Percent Discount Rate	
		Wood	Concrete	Wood	Concrete	Wood	Concrete
I. Existing Track							
A. Lay New Rail - 40 MGT	$151.5	$11.2	$ 6.6	$ 6.1	$ 3.4	$ 4.0	$ 2.2
15 MGT	151.5	6.7	3.4	3.6	1.4	2.5	1.1
B. Relay existing rail - 40 MGT	99.1	11.2	7.6	6.1	4.0	4.0	2.7
15 MGT	99.1	6.7	4.4	3.6	2.4	2.5	1.6
II. New Track - 40 MGT	208.8 Wood 228.3 Concrete	9.6	6.6	4.8	3.4	2.9	2.2
15 MGT	208.8 Wood 228.3 Concrete	5.0	3.4	2.2	1.4	1.5	1.1
III. Electrified/Interior-Lay Rail							
40 MGT	164.1	16.2	10.5	8.7	6.8	25.8	4.6
IV. Curves Only - Relay Existing Rail							
40 MGT	107.2	28.9	16.4	15.4	8.8	10.1	5.7
15 MGT	107.2	12.7	7.8	6.8	3.6	4.6	2.5

(1) Salvage credit included.

(2) Includes $38.80 for cost of concrete tie including fasteners, delivery, and 4% sales tax.

(3) Does not include cost to install concrete ties.

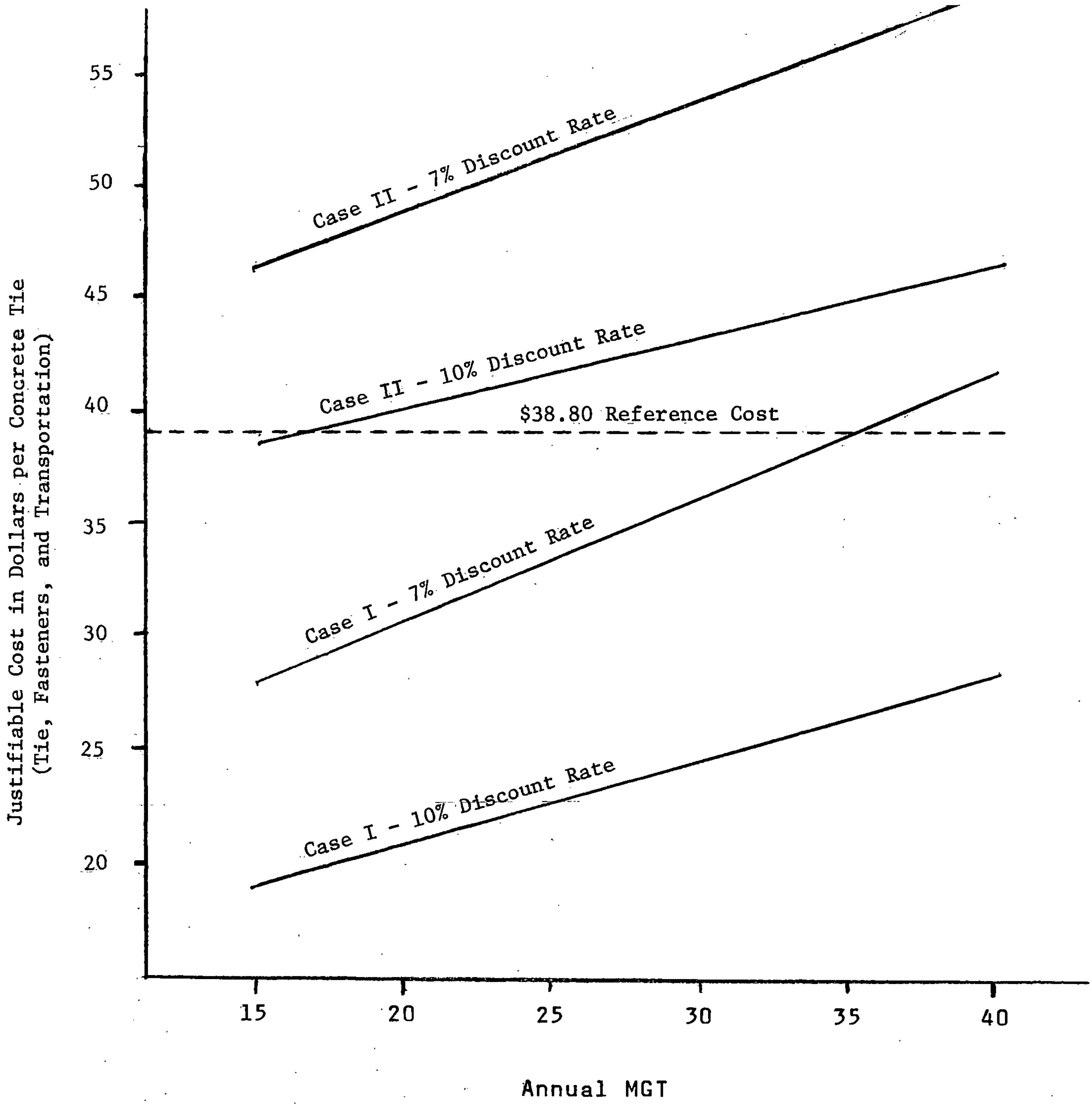

FIGURE 6-1 JUSTIFIABLE COST PER CONCRETE TIE

(Baseline analysis - Discounted 1977 Dollars inflated at 4% annually)

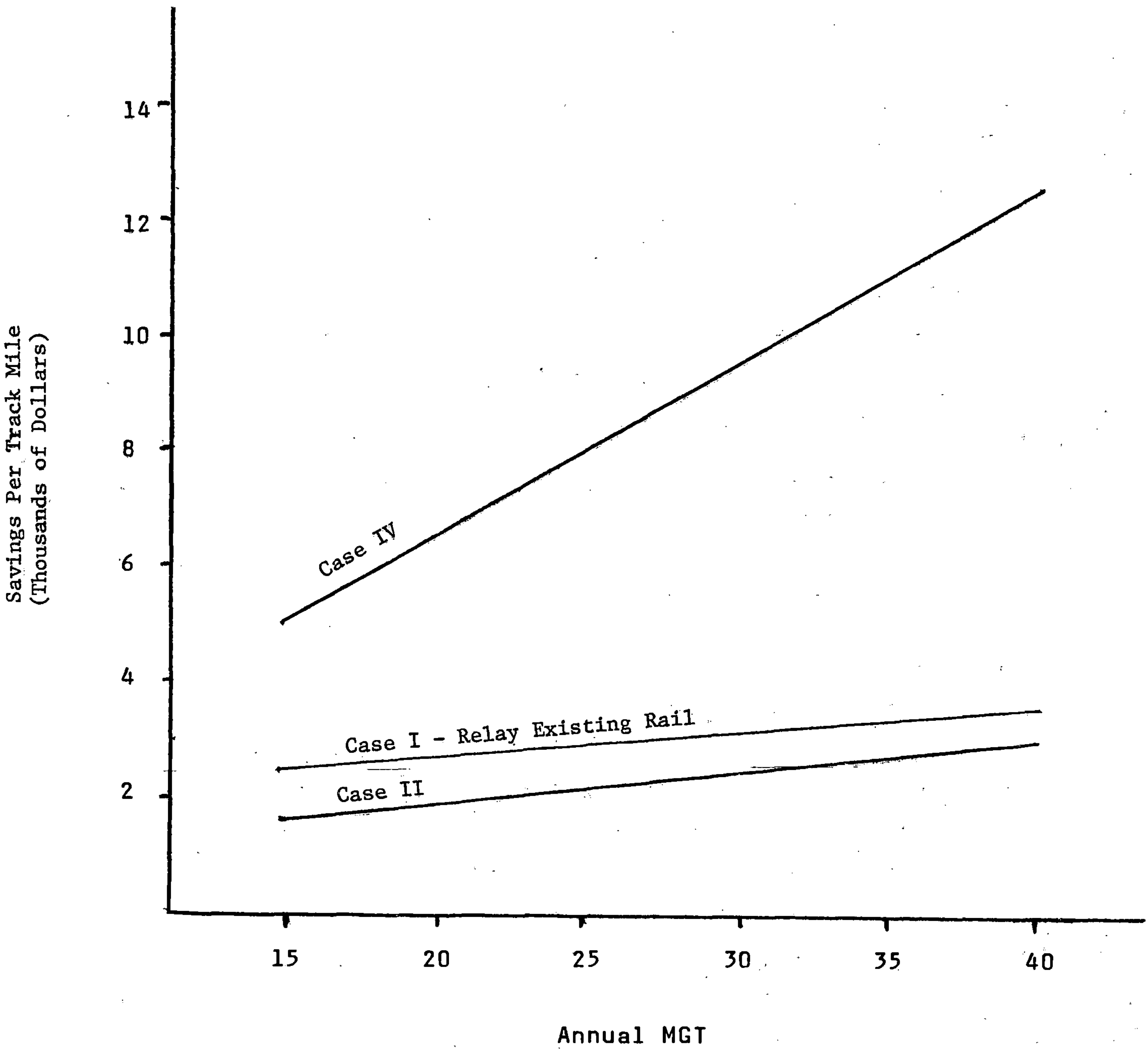

FIGURE 6-2 AVERAGE ANNUAL MAINTENANCE AND RENEWAL SAVINGS PER TRACK MILE FOR CONCRETE VERSUS WOOD TIE TRACK

(Baseline Analysis - Constant 1977 Dollars) discounted at 7 or 10 percent. Clearly, the most cost effective case would occur when the rail requires replacement at the same time the concrete ties are installed.*

The results of the baseline analysis show that for an assumed purchase price of $38.80 per concrete tie, the break even life cycle cost for concrete and wood ties occurs at approximately 35 annual MGT at the 7 percent discount rate. The break even cost point would be greater than 40 annual MGT for the 10 percent discount rate.

6.1.2 Test Case II: New Track. For new track construction, the accuracy of track construction cost estimates for both wood and concrete tie track is better than for those cases involving placement of concrete ties in existing track. Therefore, precision of life cycle costs for both wood and concrete tie track is higher in this test case than the other test cases. At an assumed purchase price of $38.80 per concrete tie, the break even life cycle cost for wood and concrete tie structures is much less than 15 annual MGT at the 7 percent discount rate. At the 10-percent discount rate, the break even point occurs at about 15 annual MGT.

6.1.3 Test Case III: Installation of Concrete Ties in Existing Electrified, Interior Track. This test case was selected in order to evaluate the impact of concrete tie economy for an existing high performance track structure, with high traffic density. The train traffic and track performance requirements used in the life cycle cost analysis were similar to those which will be experienced on the Northeast Corridor (NEC) after improvements are made.** The unit costs used in the analysis, however, were general in nature and although not grossly different from what should be incurred in the NEC, are not NEC specific.

*To answer the question of whether or not to lay new rail when concrete ties are installed, the railroad should consider the use and value of rail removed and the savings by laying rail when the ties are installed versus a separate operation at a later date.

**The cost estimates include replacing existing rail which has 50 percent of its useful life remaining. This test case does not reflect the cost/benefit of concrete ties in the NEC because the existing plant is badly deteriorated. Therefore, major upgrading is required whether or not concrete ties are installed. This situation favors the concrete tie case, especially at high discount rates, because of the early money required for the wood-tie alternative also.

The annual maintenance and renewal costs for concrete tie track are approximately 65 percent of those for wood tie track in this case. This results in an average annual savings of approximately $5,700 per track mile measured in 1977 dollars. On the life cycle cost basis for discount rates greater than about 7 percent, however, this savings is largely offset by the high cost to install concrete ties. The baseline results indicate a justifiable cost of concrete ties of $42.50 at the 7-percent discount rate and $20.80 at the 10-percent discount rate for 40 annual MGT.

6.1.4 Test Case IV: Installation of concrete ties in 4 degree curves in existing track. This test case was made to evaluate the savings resulting when concrete ties are installed only in sharp curves. The costs used reflect the increased cost of installing and maintaining concrete ties only in curves. The following frequency of component renewals was used:

	Wood-tie track		Concrete-tie track	
	15 MGT	40 MGT	15 MGT	40 MGT
Rail life	16.7 yr	6.25 yr	25 yr	9.4 yr
Tie life	21 yr	14 yr	50 yr	50 yr
Regage track	4.3 yr	1.6 yr	--	--

The extended life of rail and ties in curves and the lack of regaging results in substantial life cycle cost savings for concrete tie track. The percent savings over 50 years for concrete ties purchased at $38.80 per tie, as shown in Table 6-1, would range from 1.0 percent at the 10-percent discount rate and 15 annual MGT to 29.7-percent at the 7-percent discount rate and 40 annual MGT. The break even points occur at about 4 and 13 MGT for 7- and 10-percent discount rates, respectively.

A significant factor in the decision to install concrete ties in curves should be the quality of ballast and condition of the subgrade in the curves. The baseline analysis considered cleaning of the existing ballast only. However, as shown in the sensitivity study, complete replacement of the ballast would reduce the justifiable cost by only $4.90 per tie, so concrete ties would still be economically feasible on curves.

The Canadian National Railroad will be installing concrete ties in curves of four degrees and greater in the Rocky Mountains over the next several years. In some of these curves, the entire track structure will be removed, the subgrade will be compacted, the concrete ties and rail will be installed and new ballast will be hauled in and placed. This will be costly. However, the concrete ties should not be charged with the costs of all operations unless all the work is required solely for the improved support of the concrete ties.

The use of concrete ties in sharp curves should be very cost effective, but better ballast may be required than exists for the wood ties. Previous experience shows that very soft ballast materials experience excessive abrasion and crushing when used with concrete ties. The cost of providing this foundation should be carefully evaluated before making the decision to install concrete ties.

6.2 RESULTS OF LIFE-CYCLE COST-SENSITIVITY ANALYSES

Quantification of the effect of changes in certain variables on life cycle costs was necessary in this study as a result of:

a. Difficulty in predicting future price inflation rates

b. Lack of sufficient data to predict the cost of performing maintenance operations, particularly for concrete tie track

c. Lack of sufficient data to predict the cycle length between major maintenance operations

d. Variations in useful life of major system components

e. Regional effect on costs and track maintenance requirements

f. Variable condition of existing track systems

g. Variations in expected project life.

The results of the sensitivity analyses are shown in Table 6-1. Interpolation can be made between the results of the baseline analysis and the sensitivity analysis. Following is a discussion of the sensitivities performed.

Discount Rate

As explained previously, all costs were evaluated over the 50 year life cycle for a 0, 7 and 10 percent discount rate and a 4 percent general inflation rate. Each railroad has a different borrowing position and different investment opportunities. Therefore, the appropriate discount rate for the railroad involved should be used for evaluating concrete tie economy.

Between 1949 and 1965, the nominal rate of return (not corrected for inflation) was 12 percent return on investment for the major U.S. industries according to Stockfisch, J.A. Measuring the Opportunity Cost of Government Investment. According to the "Rail Merger Study", Rail Services Planning Office, Interstate Commerce Commission, Washington, D.C. April 15, 1977, p. 27, the average return on investment for the top (highest return on investment) five Class I carriers was 6 percent (not corrected for inflation) in 1976.

Project Life

A 50-year project life was evaluated in the study; a life which extends long enough to take full advantage of those system components with the longest service life. If the estimated project life is less than 40 years, however, the advantage of concrete ties would be significantly less, except on curves.

Concrete Tie Life

The baseline for each test case was evaluated using a 50-year life for concrete ties. A sensitivity test was made based on a concrete tie life twice that of wood, or 37 years for concrete ties at the 40 MGT level. The cost of 100 percent concrete tie renewal was input based on use of the track laying system. No salvage credit was taken. At the 10 percent discount rate, this represents a lowering of the justifiable cost of concrete ties by 4 dollars. The higher the discount rate, the less significant the reduction in service life is on life cycle costs.

Rail Grinding

There is some speculation that rail supported by concrete ties may require more frequent rail grinding than rail supported by wood ties due to a higher incidence of rail corrugations. Presumably, the corrugations are caused by a higher harmonic wheel force due to the higher track modulus for concrete tie track. Based on consultation with Dr. Stephen Marich, AAR, a sensitivity test was made for rail grinding twice as frequently on concrete tie track than wood tie track. For 40 MGT, this reduces the justifiable cost of concrete ties by $1.50 at the 10 percent discount rate.

Replace Ballast

The baseline analysis includes cleaning of existing ballast at the time concrete ties are placed in track. A sensitivity test was made based on removing the existing ballast and replacing it with ballast costing $6.50 per cubic yard, delivered. No subgrade work was included in the baseline or sensitivity analysis. The justifiable cost of concrete ties is reduced by $4.90 for all cases and discount rates if ballast is replaced.

For Test Case II, new track, a sensitivity analysis was made using a ballast cost of $4.50 per cubic yard (delivered) for wood tie track versus $6.50 per cubic yard for concrete tie track construction. (The baseline analysis included $6.50 per cubic yard for ballast for both wood and concrete tie track structures. The assumption was made for the baseline analysis that based on the track structure designs described in section 2 and the use of high quality ballast, that the surfacing and lining frequency would be equal for both track structures.) The result of using the less expensive ballast for wood tie track construction lowers the justifiable cost of concrete ties by $2.30.

Wood-Tie Life

The service life of wood ties varies considerably from one region of the country to another. This sensitivity evaluated the effect of a wood tie life 5 years longer and shorter than the baseline of 18.4 and 26.4 years for 40 and 15 annual MGT respectively for Test Case I. At 40 MGT and 10 percent discount rate the justifiable cost per concrete tie is reduced by $5.30 for a tie life of 23.4 years versus 18.4 years. For the same case the justifiable cost per concrete is increased by $9.60 for a wood tie life of 13.4 years versus 18.4 years.

Surface and Lining Frequency

One of the most significant potential cost savings that can be attributed to the concrete tie track system is the possible reduction in surfacing and lining requirements over that of wood tie track. The reduction in surfacing and lining frequency realized from the use of concrete ties will be highly correlated with the condition of the subgrade, quality of ballast, and the concrete tie spacing. However, there is not enough empirical data to quantify the effect of each of these variables on surfacing and lining operations.

For Test Case I, 40 annual MGT, surfacing concrete tie track half as often as wood tie track results in an increase of $7.50 for the justifiable costs of concrete ties. This probably represents the greatest potential saving for this item.

Wood-Tie Prices

The baseline analysis was evaluated for a wood-tie price inflation rate equal to the 4-percent general inflation rate used to escalate all costs over the 50-year period. Considering the recent rise in wood tie costs and the projections of future supply of timber suitable for mainline ties, this probably represents the lowest possible projection for the wood tie (or other than concrete tie) price inflation rate. A sensitivity test based on a 1.5 percent annual price escalation (over the general inflation rate) was made, which results in a 45 percent relative price increase of wood ties in 25 years and 110 percent in 50 years (over today). If this inflation rate is realized, the attractiveness of concrete ties is substantially greater. For Test Case I, the justifiable cost of concrete ties would be increased by $11.10 per tie at 40 MGT and 10-percent discount rate. Also, the present and projected costs of wood ties are major factors to consider in evaluating the timing of concrete tie installations.

Labor Costs

For the baseline, labor costs were inflated at the average 4-percent inflation rate. Labor costs have historically escalated at approximately 2 percent faster than the average rate. If this trend continues, and if the concrete tie track does result in substantial labor savings over the wood tie track, the life cycle labor savings for concrete as compared to wood tie track will be substantial. At the 10-percent discount rate, the additional 2-percent labor inflation represents an increase of $5.10 for the justifiable cost of concrete ties for Test Case I, 40 MGT, and a 10-percent discount rate.

Energy Savings

A potential savings that might be realized from concrete tie track is reduced energy consumption in train movements. The British have suggested that a 4-percent energy savings might be realized on concrete tie track as a result of the high track modulus, which causes a reduction in rolling resistance. No test results could be found to support a definite conclusion for use in this study, but a sensitivity analysis was performed to quantify the cost savings for a one percent energy savings.

A two-percent savings would be twice as great, and greater reductions in energy would produce a proportional increase in savings. Clearly more investigation is required into this important area. At 40 MGT, a one percent energy savings on concrete tie track would increase the justifiable cost of concrete ties by $1.80, and a 4-percent savings represents an increase of $7.20 per tie.

Track Design

Tie spacing is a primary consideration in track design affecting primarily the number of ties, the required ballast depth, and the surfacing and lining frequency. For the baseline analysis, the wood tie track had a 19.5 inch tie spacing. The concrete tie track had a 24 inch tie spacing with 2-1/2 inches greater ballast depth than wood tie track. All other costs remaining equal, the justifiable cost of concrete ties would be altered approximately two dollars per tie for a one inch change in tie spacing and one dollar per tie for every inch of ballast depth. In making the ballast depth and tie spacing decision, the effect on surfacing and lining frequency is the primary dependent variable to quantify.

6.3 PRECISION OF LIFE-CYCLE COST ANALYSIS

A measure of the precision of results presented in this report is difficult to estimate due to the impact of unknown future price inflation rates and lack of adequate data to project the frequency of track maintenance operations required for concrete tie track. The effects of perturbations from estimated values have been investigated by testing sensitivity to certain variables and parameters. The effect of these sensitivities on overall results show that the justifiable cost of concrete ties may be reduced to half that cost computed for the baseline analysis or increased to 2.3 times the cost for the baseline analysis when all sensitivities favorable to concrete ties are summed.

Clearly the economy of concrete ties is largely dependent on the physical condition, cost of materials, and traffic density for the specific railroad line. These site-specific costs should be carefully evaluated. It is observed that if labor and wood tie costs continue to escalate at a rate faster than the average rate of inflation, the net effect is to drive the results in favor of concrete ties.

6.4 EXAMPLE OF LIFE-CYCLE COST ANALYSIS

Appendix C sets out the complete derivation of the justifiable cost of concrete ties for Test Case I, installation of concrete ties in existing track (relay existing rail), for 40 annual MGT and 7- and 10-percent discount rates. Utilizing the methodology explained, and adjusting the unit costs and maintenance frequencies set out in this report to reflect site-specific conditions, concrete tie economy can be estimated for any railroad line.

The estimation of annual cash flow and the associated rate of return calculation for wood versus concrete ties is only part of the total economic study required to support the final investment decision. The effect of each investment alternative on the income statement and balance sheet in each year of the project life must also be prepared. This would require quantification of the following items not covered in this report:

- Sources and methods of financing and associated costs
- Effect of investment in concrete ties on railroads (present and future) ability to invest in other capital intensive projects
- Risk analysis of the investment
- Tax and insurance costs
- Effect of the investment on overhead costs
- Depreciation options
- Ranking with other investment alternatives

APPENDIX A

PRODUCTIVITY INVESTIGATION

1. Productivity - Rail Laying

Reference	Railroad	Year	Crew Size	Track-Mile Shift	M-H/ Tr Mi	On-Track M-H/Tr Mi
						(Inside Tr. not used)
A-1	USRA	74	80	0.5	1600	1280
A-2	N&W	74	76	0.5	1520	
				0.75	1014	811
A-3	Soo Line	73	42	0.4	840	609
A-4	AREA	74	81	1.0	985	764
A-4	"Example RR"	72			837	649

Wood Tie Track - Average

Average on-track man-hours per track mile = 708

For 61 man rail gang: 12 hrs./mile

Use 2 days @ 6 hrs. per day per mile

Concrete Tie Track - Estimated

Average 2 days @ 6 hrs. per day per mile

45 man rail gang estimated

2. Productivity - Tie Replacement

Reference	Railroad	Year	Crew Size	Aver. Prod. Tie/Shft	Aver. Prod. M-H Tie	On-Track Prod. Tie/Hr	On-Track Prod. M-H/Tie
A-5	AREA (Aver.)	67	15-38		0.56		0.18
A-5	B.N.	67	22	833	0.21		
A-7	P.C.	68	28	560	0.4	70	0.4
A-8	C&NW	71	18			83	0.22
A-9	CRI&P	72	50	1000	0.4	300	0.17
A-10	N&W	73	35	540	0.52	135	0.26
A-11	N&W	73		530			
A-12	AT&SF	75	32	720	0.35	240	0.13
A-13	M.P.	76	30	1120	0.21	160	0.19
A-11	U.P.	76	30			165	0.18
A-11	AT&SF	76	35	1000	0.28	200	0.18
A-1	USRA	74	38	400	0.95	50	0.76
	Wood Tie Track						
	Average:			745	0.431	156	0.267

For 34 man tie gang: 127 ties/hr. on track
with 25% replacement 812/mile use
6 1/2 hr. per day/mile

Concrete Tie Track - Estimated

Assume 1/2 the wood tie productivity (0.6 man hours/tie) because:

(1) Heavier tie and removed in one piece
(2) Work takes place over greater distance
(3) Tie shoulder interference

For 24 man tie gang: 40 ties/hr. on track with 100/mile replacement: 2 miles per day @ 5 hrs. on track

3. Productivity - Surfacing & Lining

Reference	Railroad	Year	Crew Size	Aver. Prod. Mile/Shft	Aver. Prod. M-H/Mile	On-Track Prod. Mile/Hr	On-Track Prod. M-H/Mi	Raise
A-12	LI	68	6	0.46	104	0.189	32	1"
A-8	C&NW	71	7			0.27	26	
A-13	CRI&P	73		0.95		0.189		
A-11	N&W	73		0.76				
A-1	USRA	74	8			0.14	57	2"
		74	8			0.13	62	4"

Wood Tie Track 3-4 Inch Raise - Average

Average 60 man-hours on track/mile with 2 tampers

For 10 man surfacing gang 1 mile/day @ 6 hrs.

Concrete Tie Track 3-4 Inch Raise - Estimated

Less ties per mile:

$$1 \text{ mile } \frac{3250}{2640} = 1.23 \text{ miles/shift}$$

No down ties, use 1.3 miles/6 hrs. on track

4. Productivity - Ballast Undercutting

Reference	Railroad	Year	Crew Size	Aver. Prod. Mile/Sft	Aver. Prod. M-H/Mile	On-Track Prod. Mile/Hr	On-Track Prod. M-H Mi	Depth
A-16	AREA	74	11	0.22	400	0.08	138	6"
A-1	USRA	74	14	1.2	117	0.15	94	?
A-17	Northeast Corridor	75		2		0.25		
A-18	MATISA Undercutter					785 cu yds/hr 165 ft to 1800 ft/hr		
A-20	Plasser Undercutter					720 cu yds/hr		

Wood Tie Track - undercut 8" = 2600 cy yds.

For 15 men with undercutter use 450 ft/hr or 176 man-hours/mile

Use 1 mile per 3 days @ 4 hrs. running undercutter (6 hrs. track time total to allow surfacing)

Concrete Tie Track - Estimated

Faster since less ballast and fewer down ties: use 1.25 miles per 3 days @ 4 hrs. running undercutter.

5. Productivity - Track Sledding With Plow

Reference	Railroad	Year	Crew Size	Aver. Mile/Shift	On-Track Prod. Mile/Hr	M-H/Mi	Depth
A-14	AREA	74		0.70	(0.23)		
A-1	USRA	74	11		0.76		
A-19	B&LE	76	25		0.47	53	6"

Wood Tie Track

Since slid-rate is not limiting, use lowest rate (.23 mi/hr)

For 16 man gang, 8" cut, 1220 ft/hr.

Productivity = 69 M-H/Mi

Use 1 mile in 1.1 days @ 4 hr plowing time. (6 hr track time to allow surfacing)

Concrete Tie Track - Estimated

Since no down ties use 2000 ft/hr

Use 1 mile in 1 day @ 3 hrs plowing time. (6 hrs track time to allow surfacing)

6. Productivity - Track Relaying

Reference	Type	Crew Size	Average Prod. Mile/Shift	On-Track Prod. Ft/Hr
A-21	Plasser SU 2500J		0.29	656
A-18	Plasser	70	1	
A-18	RMC/Secmafer	25 oper.	1.8	
A-18	Matisa			
A-22	CN		0.23	

Use 1200 ft/hr average for wood and concrete tie track.

APPENDIX B

CONSTRUCTION AND MAINTENANCE COST-ESTIMATING ASSUMPTIONS

1. Lay New Rail

The replacement of worn CWR rail with new CWR includes the following primary activities:

Unload CWR
Distribute OTM
Remove old CWR
Lay new CWR
Pick up CWR released
Pick up scrap OTM

Assumptions made in estimating cost per mile to lay rail include:

Wood Tie Track	Concrete Tie Track (if different than wood)
44 man rail gang	31 man rail gang
17 men involved in material unloading and pick-up	
6-1/2 hrs track time, in one block per 8 hr. shift	
1/2 track mile of rail relayed per day	
CWR unloaded at rate of 4-1/2 hrs. per track mile	
CWR pick-up at rate of 6-1/2 hrs. per track mile	
50% spike replacement required	5% Pandrol clip replacement
5% Tie plate replacement required	100% Pad replacement
50% Rail anchor replacement required with every other tie box anchored.	100% Insulator replacement
9 thermite welds per mile	
Two mechanics included to perform light maintenance	One mechanic included
House trailers and kitchen trailers provided for rail gang personnel only	

2. Tie Replacement

The replacement of failed cross ties with new cross ties consists of the following primary activities:

- Distribute new cross ties
- Removal of old ties
- Install new ties
- Haul away scrap ties

Assumptions made in estimating cost per mile to replace cross ties are:

Wood Tie Track	Concrete Tie Track (if different than wood)
30 man tie gang	20 man tie gang
4 men involved in material handling	
25% tie replacement (812 ties per mile)	100 ties per mile replaced
6-1/2 hrs. on-track time per 8 hr. shift	5 hrs on-track time per 8 hr. shift
1 track mile of ties replaced per day	Two miles of ties replaced per day
50% spike replacement	4 pandrol clips per tie replaced
Ties cut in thirds for removal	Ties removed in one piece
Scrap ties disposed of nearby	2 pads and 4 insulators per tie replaced
Ties tamped after replacement	

3. Surface and Line Track

Surfacing and lining consists of the following primary activities:

- Unload ballast
- Raise and line track
- Tamp ties
- Dress ballast with regulator

Assumptions made in estimating cost per mile to surface track include:

Wood tie track	Concrete Tie Track (if different than wood)
9 man surfacing gang	8 man surfacing gang
3 man ballast unloading	
6 hrs track time per 8 hr. shift	
1 mile of track surfaced per day	1.3 miles of track surfaced per day (less insertions per mile)

Wood Tie Track	Concrete Tie Track (if different than wood)
3" Raise	
17 cars of ballast per mile	
Production tamper raise & line track and tamp every other tie	
Spot tamper tamp other ties	
One mechanic required for light maint.	
House and kitchens trailers furnished	

4. Clean ballast and surface and line track

The cleaning of ballast with the undercutter and resurfacing include the following primary activities:

Run undercutter: 8 inch cut
Move scrap ballast away from track
Adjust ties, replace if broken
Unload ballast
Raise and line track: two, 4 inch raises
Dress ballast with regulator.

Assumptions made in estimating cost per mile to undercut ballast are:

Wood Tie Track	Concrete tie track (if different than wood)
17 men with undercutter	
8 man surfacing gang	
6 hr. track time in one block per 8 hr. shift	
One mile undercut per 3 days	One mile undercut per 2.4 days
20% ballast replacement	
5% tie replacement	No tie replacement
For new ties installed 50% of spikes replaced.	No OTM replacement

5. Regage rail

The regaging of rail on wood tie track includes the following primary activities:

Move equipment to curve
Adze tie at inside edge of tie plate
Respike rail.

Assumptions made in estimating cost per mile to regage track are:

- 13 man gang
- 5 hrs. on track time per 8 hr. shift
- 1/2 miles regaged per day
- Regaging done on curves only, production includes moving from curve to curve on-track
- 20% spike replacement.

6. Transpose rail

The transposing of rail from the high to the low side of curves includes the following primary activities:

- Move equipment to curve
- Remove CWR
- Transpose rails
- Make field welds.

Assumptions made in estimating cost per mile to transpose rail:

Wood tie track	Concrete tie track (if different than wood)
35 man rail gang	25 man rail gang
6 hrs track time per 8 hr.	
1/4 track mile per day transposed	
25% spike replacement	5% pandrol clips replaced
No other OTM replaced	30% of pads and insulators replaced
Ties adzed	Not applicable
12 thermite welds/mile	
Rails transposed on curves only, travel from curve to curve off-track included in production.	

7. Spot Surfacing

Spotting track is one of the on going track maintenance activities required on both concrete tie track and wood tie track. The work includes locating "spots" in the track where surface, cross level, or line defects are excessive. Correction includes raising and/or lining the track and tamping ties, shoveling in ballast from the shoulders.

Most of the work would be at:

- Areas of poor subgrade
- Joints
- Bridge approaches
- Crossings
- Turnouts.

Assumptions made in estimating cost per mile to spot track included:

Wood tie track	Concrete tie track (if different than wood)
4 man spotting gang	
4 hrs on-track time per 8 hr shift	
1 mile covered per day	1.25 miles covered per day
No additional ballast used	
Equipment moved on-track from spot to spot	

8. Repair Minor Derailment

The repairing of damage to the track caused by a minor derailment such as one truck or one wheel off and running on the ties for a short distance is not uncommon. This type of accident is considered here because of the large difference in repair costs between wood and concrete tie track. On wood tie track, the derailed wheel would "mark" or cut the tie but usually only a small number require replacement. Concrete ties on the other hand have a much higher tendency to break completely on impact from the derailed wheel. The activities that would be included in a typical derailment repair are listed below.

- Inspect track to determine damage
- Load material, haul to site, unload
- Replace broken ties and OTM
- Haul broken material away.

Assumptions made in estimating costs of minor derailment repair are:

Wood tie track	Concrete tie track (if different than wood)
Wheels off for 2,000 feet	
Three 9-man gangs	four, 8-man gangs and 6 operators or truck drivers
One supervisor	

Wood tie track	Concrete tie track (if different than wood)
8 hrs required to make repairs	12 hrs required to make repairs
4 hrs at overtime rate	
no rail damaged	
10% of ties broken	70% of ties broken
10% of OTM broken	30% of all clips and insulators broken
80% of ties marked	50% of pads on broken ties replaced
Track surface and line not affected	
Replacement ties hauled to site by crew trucks, loaded and unloaded by hand	Replacement ties hauled by truck w/ flatbed trailer, loaded and unloaded by crane
Ties removed and installed by hand	Ties removed and installed with aid of end loader or speed swing
Crews not in trailers	

9. Grind Rail

Rail grinding to 0.024" depth was estimated for both wood and concrete tie track, this includes:

one rail grinding train (sub-contractor)
one work train (4 man crew)
one supervisor and two laborers
12 hour day for train crew and laborers
7 miles day production - 2 passes.

10. 100 Percent Replacement of Concrete Ties and Clean Ballast

Total replacement of existing concrete ties with new concrete ties includes the following primary activities:

remove rail fasteners
operate track renewal train
attach rail to fasteners
unload ballast
raise and line track - two, 4 inch raises
dress ballast with regulator
load.

Assumptions made in estimating cost per mile:

56 man total crew

7 hr. on track time

1 mile production per day

30% new ballast required.

11. Replace Existing Rail and Wood Ties With New CWR, Concrete Ties, and Clean Ballast

The replacement of the entire track system includes the following primary activities:

Unload CWR

remove rail fasteners

operate track renewal train

attach rail to fasteners

undercut track 8"

unload ballast

raise and line track: two, 4 inch raises

dress ballast with regulator

load and unload ties at yard

pick-up rail and OTM released.

Assumptions made in estimating cost per mile to renew track are:

77 man total crew

7 hr on track time

1 mile production per day

30% new ballast required

wood ties sold at renewal train unloading site.

12. Replace Existing Rail and Wood Ties With New CWR, Concrete Ties, and Replace Ballast

This construction includes the following primary activities:

unload CWR

operate track renewal train

attach rail to fasteners

plow 8" of ballast with work train locomotive

move scrap ballast away from track

unload new ballast

raise and line track: two 4 inch raises

dress ballast with regulator

pick-up rail and OTM released.

Assumptions made in estimating cost per mile are:

85 man total crew

6 hours on track time

1.25 mile production per day

wood ties sold at renewal train unloading site.

13. <u>Replace Existing Wood Ties With Concrete Ties and Clean Ballast</u>

This operation includes the following primary activities:

remove rail fasteners

operate track renewal train

attach rail to fasteners

undercut track 8"

unload ballast

raise and line track: two, 4 inch raises

dress ballast with regulator

load and unload ties at yard

pick-up OTM released.

Assumptions made in estimating cost per mile:

58 man total crew

7 hr. on track time

1 mile production per day

wood ties sold at renewal train.

14. <u>Replace Existing Wood Ties With Concrete Ties and Replace Ballast</u>

This operation includes the following primary activities:

remove rail fasteners

operate track renewal train

attach rail to fasteners

plot 8" of ballast with work train locomotive

move scrap ballast away from track

unload new ballast

raise and line track

dress ballast with regulator.

Assumptions made in estimating cost per mile:

- 65 man total crew
- 6 hours on track time
- 1.25 mile production per day
- wood ties sold at renewal train unloading site.

15. Construct New Track

Construction of new track on prepared subgrade includes the following primary activities.

- distribute and space cross ties
- distribute OTM
- unload CWR
- gage and spike CWR
- unload ballast
- surface and line track: 3 raises: 3", 3", 2"
- make field welds
- dress ballast.

Assumptions made in estimating cost per mile to construct new track:

Wood tie track	Concrete tie track (if different than wood)
80 man total crew	72 man total crew
8 hrs production per day	
subballast in place and compacted	
One mile per day constructed	2-1/2" additional ballast required for 24" concrete tie spacing

APPENDIX C

LIFE-CYCLE COSTING METHODOLOGY

C.1 Introduction

Computing life cycle costs involves the following steps:

1. Compute the annual cash flow in constant dollars over the life cycle for each cost item.
2. Compute the residual values in constant dollars at the end of the project life.
3. Inflate the annual constant dollar costs by the desired inflation rate.
4. Discount the inflated annual costs at the desired discount rate.
5. Sum life cycle costs.

Following is the derivation of the justifiable cost of concrete ties for the Test Case I, baseline analysis installation of concrete ties in existing track (relaying existing rail), at 40 annual MGT using the above 5 steps. The 50 year cash flow summary is shown in Tables C-3 and C-4 for wood and concrete ties respectively.

C-2 Annual Cash Flow in Constant Dollars

Tables C-1 and C-2 show the unit costs, frequency of maintenance and renewals, and annual costs in constant dollars for each of the nine operations included in the life cycle costing. The unit costs are taken from Table 2-7 and the frequencies from Table 3-2.

The costs to install concrete ties and the cost to lay new rail have been entered in the cash flow table in the year in which the costs are actually expended. The costs of the remaining maintenance and renewal operations have been entered into the cash flow summary table annually. Annuitizing costs does not distort the results as long as the cost of the operation is relatively low and/or the time interval between operations is relatively short.

TABLE C-1. COST TO MAINTAIN AND RENEW WOOD-TIE TRACK - TEST CASE I-RELAY EXISTING RAIL - 40 ANNUAL MGT

(1977 dollars in thousands)

Operation	Cost Per Track(1) Mile	Frequency(2) in Years	Values Entered in Table C-3	
			Cost	Years
1. Lay Rail	$93.9	30	$93.9	15, 45
2. Tie Replacement	18.5	4.6	4.0	Annually
3. Surface and Line	9.4	3.6	2.6	Annually
4. Clean Ballast	10.6	10.8	0.98	Annually
5. Regage Track	0.9	13.8	0.06	Annually
6. Transpose Rail	5.9	27.6	0.21	Annually
7. Spot Work	1.5	Annually	1.5	Annually
8. Repair Derailments	6.1	42	0.15	Annually
9. Grind Rail	0.94	4	0.24	Annually

(1) See Table 2-7.
(2) See Table 3-2.

TABLE C-2. COST TO INSTALL CONCRETE TIES, MAINTAIN, AND RENEW CONCRETE-TIE TRACK-TEST CASE I-RELAY EXISTING RAIL - 40 MGT

(1977 dollars in thousands)

Operation	Cost Per Track(1) Mile	Frequency(2) in Years	Values Entered in Table C-4	
			Cost	Year(s)
13. Install Concrete Ties-Concrete Tie Cost not included	$-3.3	One Time	$-3.3	1
1. Lay Rail	94.6	31	94.6	15, 46
2. Tie Replacement	6.1	One Time	6.1	5
	0.8	5	0.16	Annually
3. Surface and Line	8.5	3.6	2.36	Annually
4. Clean Ballast	5.9	10.8	0.55	Annually
5. Regage Track	N/A	N/A	N/A	N/A
6. Transpose Rail	4.4	29.4	0.15	Annually
7. Spot Work	1.19	Annually	1.19	Annually
8. Repair Derailments	30.6	42	0.73	Annually
9. Grind Rail	0.94	4	0.24	Annually

(1) See Table 2-7.
(2) See Table 3-2.

C.3 Residual Values

The life cycle cost analysis was based on the premise that the railroad would continue to operate beyond the 50 years studied. Therefore, we seek to take credit for the useful life remaining in major system components at 50 years. Those components are rail and ties. For these we have:

Concrete Tie Track

Ties	-0-	
Rail	$\frac{(\$94,600)\ [31\ \text{yr}-(50\ \text{yr}-46\ \text{yr})]}{31\ \text{yr}}$	= $82,394 per mile
Total		$82,394 per mile

Wood Tie Track

Ties	$74,000 x 50 percent*	= $37,000 per mile
Rail	$\frac{(\$93,900)\ [30\ \text{yr}-(50\ \text{yr}-45\ \text{yr})]}{30\ \text{yr}}$	= $78,250 per mile
Total		$115,250 per mile

*Value of ties is $18,500 per quarter mile x 4 = $74,000 per mile. Using annuitized method, the ties are taken as having 50 percent useful life remaining.

The cash flow summary for installation, maintenance, renewal, and residual values is shown in Table C-3 and C-4.

C.4 Adjust for Inflation

In this study an average annual inflation rate of four percent was used. The equation to compute the factor to escalate the cost is:

$$F = (1 + i)^n$$

where: F = compound amount factor in period n

i = interest rate per interest period

n = number of interest periods.

See interest tables for F as a function of i already computed. F for 4 percent ranges from 1.0 in year 1 of the project life to 6.83 in year 50. The factor for each year is shown in Table C-3.

C.5 Discounted Costs

Costs were discounted at 0, 7, and 10 percent in this study. The equation to compute the present worth factor is:

$$P = 1/(1 + i)^n$$

TABLE C-3 FIFTY YEAR CASH FLOW - TEST CASE I: MAINTAIN EXISTING WOOD TIE TRACK - 40 ANNUAL MGT

(1977 dollars in thousands)

Year	1 Lay Rail	2 Tie Replacement	3 Surface & Line	4 Clean Ballast	5 Regauge Track	6 Transpose Rail	7 Spot Work	8 Repair Derailment	9 Grind Rail	Total Constant Dollars	Inflation Factor 4%	Total Inflated Dollars	Discount Factor 7%	7% Total Discounted Dollars	Discount Factor 10%	10% Total Discounted Dollars
1		4.02	2.61	0.98	0.06	0.21	1.52	0.14	0.24	9.78	1.0	9.78	1.0	9.78	1.000	9.78
2		4.02	2.61	0.98	0.06	0.21	1.52	0.14	0.24	9.78	1.04	10.17	0.93	9.46	0.909	9.24
3		4.02	2.61	0.98	0.06	0.21	1.52	0.14	0.24	9.78	1.08	10.56	0.87	9.19	0.826	8.72
4		4.02	2.61	0.98	0.06	0.21	1.52	0.14	0.24	9.78	1.12	10.95	0.82	8.98	0.751	8.22
5		4.02	2.61	0.98	0.06	0.21	1.52	0.14	0.24	9.78	1.17	11.44	0.76	8.69	0.683	7.81
6		4.02	2.61	0.98	0.06	0.21	1.52	0.14	0.24	9.78	1.22	11.93	0.71	8.49	0.621	7.41
7		4.02	2.61	0.98	0.06	0.21	1.52	0.14	0.24	9.78	1.27	12.42	0.67	8.32	0.565	7.02
8		4.02	2.61	0.98	0.06	0.21	1.52	0.14	0.24	9.78	1.32	12.91	0.62	8.00	0.513	6.62
9		4.02	2.61	0.98	0.06	0.21	1.52	0.14	0.24	9.78	1.37	13.40	0.58	7.77	0.467	6.26
10		4.02	2.61	0.98	0.06	0.21	1.52	0.14	0.24	9.78	1.42	13.89	0.54	7.50	0.424	5.89
11		4.02	2.61	0.98	0.06	0.21	1.52	0.14	0.24	9.78	1.48	14.47	0.51	7.38	0.386	5.59
12		4.02	2.61	0.98	0.06	0.21	1.52	0.14	0.24	9.78	1.54	15.06	0.48	7.23	0.351	5.29
13		4.02	2.61	0.98	0.06	0.21	1.52	0.14	0.24	9.78	1.60	15.65	0.44	6.89	0.319	4.99
14		4.02	2.61	0.98	0.06	0.21	1.52	0.14	0.24	9.78	1.67	16.33	0.42	6.86	0.290	4.74
15	93.9	4.02	2.61	0.98	0.06	0.21	1.52	0.14	0.24	103.68	1.73	179.37	0.39	69.96	0.263	47.17
16		4.02	2.61	0.98	0.06	0.21	1.52	0.14	0.24	9.78	1.80	17.60	0.36	6.34	0.239	4.21
17		4.02	2.61	0.98	0.06	0.21	1.52	0.14	0.24	9.78	1.87	18.29	0.34	6.22	0.218	3.98
18		4.02	2.61	0.98	0.06	0.21	1.52	0.14	0.24	9.78	1.95	19.07	0.32	6.10	0.198	3.78
19		4.02	2.61	0.98	0.06	0.21	1.52	0.14	0.24	9.78	2.03	19.85	0.30	5.96	0.180	3.57
20		4.02	2.61	0.98	0.06	0.21	1.52	0.14	0.24	9.78	2.11	20.64	0.28	5.78	0.164	3.38
21		4.02	2.61	0.98	0.06	0.21	1.52	0.14	0.24	9.78	2.19	21.42	0.26	5.57	0.149	3.19
22		4.02	2.61	0.98	0.06	0.21	1.52	0.14	0.24	9.78	2.28	22.30	0.24	5.35	0.135	3.01
23		4.02	2.61	0.98	0.06	0.21	1.52	0.14	0.24	9.78	2.37	23.18	0.23	5.33	0.123	2.85
24		4.02	2.61	0.98	0.06	0.21	1.52	0.14	0.24	9.78	2.46	24.06	0.21	5.05	0.111	2.67
25		4.02	2.61	0.98	0.06	0.21	1.52	0.14	0.24	9.78	2.56	25.04	0.20	5.00	0.102	2.55
26		4.02	2.61	0.98	0.06	0.21	1.52	0.14	0.24	9.78	2.67	26.11	0.18	4.70	0.092	2.40
27		4.02	2.61	0.98	0.06	0.21	1.52	0.14	0.24	9.78	2.77	27.10	0.17	4.61	0.084	2.28
28		4.02	2.61	0.98	0.06	0.21	1.52	0.14	0.24	9.78	2.88	28.17	0.16	4.51	0.076	2.14
29		4.02	2.61	0.98	0.06	0.21	1.52	0.14	0.24	9.78	3.00	29.34	0.15	4.40	0.069	2.02
30		4.02	2.61	0.98	0.06	0.21	1.52	0.14	0.24	9.78	3.12	30.51	0.14	4.27	0.063	1.92
31		4.02	2.61	0.98	0.06	0.21	1.52	0.14	0.24	9.78	3.24	31.69	0.13	4.12	0.057	1.81
32		4.02	2.61	0.98	0.06	0.21	1.52	0.14	0.24	9.78	3.37	32.96	0.12	3.96	0.052	1.71
33		4.02	2.61	0.98	0.06	0.21	1.52	0.14	0.24	9.78	3.51	34.33	0.115	3.95	0.047	1.61
34		4.02	2.61	0.98	0.06	0.21	1.52	0.14	0.24	9.78	3.65	35.70	0.107	3.82	0.043	1.54
35		4.02	2.61	0.98	0.06	0.21	1.52	0.14	0.24	9.78	3.79	37.07	0.100	3.71	0.039	1.45
36		4.02	2.61	0.98	0.06	0.21	1.52	0.14	0.24	9.78	3.95	38.63	0.094	3.63	0.036	1.39
37		4.02	2.61	0.98	0.06	0.21	1.52	0.14	0.24	9.78	4.10	40.10	0.088	3.53	0.033	1.32
38		4.02	2.61	0.98	0.06	0.21	1.52	0.14	0.24	9.78	4.27	41.76	0.082	3.42	0.030	1.25
39		4.02	2.61	0.98	0.06	0.21	1.52	0.14	0.24	9.78	4.44	43.42	0.076	3.30	0.027	1.17
40		4.02	2.61	0.98	0.06	0.21	1.52	0.14	0.24	9.78	4.62	45.18	0.071	3.21	0.025	1.13
41		4.02	2.61	0.98	0.06	0.21	1.52	0.14	0.24	9.78	4.80	46.94	0.067	3.14	0.022	1.03
42		4.02	2.61	0.98	0.06	0.21	1.52	0.14	0.24	9.78	4.99	48.80	0.062	3.03	0.020	0.98
43		4.02	2.61	0.98	0.06	0.21	1.52	0.14	0.24	9.78	5.19	50.76	0.058	2.94	0.018	0.91
44		4.02	2.61	0.98	0.06	0.21	1.52	0.14	0.24	9.78	5.40	52.81	0.055	2.90	0.016	0.84
45	93.9	4.02	2.61	0.98	0.06	0.21	1.52	0.14	0.24	103.68	5.62	582.68	0.051	29.72	0.015	8.74
46		4.02	2.61	0.98	0.06	0.21	1.52	0.14	0.24	9.78	5.84	57.11	0.048	2.74	0.013	0.74
47		4.02	2.61	0.98	0.06	0.21	1.52	0.14	0.24	9.78	6.07	59.36	0.044	2.61	0.012	0.71
48		4.02	2.61	0.98	0.06	0.21	1.52	0.14	0.24	9.78	6.32	61.81	0.042	2.60	0.011	0.68
49		4.02	2.61	0.98	0.06	0.21	1.52	0.14	0.24	9.78	6.57	64.25	0.039	2.51	0.010	0.64
50		4.02	2.61	0.98	0.06	0.21	1.52	0.14	0.24	9.78	6.83	66.80	0.036	2.40	0.009	0.60
Subtotal: Years 1 - 50										676.80	--	2183.17	--	354.90	--	218.95
Residual: Year 51										-115.25	7.11	-819.43	0.034	-27.86	0.008	-6.55
Grand Total										561.55	--	1363.74	--	327.04	--	212.40

TABLE C-4 FIFTY YEAR CASH FLOW - TEST CASE I: INSTALL CONCRETE TIES IN EXISTING TRACK AND RELAY EXISTING RAIL - 50 ANNUAL MGT

(1977 dollars in thousands)

Year	1 Lay Rail	2 Tie Replacement	3 Surface and Line	4 Clean Ballast	5 Regauge Track	6 Transport Rail	7 Spot Work	8 Repair Derailment	9 Grind Rail	Total Constant Dollars	4% Total Inflated Dollars	7% Total Discounted Dollars	10% Total Discounted Dollars
1	-3.3*	.16	2.36	0.51	n/a	0.15	1.19	0.73	0.24	2.04	2.04	2.04	2.04
2		.16	2.36	0.51	n/a	0.15	1.19	0.73	0.24	5.34	5.55	5.16	5.04
3		.16	2.36	0.51	n/a	0.15	1.19	0.73	0.24	5.34	5.77	5.02	4.77
4		.16	2.36	0.51	n/a	0.15	1.19	0.73	0.24	5.34	5.98	4.90	4.49
5		+6.1	2.36	0.51	n/a	0.15	1.19	0.73	0.24	11.44	13.38	10.17	9.14
6		.16	2.36	0.51	n/a	0.15	1.19	0.73	0.24	5.34	6.51	4.62	4.04
7		.16	2.36	0.51	n/a	0.15	1.19	0.73	0.24	5.34	6.78	4.54	3.83
8		.16	2.36	0.51	n/a	0.15	1.19	0.73	0.24	5.34	7.05	4.37	3.62
9		.16	2.36	0.51	n/a	0.15	1.19	0.73	0.24	5.34	7.32	4.25	3.42
10		.16	2.36	0.51	n/a	0.15	1.19	0.73	0.24	5.34	7.58	4.10	3.21
11		.16	2.36	0.51	n/a	0.15	1.19	0.73	0.24	5.34	7.90	4.03	3.05
12		.16	2.36	0.51	n/a	0.15	1.19	0.73	0.24	5.34	8.27	3.95	2.89
13		.16	2.36	0.51	n/a	0.15	1.19	0.73	0.24	5.34	8.54	3.76	2.72
14		.16	2.36	0.51	n/a	0.15	1.19	0.73	0.24	5.34	8.92	3.75	2.59
15	94.6	.16	2.36	0.51	n/a	0.15	1.19	0.73	0.24	99.94	172.90	67.43	45.57
16		.16	2.36	0.51	n/a	0.15	1.19	0.73	0.24	5.34	9.61	3.46	2.30
17		.16	2.36	0.51	n/a	0.15	1.19	0.73	0.24	5.34	9.99	3.40	2.18
18		.16	2.36	0.51	n/a	0.15	1.19	0.73	0.24	5.34	10.41	3.33	2.06
19		.16	2.36	0.51	n/a	0.15	1.19	0.73	0.24	5.34	10.84	3.25	1.95
10		.16	2.36	0.51	n/a	0.15	1.19	0.73	0.24	5.34	11.27	3.16	1.85
21		.16	2.36	0.51	n/a	0.15	1.19	0.73	0.24	5.34	11.69	3.04	1.74
22		.16	2.36	0.51	n/a	0.15	1.19	0.73	0.24	5.34	12.18	2.92	1.64
23		.16	2.36	0.51	n/a	0.15	1.19	0.73	0.24	5.34	12.66	2.91	1.51
24		.16	2.36	0.51	n/a	0.15	1.19	0.73	0.24	5.34	13.14	2.76	1.46
25		.16	2.36	0.51	n/a	0.15	1.19	0.73	0.24	5.34	13.67	2.73	1.39
26		.16	2.36	0.51	n/a	0.15	1.19	0.73	0.24	5.34	14.26	2.57	1.31
27		.16	2.36	0.51	n/a	0.15	1.19	0.73	0.24	5.34	14.79	2.51	1.24
28		.16	2.36	0.51	n/a	0.15	1.19	0.73	0.24	5.34	15.38	2.46	1.17
29		.16	2.36	0.51	n/a	0.15	1.19	0.37	0.24	5.34	16.02	2.40	1.11
20		.16	2.36	0.51	n/a	0.15	1.19	0.73	0.24	5.34	16.66	2.33	1.05
31		.16	2.36	0.51	n/a	0.15	1.19	0.73	0.24	5.34	17.30	2.25	0.99
32		.16	2.36	0.51	n/a	0.15	1.19	0.73	0.24	5.34	18.00	2.16	0.94
33		.16	2.36	0.51	n/a	0.15	1.19	0.73	0.24	5.34	18.74	2.15	0.88
34		.16	2.36	0.51	n/a	0.15	1.19	0.73	0.24	5.34	19.49	2.09	0.84
35		.16	2.36	0.51	n/a	0.15	1.19	0.73	0.24	5.34	20.24	2.02	0.79
36		.16	2.36	0.51	n/a	0.15	1.19	0.73	0.24	5.34	21.10	1.98	0.76
37		.16	2.36	0.51	n/a	0.15	1.19	0.73	0.24	5.34	21.89	1.93	0.72
38		.16	2.36	0.51	n/a	0.15	1.19	0.73	0.24	5.34	22.80	1.87	0.68
39		.16	2.36	0.51	n/a	0.15	1.19	0.73	0.24	5.34	23.71	1.80	0.64
40		.16	2.36	0.51	n/a	0.15	1.19	0.73	0.24	5.34	24.67	1.75	0.62
41		.16	2.36	0.51	n/a	0.15	1.19	0.73	0.24	5.34	25.63	1.72	0.56
42		.16	2.36	0.51	n/a	0.15	1.19	0.73	0.24	5.34	26.65	1.65	0.53
43		.16	2.36	0.51	n/a	0.15	1.19	0.73	0.24	5.34	27.71	1.61	0.50
44		.16	2.36	0.51	n/a	0.15	1.19	0.73	0.24	5.34	28.84	1.59	0.46
45		.16	2.36	0.51	n/a	0.15	1.19	0.73	0.24	5.34	30.01	1.53	0.45
46	94.6	.16	2.36	0.51	n/a	0.15	1.19	0.73	0.24	99.94	583.65	28.02	7.59
47		.16	2.36	0.51	n/a	0.15	1.19	0.73	0.24	5.34	32.41	1.43	0.39
48		.16	2.36	0.51	n/a	0.15	1.19	0.73	0.24	5.34	33.75	1.42	0.37
49		.16	2.36	0.51	n/a	0.15	1.19	0.73	0.24	5.34	35.08	1.37	0.35
50		.16	2.36	0.51	n/a	0.15	1.19	0.73	0.24	5.34	36.47	1.31	0.33
Subtotal: Years 1 - 50										459.00	1542.74	236.97	143.72
Residual: Year 51										-82.39	-585.80	-19.90	-4.69
Grand Total										376.61	956.94	217.07	139.03

* NOTE: Cost to install concrete ties minus cost of concrete ties. The -$3,300 includes cost item 13 in Table 2-6, -$6,300 plus $3,000 for operational delays installing concrete ties.

where: P = present worth factor in period or

i = interest rate per interest period

n = number of interest periods.

At i = 0 percent for i, P = 1.0 and we have actual costs, inflated at 4 percent in this case. At i = 10 percent, the factor ranges from 1.0 in year 1 to 0.009 in year 50. At i = 7 percent, the factor ranges from 1.0 in year 1 to 0.36 in year 50. The discount factors for each year are shown in Table C-3.

C.6 Life Cycle Cost Summary

A summary of the total costs in Tables C-3 and C-4 and derivation of justifiable cost of concrete ties and percent savings based on $38.80 per tie is shown below:

		(1977 Dollars)	
Test Case I	4% Inflation	7% Discount Rate	10% Discount Rate
Wood Ties	$1363.74 K	$327.04 K	$212.40 K
Concrete Ties (less cost of ties)	956.94 K	217.07 K	139.00 K
Difference	406.80 K	109.97 K	73.40 K
Justifiable cost of Concrete Ties-2640/mile	$ 154.00	$ 41.60	$ 27.80
Savings for concrete tie track vs. wood using $38.80 for cost of concrete ties	$38.80/tie x 2640 ties/mile = $102.40 K/mile		
	956.94	217.07	139.00
	+102.40	+102.40	102.40
	1059.34	319.47	241.4
	(1364-1059)/1364 = +22.3%	(327-319)/327 = +2.4%	(212-241)/212 = -13.7%

APPENDIX D

REPORT OF INVENTIONS

This report contains general methodology and sufficient cost data to evaluate the economic benefits of concrete versus wood ties for any railroad line. After a diligent review of the work performed under this contract, it is concluded that no inventions, discoveries, or improvements of inventions were made. However, the results from the economic study revealed several factors that have a significant impact on the economic benefits of concrete ties over a 50-year life cycle. A baseline economic analysis and various sensitivity evaluations were made for four typical test cases of track construction and rehabilitation.

The development of the life cycle costing methodology to compute the justifiable cost for concrete ties is a major accomplishment of this project. This methodology is demonstrated with an example problem in Appendix C.

The collection and organization of material and labor cost data for all of the maintenance, renewal and construction tasks required for railroad track is also a valuable contribution for future economic evaluations. These data are reported in detail in Sections 2 and 3 and include the following:

a. Hourly Labor Rates - Table 2-1
b. Equipment Cost Summary - Table 2-2
c. Material Unit Costs - Table 2.3
d. Productivity Rates for Construction, Maintenance and Renewal Operations - Table 2-5
e. Productivity Investigation - Appendix A
f. Construction and Maintenance Cost Estimating Assumptions - Appendix B

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