REPORT NO. FRA/ORD-77/76 ~~ROA-2~~ PB

REFURBISHMENT OF RAILROAD CROSSTIES
A TECHNICAL AND ECONOMIC ANALYSIS

December 1977
Final Report

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Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL RAILROAD ADMINISTRATION
Office of Research and Development
Washington, D.C. 20590

01-Track & Structures

Technical Report Documentation Page

1. Report No. FRA/ORD-77/76	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle REFURBISHMENT OF RAILROAD CROSSTIES A Technical and Economic Analysis		5. Report Date December 1977
		6. Performing Organization Code
7. Author(s) A.V. Loomis and T. Anyos		8. Performing Organization Report No. DOT-TSC-FRA-77-29
9. Performing Organization Name and Address Stanford Research Institute* Menlo Park CA 94025		10. Work Unit No. (TRAIS) RR819/R8306
		11. Contract or Grant No. RA 75-29
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Railroad Administration Office of Research and Development Washington DC 20690		13. Type of Report and Period Covered Final Report Sept. 1975 - May 1976
		14. Sponsoring Agency Code

15. Supplementary Notes

*Under contract to: U.S. Department of Transportation
Transportation Systems Center
Kendall Square
Cambridge MA 02142

16. Abstract

An analysis of the principal modes of failure for wooden railroad crossties was conducted and an evaluation of the technical and economic feasibility of refurbishing these ties was conducted. Among the principal modes of structural deterioration, only spike-killed tie repair was identified as practically feasible for in-situ treatment. However, once ties were removed from track, the feasibility of an in-plant repair of selected ties was found to be technically feasible for plate-cut and spike-killed ties. Such a repair operation could result in cost savings of 19-50% over the cost of new tie insertion, depending on the nature of the process selected and the assumed salvage value of a "spent" tie.

Candidate process plant flow descriptions have been developed and the initial (capital) costs and annual operating costs evaluated. Recommendations for process evaluation are included as a starting point for continued investigations of crosstie reuse.

17. Key Words Crossties, Wood Refurbishment, Economic Analysis	18. Distribution Statement DOCUMENT IS AVAILABLE TO THE U.S. PUBLIC THROUGH THE NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD, VIRGINIA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	132	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

PREFACE

This report represents the final conclusions of a technical and economic analysis of the feasibility of refurbishing wooden crossties for reuse in track. It was prepared by the Stanford Research Institute (SRI) under contract to the Transportation Systems Center (TSC), under the sponsorship of the Federal Railroad Administration (FRA). This activity was conducted as part of FRA's Improved Track Structures Research Program in an effort to investigate approaches to improving the safety, reliability and economic performance of existing railroad track.

The authors wish to extend their thanks to Mr. Donald P. McConnell, of TSC, the Technical Monitor of this activity, for his guidance and cooperation throughout this project and especially for his contributions to the final report. The comments and suggestions offered by Dr. R.M. McCafferty, Mr. W.B. O'Sullivan and Mr. H. Moody of the FRA during the preparation of this final report are gratefully acknowledged. The authors also wish to thank the various sources of photographic material for the use of their materials in illustrating the report.

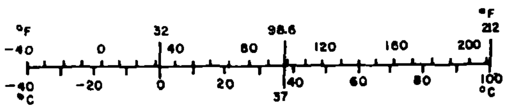
Approximate Conversions to Metric Measures

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

METRIC CONVERSION FACTORS

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. EXECUTIVE SUMMARY

The generally deteriorated condition of a high percentage of United States railroad trackage is acknowledged by many in the industry today. It has also been recognized that any comprehensive program of track rehabilitation must give first priority to rails and crossties, and to restoring track geometry.

In an attempt to offer the railroad industry a choice greater than just wood for crosstie use, over 2500 patented ties have been introduced over the years. None of these however, have seriously threatened to replace the wood tie, which in modern times differs only slightly from those used in the early days of railroading.

Tie replacement costs, which aggregate more than 100 million dollars annually, are still one of the largest single railroad maintenence expenditures. The improvement of tie performance could only improve the effectiveness of maintenance of way budgets. To date, efforts directed toward techniques of extending tie life, or of tie refurbishment have been only minimally successful. The use of substitute tie materials, such as concrete, have also been quite limited, and have met with less than the hoped for success.

In light of these problems, it appears appropriate to closely examine the overall technical and economic aspects of crosstie refurbishment and reuse, as one potential solution to tie life extension. In this study, therefore, wood tie supply in the United States, reported modes of tie deterioration, current and projected replacement and refurbishment techniques, and the economics of tie life extension are all considered in an effort to bring this approach into proper perspective.

In the United States, hardwoods (used primarily in shipping, furniture, and crossties) represent approximately 36 percent of the available wood supply. According to a report issued by the General Accounting Office (GAO), the United States Department of Agriculture (USDA) has compared supply and demand projections for hardwood timber products, and has estimated that the supply of hardwood will exceed demand until at least the year 2000. However, competing wood products, such as pallets and wood pulp, could result in higher prices for certain hardwood timber products.

Discussions held between the GAO and the Railway Tie Association (RTA) indicated that the tie producers could realistically supply the railroad industry with all the ties it would require, even for a comprehensive program of track reconstruction, if the railroads altered their current purchasing practices. This alteration, from current practice to a more regularized schedule, would allow the tie producers more time for adequate planning and scheduling of tie production. This improvement in production scheduling and control would allow a significant increase in crosstie manufacture over that now reported.

The manufacture of crossties begins with the lumbering operation, moves through a number of trimming and boring operations, and terminates in a preservative treatment step. Although the tie producing industry is difficult to profile because of the relatively scattered locations of sawmills and treating facilities, the varying size of these mills and facilities, the different equipment used and the varying constraints imposed by climatic conditions, the general manufacturing scheme remains the same throughout the industry.

During the last four years treated crosstie prices have risen from \$5 to \$6 per tie to \$11 to \$13 per tie. Adding \$5 per tie to cover cost of shipping and installation, currently the average cost for an installed crosstie can be expected to be in the \$16 to \$18 range.

The principal modes of deterioration of ties in service are mechanical wear, physical damage, and to some extent termite infestation and attack by decay fungi. While ties subjected to the latter two modes are difficult, if not impossible, to repair after these types of attack have been underway for extended periods of time, the former modes are more forgiving and ties are more easily returned to service (on lighter load track) after repair of the defects requiring their removal. These defects include plate cutting, spike kill, checking and splitting, and crushing. Severe mechanical damage, such as ties broken through more than half their thickness, or so severely plate cut that significant rebuilding of the plate area would be required, does not fall into this category.

Despite the fact that specific modes of deterioration are not critically cataloged when ties are removed from track, and, more often than not more than one form of deterioration has caused the removal of the tie, detailed interviews with railroad personnel and American Railway Engineers Association (AREA) Committee 3 members have enabled us to estimate the population of ties in each defect class. This population is shown in Table 1.1.

TABLE 1.1 PERCENTAGE POPULATION OF TIE DETERIORATION MODES

Tie Deterioration Mode	Population (% removed annually)
Decay & wood deterioration (crushing)	43-44
Plate cutting	18-20
Splitting	16-18
Spike killing	14-16
Broken ties	2-3
Other (mechanical damage, such as derailments, and rail anchor damage)	2-4

We assume the above figures to be generally representative of annual tie removals. As no statistical data are kept by the railroads, these represent the average of the best estimates of experts in the field.

Failed crossties are removed from track if they do not adhere to the railroad's standards for tie condition. While varying somewhat from road to road, a worst case would be the limits set by the Federal Railroad Administration (FRA) Track Safety Standards (213.109 Crossties). This standard requires that ties be removed if they are (1) broken through, (2) split or otherwise impaired to the extent they will not hold spikes or will allow ballast to work through, (3) so deteriorated that the tie plate or base of the rail can move laterally more than one-half inch relative to the crosstie, (4) cut by the tie plate through more than 40 percent of their thickness, or (5) not spiked as required by 213.127 of the FRA Track Safety Standard. Although inspection of ties is generally accomplished with these standards in mind, often the overall condition of the line is the first factor to be considered. In the event that an entire section of line is in unacceptable condition, a timbering and surfacing operation will be undertaken, which calls for substantial tie renewal. Increased interest in the complete tie removal approach by U.S. railroads has been noted in recent trade literature. This approach, practiced in the Soviet Union and some Western European nations, has some apparent technical and economic advantages. These include increased train speeds, extension of useful tie life by an estimated 25 percent, and track resurfacing and retimbering at an estimated savings of 5 percent per mile.

During 1975, an estimated 19,300,000 wooden crossties were laid in replacement in Class I railroads in the United States. The estimated tie population by defect class is shown in Table 1.2.

TABLE 1.2 TIE POPULATION BY DEFECT CLASS (1975)

Deterioration Mode	Tie Population (thousands)
Decay and Crushing	8,400
Plate Cutting	3,650
Splitting	3,300
Spike Killing	2,900
Broken Ties	480
Other	570

The average life of a crosstie can be expected to vary with severity of use and exposure to climatic conditions. One might hypothesize that ties in the eastern and southern states trackage would normally operate under more severe conditions than those in the western states; some statistics are available to verify this hypothesis. Indeed, a comparison of percent renewal to all ties (in-track) for 1975 for Class I Railroads in the United States shows that the Eastern and Southern Districts renewals were 2.41 and 2.32 percent of all ties per mile, respectively, laying 72 and 71 new ties per mile of track, as compared to the Western District's percent renewal figure of 1.94 with only 59 new crossties inserted per mile of track. However, no quantitative report on modes of deterioration has been assembled.

The extension of crosstie life has been, and continues to be, a major concern of the United States' Railroad industry. Two philosophical approaches to this extension have been noted in the course of this study. The first, representing the industry's trend to date, encompasses all those approaches which "make the tie last as long as possible at the least possible cost". This approach results in the removal of ties from Class I track after 20-30 years. After that time period a high percentage of those ties are beyond repair. The second approach, the antithesis of the first, is that which considers the cascading of ties, i.e., taking them out of track after a short period of time (7 to 10 years), totally resurfacing and retimbering the track, and retiring the removed ties, after minimal repair (if necessary) to secondary or more lightly loaded track. Strictly from the refurbishment point of view, the latter approach appears more appealing, as the returned (removed) ties can be anticipated to exhibit less deterioration than in the former case, and thus be more readily repairable.

From a strictly technical point of view, the modes of deterioration most readily repaired by techniques employing currently available technology (or technology projected for the near future) include: spike kill, plate cutting and to some degree, checking and splitting. These repairs could be performed either in situ (in-place), on-site (tie removed from track, but not transported to a repair facility), or in a tie refurbishment facility. Spike kill can readily be repaired either on-site or at a repair facility; plate cutting might best be repaired in a refurbishment plant. Checking and splitting, if not severe, might be repaired on site; however, the advantage gained by this repair is not really evident at this time.

When the economics of tie life extension by pretreatment or repair are considered, it would be economical to spend as much as $1.95 per tie prior to installation, if its life could be extended 10 years. It also appears economical to repair spike-killed ties, on site or in a batch-type refurbishment plant. Plate cut ties can be economically repaired in a batch plant operation as well. Savings to the railroad on this type of repair are illustrated in Table 1.3. Ties not severely checked or split might be repaired by coating in-place, extending tie life by 10 years in an economical manner. All of these repair operations must, of course, be experimentally verified prior to full-scale use in the field.

TABLE 1.3 COMPARISON OF ALTERNATIVE APPROACHES TO CROSSTIE REPLACEMENT
(Via Discounted Cash Flow Method)

Plan of Operation	Cost ($)	Initial Plant Cost	Total Present Worth @ 10%		% Savings	
			30-year cycle	7-year cycle	30 yr	7 yr
A. Buy and Install 210,000 New Ties Each Year	3,780,000		35,634,000	18,401,104	-	-
B. Renovate* and Install 210,000 Ties Each Year	2,697,133[1]	1,250,000	26,675,872	14,379,643	23	19
C. Renovate** and Install 210,000 Ties Each Year	1,831,467[2]	1,000,000+	18,265,239	9,915,580	42	50

* Repairing spike kill, plate cutting and inserting anti-splitting devices.
** Repairing spike kill only.
\+ Plant costs for spike-kill repair only, estimated @ $1,000,000.

[1] Plan B Calculation

Cost: $1,688,800 operating expense - $41,667 plant depreciation + $1,050,000 ties installation cost = $2,697,133 per year

PV @ 10% = 25,425,872 + 1,250,000 initial plant cost = $26,675,872

[2] Plan C Calculation

Cost: 814,800 operating expense - $33,333 plant depreciation + $1,050,000 tie installation cost = 1,831,467

PV @ 10% = 17,265,239 + 1,000,000+ initial plant cost = 18,265,239

In-plant repair of deteriorated ties has as immediate and obvious advantages: (1) a centralized (or centralizable) location for tie repair in a given geographic or demographic region, (2) round-the-clock availability of equipment specifically designed for the refurbishment operation, (3) availability of crews trained specifically for tie refurbishment, and (4) a centralized distribution point for refurbished or second-use ties. Secondary benefits might arise from the fact that if all grading of ties is accomplished at the refurbishment facility, discarded ties (those too deteriorated for railroad use) (1) would have been removed from the right-of-way, and (2) could be sold from a regionally centralized location.

Possible immediate disadvantages of this approach are: (1) high capitalization costs with yet unproven technical feasibility, (2) questionable need and/or industry acceptance of refurbished ties at tie costs yielding acceptable ROI values, and (3) difficulties in identifying the segment of industry to be involved (i.e., railroads, tie producers, tie treaters, or others).

The in-plant refurbishment approach taken by the Soviet Union might well serve as a model for the U.S. railroad industry. Although economic factors are greatly magnified in the United States, it appears that a tie cascading approach, coupled with in-plant refurbishment, can be the most technically and economically feasible concept for tie refurbishment. This approach also mandates that a zero dollar value be placed on all ties removed from track, if they are to be economically refurbished, thus identifying the railroads (the owners of the ties) as the most logical segment of the tie producer/user industry to be involved in the refurbishment process. This might be accomplished either by their capitalizing a plant individually, or as a group, or possibly by negotiating an agreement with existing tie producers in which the railroad would provide returned ties to them, free of charge, for subsequent refurbishment.

In conclusion, the data generated in this study on the technical and economic feasibility of refurbishing wood crossties have shown that tie replacement costs are still one of the largest single railroad maintenance expenditures. In light of this situation, and the increasingly stringent demands made on crossties in service, tie life extension and/or refurbishment is still a topic of considerable importance. Inherent in any discussion of tie refurbishment is a consideration of tie renewal practices and the contrasts between those now considered standard (i.e., spot replacements of failed ties) and out-of-face replacement techniques coupled with surfacing operations. The latter approach to tie renewal lends itself much more favorably to the refurbishment approach.

On-site tie repair appears feasible from a technical and economic point of view only with spike-killed ties. Overall tie refurbishment especially of spike kill and plate cutting, may be technically and economically feasible in a batch plant operation specifically designed for tie refurbishment. Other modes of deterioration either may be too expensive to repair or may not lend themselves to a repair process. Alternative tie renewal techniques such as tie cascading would allow ties only minimally damaged to be returned for minor refurbishment and subsequent use in lighter load trackage.

Based on these conclusions, one can recommend that experimental work to verify the feasibility of repairing spike kill and plate cut ties should be initiated. This experimental program should investigate not only currently available repair techniques, but should also consider accelerated testing of such repaired ties to determine actual life in service. In addition, a technoeconomic survey on the benefits/constraints of tie cascading practices in the United States should be carried out. One U.S. railroad has initiated some tie cascading practices and could possibly be used as a model for the industry.

If these recommendations appear technically feasible, a pilot refurbishment facility might be designed and constructed to assess the overall benefits to be gained from such an operation.

2. INTRODUCTION

Railroad ties, depending upon the manner in which they are used, fall into one of three general classes: (1) crossties, or sleepers as they are more commonly known in many other parts of the world, (2) switch ties, and (3) bridge ties. Crossties are transverse beams set in a roadbed to position and support railroad rails. Switch ties, which are greater in length, but otherwise similar to crossties, are used under the rails at frogs and switches. Bridge ties are closely spaced and transversely oriented beams attached to the stringers of bridges and trestles and upon which the rails are anchored. Switch and bridge ties are usually sawed on four sides, but crossties may be either sawed or hand-hewed and furnished with two opposite faces, or faced on all four sides. Years ago, most crossties were hand-hewed, but by 1962 somewhat more than 60 percent of all crossties produced annually were manufactured at sawmills.[1] Although difficult to verify statistically, we estimate that by 1976 this figure has risen to 99 percent or greater.

Over the years, more than 2,500 patented ties have been introduced, yet none has ever seriously threatened to replace the wood tie, which in modern times differs but little from those used in the early days of railroading. In 1975, for example, statistics show that 18,770,589 new wooden ties and 526,872 second-hand wooden ties were laid in replacement in Class I track in the United States.[2]

While wood has several properties that collectively make it the favored tie material, it also possesses others that work to its disadvantage. Principal among these are:

1. A. T. Panshin et al., Forest Products: Their Sources, Production and Utilization, pp. 94-105 (McGraw-Hill Book Co., Inc., New York, 1972).
2. Crossties, October 1976, pp. 58-59.

(1) It is subject to attack by wood-destroying fungi.

(2) It checks and splits in seasoning, particularly in "boxed-pith" pieces. Checking in boxed-pith ties is unavoidable because of the difference in tangential and radial shrinkage of wood. Sawed and hewed ties from small trees and ties sawed from the centers of large logs exhibit this fault. Pith-free, flat-grained ties are usually not subject to severe checking and they are likely to have greater spike-holding power because, in normal tree growth, the density of annual rings of the wood of most species becomes greater as the distance from the pith increases. This usually means that the wood directly under the rails is denser than that bearing on the ground, for the top of the tie is always considered to be the wide face that is farthest removed from the pith, whether the pith is present or not.

(3) It burns. Although not as serious a problem now as when coal-burning engines were operational, a creosote-impregnated crosstie does represent a fire hazard.

(4) It is subject to mechanical wear. Even crossties that have been treated with excellent preservatives often wear out and must be replaced before they decay. This mechanical wear is thought to be largely due to the actual abrasion of the wood by the movement of the steel tie plates or rails over the surface of the tie, particularly when sand intrudes between the wood and the metal. To a lesser extent, crushing of the wood fibers contributes to mechanical failure.

Tie-replacement costs, which aggregate more than $100 million annually, are still one of the largest single railroad maintenance expenditures[1]. This represents a significant portion of the rail-

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1. A. T. Panshin, et al., Forest Products: Their Sources, Production and Utilization, pp. 94-105, McGraw-Hill Book Company, Inc., (New York, 1962).

roads' annual maintenance expenditure and savings in this area could substantially improve the economies of track operation. All the railroad companies are endeavoring to prolong the service life of ties by adopting new practices and equipment that attempt to inhibit decay and reduce mechanical wear, breakage, spike-pulling, lateral thrust of spikes, and the development of such seasoning defects as splitting and checking.

Railroads such as the Atchison, Topeka and Santa Fe Railway and the Southern Railway, research laboratories such as Brookhaven National Laboratory working with the Federal Railroad Administration, and the Forest Products Laboratory working in conjunction with the Railway Tie Association and the Association of American Railroads, have investigated methods for crosstie refurbishment. The results of their efforts to date have shown some feasibility for the concept. However, only minimal effort has been expended to determine the total technoeconomic feasibility of using either substitute or refurbished wooden crossties in place of the wooden tie currently used.

While this effort continues, the situation appears to indicate a continued reliance on wooden crossties in the immediate future. Barring severe competition from other wood products, most notably construction grade and pallet lumber, wood ties trackage should continue to constitute the majority of the railroad track miles for some time to come. In light of the increasingly stringent demands being placed on wood ties, and the dictate of the marketplace for longer service life at competitive costs, the refurbishment of existing wood ties remains a topic of considerable importance. This facet of tie supply would remain unchanged even in the event of adoption of alternative tie materials, such as concrete, since the introduction of such materials in a program of capital reconstruction of track would result in the release of a large number of existing ties potentially suitable for refurbishment and reuse.

This report examines the technical and economic aspects of crosstie refurbishment and reuse. By means of examination of the wood tie supply in the United States, the modes of tie deterioration, current and projected replacement and refurbishment techniques, and the economics of tie reuse, the study will attempt to determine if tie service life can be meaningfully extended at a cost competitive with new tie costs.

3. WOOD TIES: SUPPLY, NEED, AND MANUFACTURE

The generally deteriorated condition of a high percentage of railroad trackage is acknowledged by many in the industry today.[1] It is also recognized that rails and ties, and simultaneously line and surface, have first priority in any program of track rehabilitation. The evaluation of the feasibility or requirement for tie refurbishment facilities rests on its relation to the economics and processes of new tie production, since it is in this market that such reworked ties would compete. The structure of the market is discussed in this section as an introduction to the industry in which an economically feasible tie refurbishment process could be introduced.

3.1 Wood Tie Supply

A recent study[2] by the General Accounting Office (GAO) reported that "as of June 1976, no organization or individaul either within or outside of the tie industry has determined the total industry's production capability". The primary reason given for this lack of statistical information was the variability of the factors which determine capacity. For example, these include "the (varying) number of sawmills across the country, the size of these mills, the type of equipment used, constraints imposed by the weather, and the availability of treating facilities and treating solution."

The GAO goes on to report that the number of crossties produced since 1953 has varied from a high of 38.5 million in that year to a low of 13 million in 1962. From 1965 to 1974, the production has averaged about 23 million crossties per year.

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1. "Can Suppliers Meet Demand for Rails and Crossties?", Track and Structures, February 1977, pp. 24-25.

2. "Industry Capability to Produce Rail and Crossties for Nationwide Railroad Track Rehabilitation," Comptroller General of the United States (September 1976).

Forests occupy about 28 percent of the world's land area, representing 9.2 billion acres. About two-thirds of this area are hardwood forest and one-third softwood; however only 5.6 billion acres are available for wood production.

In the United States, softwoods account for an estimated 64 percent of the total available timber, while hardwoods represent the remaining 36 percent. Softwoods are used in the housing and pulp industries, whereas hardwoods are used in shipping, furniture and crossties. Only 10 to 20 percent of the crossties produced are made from softwoods. Table 3.1 illustrates the species used and their share of the crosstie market according to USDA's Forest Products Marketing Laboratory.

TABLE 3.1 SPECIES OF WOOD USED FOR CROSSTIES

Species	Class	Typical Percentage of Crosstie Market
Oak (red and white)	Hardwood	52
Mixed hardwoods, (beach, birch, maple, hickory, etc.)	Hardwood	23
Gum (black and red)	Hardwood	9
Douglas fir	Softwood	6
Hemlock	Softwood	3
Mixed softwoods (larch, cedar, etc.)	Softwood	3
Pine (southern ponderosa, lodgepole)	Softwood	4

According to the GAO, the U.S. Department of Agriculture has compared supply and demand projections for hardwood timber products and has found that the supply of hardwood will exceed demand until at least the year 2000. However, competing wood products such as pallets and wood pulp could result in higher prices for certain hardwood timber products.

3.2 Estimated Crosstie Need

The Federal Railroad Administration's (FRA) 1974 study entitled "Estimate of Deferred Maintenance in Track Materials for Twenty-five Railroads" provided the basis for the GAO's projection of crosstie needs for all 67 Class I railroads. These projections showed that for the necessary rehabilitation of track over the next 10 to 20 years, between 172 and 220 million more crossties than the past annual average would be needed (see Table 3.2).

TABLE 3.2 GAO PROJECTED CROSSTIE NEEDS TO 1996[1]

Projection	10-year period	15-year period	20-year period
Average annual production	23,000,000	23,000,000	23,000,000
Projected production	230,000,000	345,000,000	460,000,000
GAO estimate of need	401,797,270	540,999,720	680,202,180
Shortfall	171,797,270	195,999,720	220,202,180

In discussions between GAO researchers and the Railway Tie Association (RTA), the RTA indicated that its members not only could sustain a sufficiently high level of production to meet the needs outlined in Table 3.2 above, but could also meet an even higher level of need than projected (see Table 3.3).

1. "Can Suppliers meet Demand for Rails and Crossties," Track and Structures, February 1977, pp. 24-25.

TABLE 3.3 ANNUAL CAPACITY ESTIMATED BY THE RAILWAY TIE ASSOCIATION[1]

Estimation	10-year period	15-year period	20-year period
Average Annual production	42,000,000	42,000,000	42,000,000
Projected capacity	420,000,000	630,000,000	840,000,000
RTA estimate of need	401,797,270	540,999,720	680,202,180
Surplus	18,202,730	89,000,280	159,797,820

This estimate by the RTA is based on a 4-month period in 1974 in which 85 percent of the industry produced 3 million crossties monthly, a possible 3.5 million for the entire industry or a possible annual output of 42 million crossties. The RTA claims that this capacity can be realistically met, however, only if the railroads alter their purchasing policies to a regular schedule to allow the tie producers adequate time for planning.

The ramifications of the GAO report are difficult to assess. At present, the railroads enjoy an adequate supply of wood crossties and therefore cannot see the rationale of a regularized tie purchasing schedule, especially as such a schedule would tie up important capital resources. In the absence of such a schedule, as previously stated, the tie producers see no need to expand production or, presumably to consider installation of refurbishment facilities. On this basis, the situation appears likely to remain unchanged until such time as wood for crosstie use once again becomes scarce.

1. "Can Suppliers meet Demand for Rails and Crossties?," Track and Structures, February 1977, pp.24-25.

3.3 Manufacture of Crossties

Manufacture of crossties begins with the lumbering operation. Trees to be used for crosstie manufacture are selected such that ties produced from them will meet the specifications set out by the American Railway Engineering Association (AREA) Bullentin 645, Volume 75 (see Appendix A). The logs are generally transported to the saw mill where they are cut to specified size, based on the AREA specifications and the requirements of the customer.

From the mill, the ties are taken to the tie concentration yard, where they are inspected and graded, and then to the treating facility, where they are inspected by an agent of the railroad purchasing the ties. An overall view of a large treating facility is shown in Figure 3.1. The pressure treating facilities are shown in the foreground, the lumber stockpiles (Figure 3.2) and processing stations in the background.

Processing of the railroad ties begins with end trimming, curfing (marking the tie to enable proper alignment along a rail bed), and branding (Figure 3.3), and selection of appropriate wood species (Figure 3.4). In some treating plants, prior to drying or preservative treatment, ties are then bored, adzed (if required), and incized. Boring provides the hole in which the spike is driven and reduces splitting of ties during spiking. More importantly, these holes allow penetration of preservative into the area of the tie beneath the tie plate, an area very susceptible to decay. Incizing creates many small holes in the surface of the tie to allow greater preservative penetration. Incizing also helps to prevent checking during seasoning of ties.

In addition to the lumbering operations, crossties must be seasoned (or dried) to remove excess moisture content. This drying process involves either an air-drying or vapor-drying method. The air seasoning schedules depend upon the type of wood and climatic conditions. Seasoning periods of four to six months are generally required for softwoods, eight

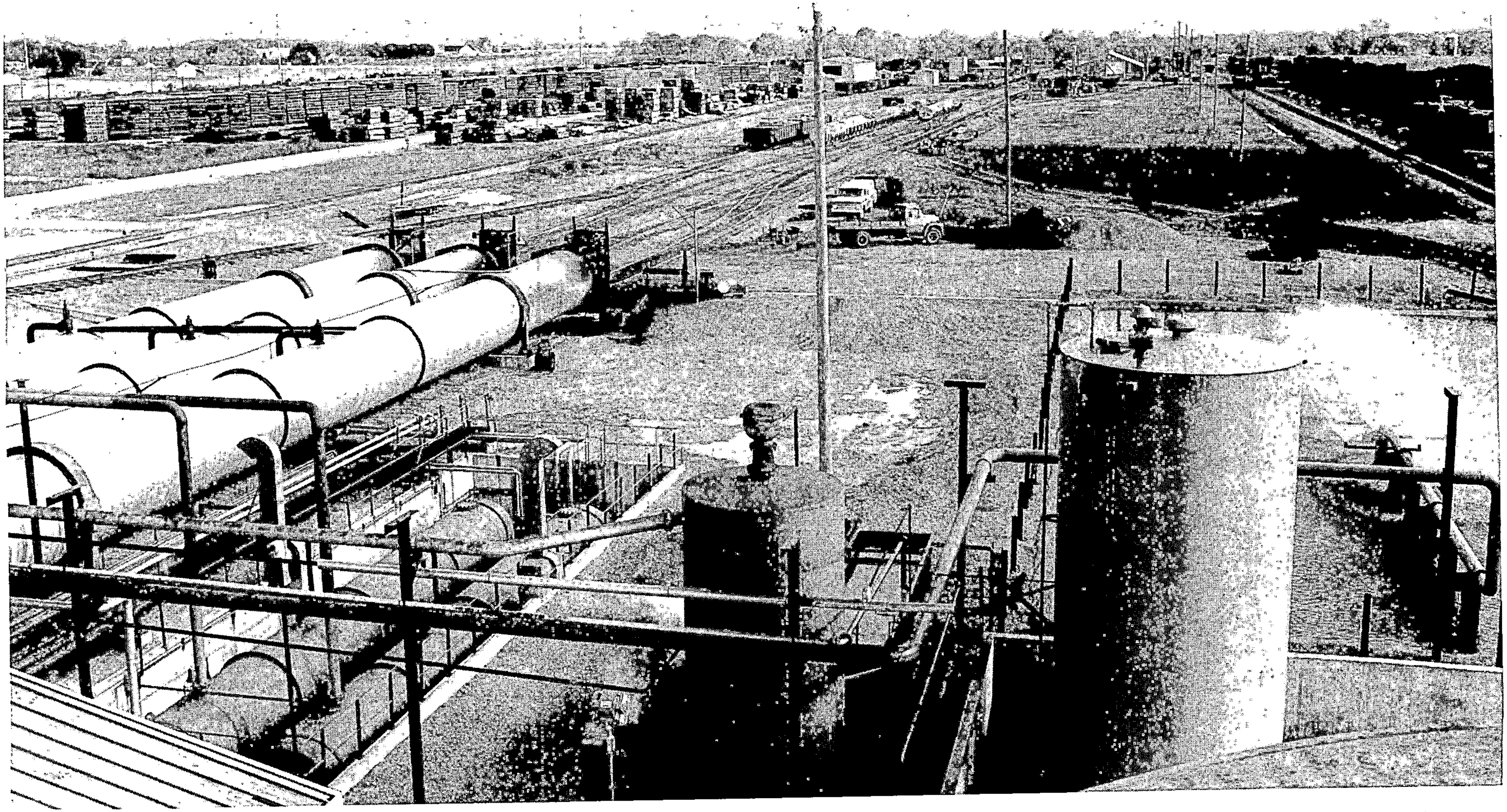

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FIGURE 3.1 OVERVIEW OF A TIE TREATING FACILITY
SOURCE: The Koppers Company

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FIGURE 3.2 STOCKPILE OF HARDWOOD LUMBER FOR CROSSTIE USE

SOURCE: The Koppers Company

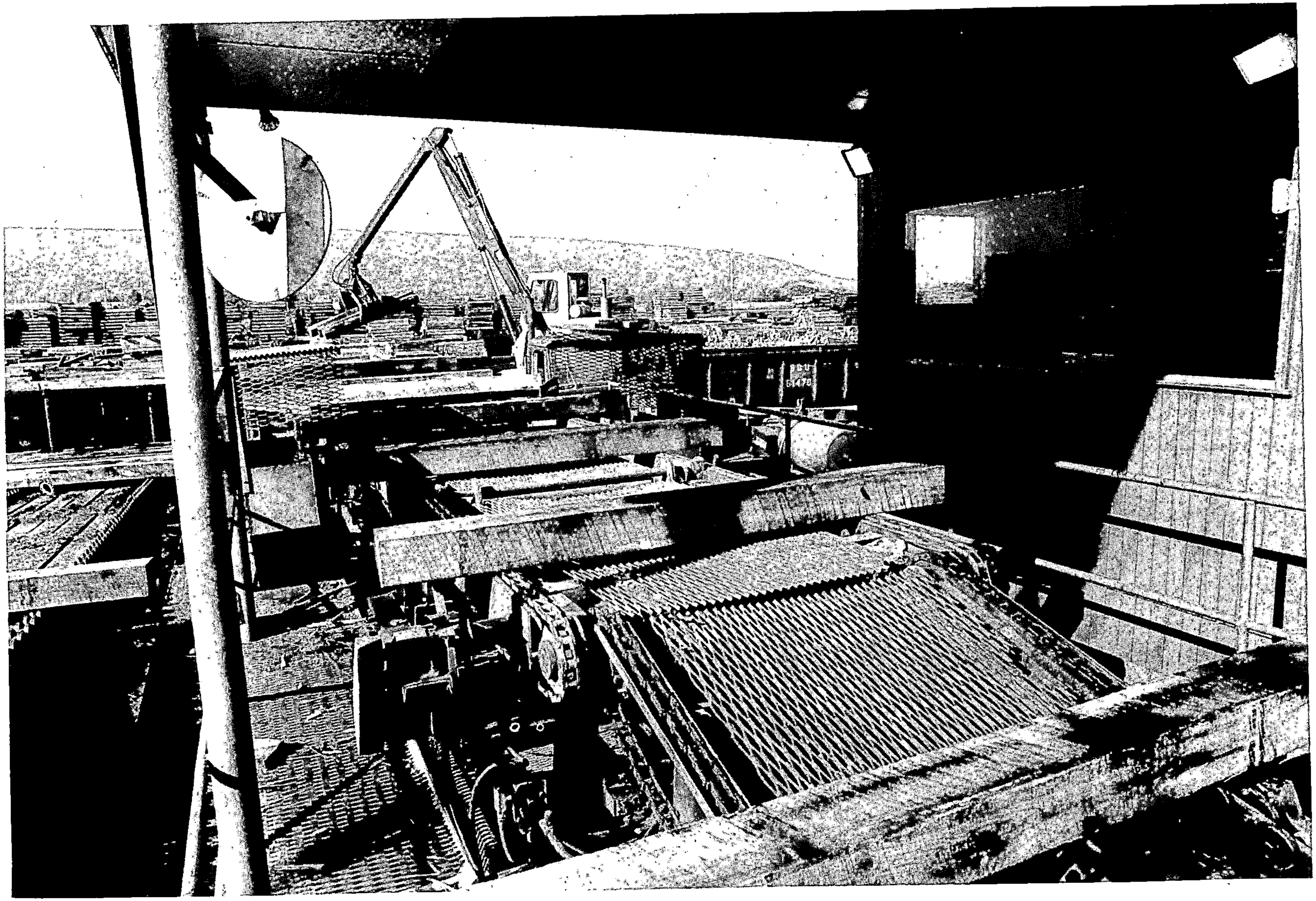

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FIGURE 3.3 END TRIMMING, CURFING AND BRANDING
SOURCE: The Koppers Company

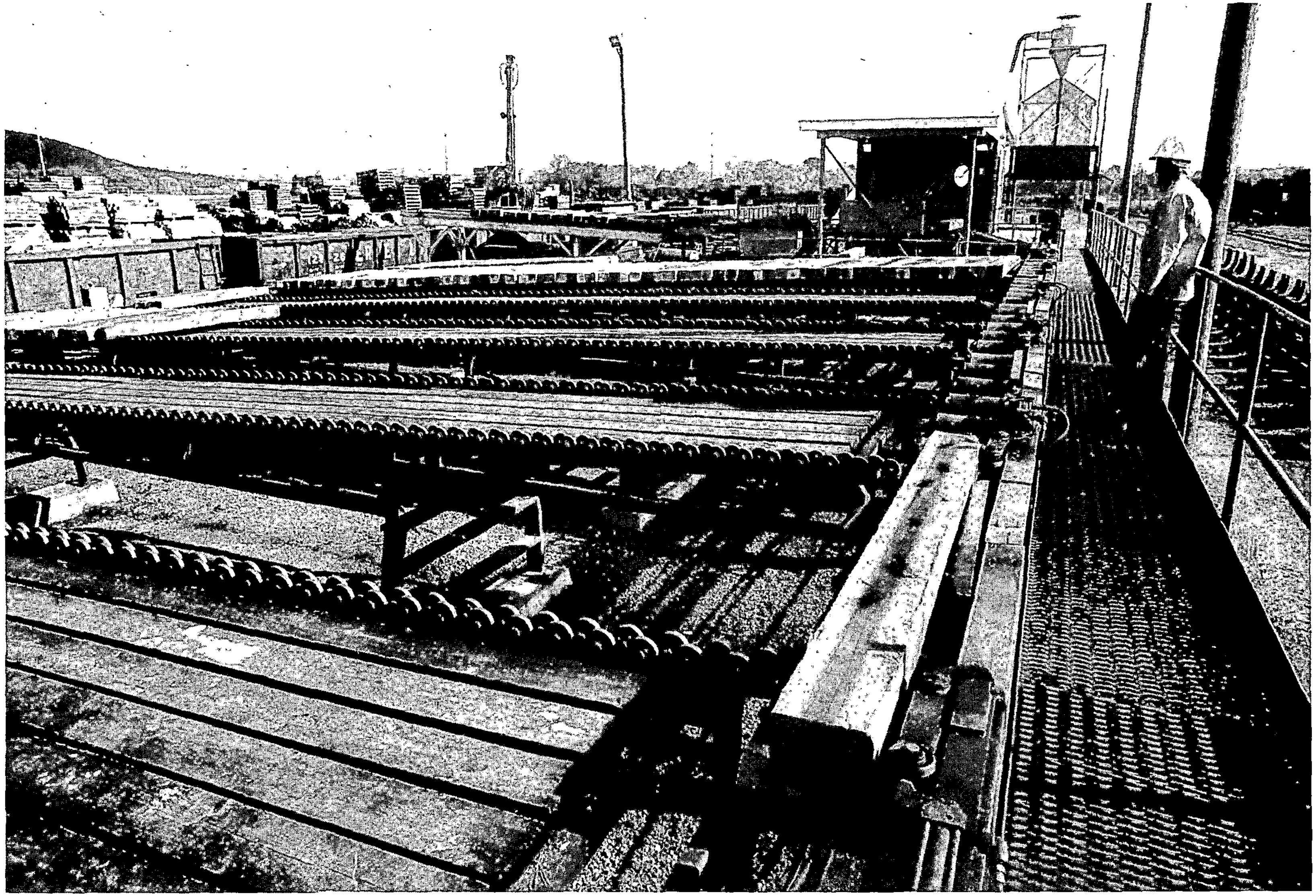

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FIGURE 3.4 THE INSPECTION AND SEPARATION ACCORDING TO WOOD SPECIES

SOURCE: The Koppers Company

to nine months for mixed hardwoods, and approximately 10 to 14 months for oak. Deterioration of ties because of fungus attack during the seasoning period prior to preservative treatment, which was a problem for many years, has been reduced by better methods of piling and better yard sanitation.

The vapor-drying method is attractive in that it requires only approximately 12 to 14 hours to reach the desired moisture content. In the vapor-drying process organic solvent vapors are used to extract the moisture from and condition the green ties for the preservative treatment. The green ties are stacked on small rail cars (Figure 3.5) and placed in a treatment chamber containing an organic solvent, which is heated to a temperature averaging approximately 270°F. The hot solvent vapors raise the internal temperature of the ties, causing moisture to migrate from the tie interior to its surface. This moisture combines with the solvent vapors and is circulated out of the cylinder. The moisture and solvent are separated and the solvent reused. After vapor-drying, the crosstie can be treated with preservatives in the same cylinder.

In light of energy considerations and the general conservative nature of the industry, air drying is still reportedly the most popular and cost-effective means of drying.[1] Also vapor drying is felt to use up a considerable amount of treating cylinder time.

After seasoning, the crossties are impregnated with a preservative. The most effective method of controlling decay caused by infestations of fungi and termites is to poison the food supply of the organisms by treating the wood with creosote or other chemicals applied under pressure. Each tie retains about 2.75 gallons of the preservative,

1. "Industry Capability to Produce Rail and Crossties for Nationwide Railroad Track Rehabilitation," Comptroller General of the United States (September 23, 1976).

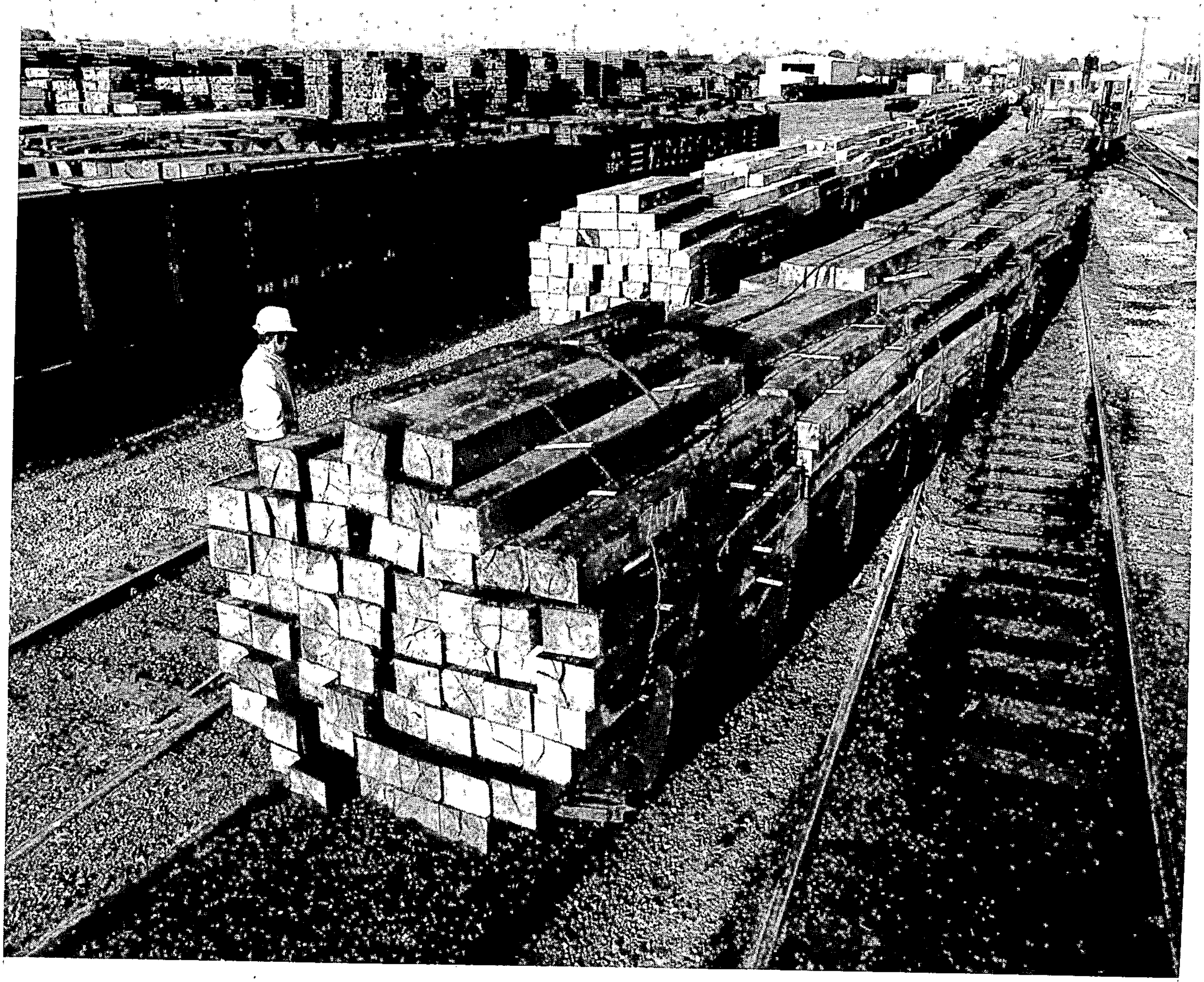

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FIGURE 3.5 TIES AWAITING DRYING AND CREOSOTE TREATMENT
SOURCE: The Koppers Company

usually either solutions of creosote and coal tar or creosote with petroleum. In 1974, the reported 23 million crossties produced would have used 63 million gallons of preservative.

To undergo the preservative process, the ties, stacked on small open rail cars, are placed into the steel treatment cylinder. The cylinder is then closed and filled with preservative. Pressures in the range of 125 psi to 175 psi are used to force the preservative into the wood until the desired amount is absorbed or until saturation.

One of two processes, the full-cell or the empty-cell, is commonly used. The full-cell method is used for timber requiring full creosote protection against marine borers and for waterborne preservatives such as pentachlorophenol in a process formula known as "Cellon". Since the Cellon process uses a highly volatile petroleum gas, closer control over preservative retention may be achieved by using the empty-cell method, which substitutes a noncombustible gas such as nitrogen.

For treatment with oil preservatives, two empty-cell processes, the "Rueping", and the "Lowry", are both widely used in Europe and the United States. In the Rueping process, air under pressure is forced into the treating cylinder and maintained between 25 and 100 psi for one-half to one hour (depending on the penetration resistance of different species of wood). Preservative is then pumped in, displacing the air into an equalizing (Rueping) tank at a rate that keeps the pressure constant in the cylinder. When the cylinder is filled with preservative, the air pressure is raised to above normal and maintained until the wood is saturated, or acquires the desired retention level. The Lowry method is similar to the Rueping but without the use of an initial air pressurization step; hence, an air compressor, pump, and extra cylinder or Rueping tank are unnecessary.

As previously mentioned, the pressures used to retain the preservatives are commonly 125 to 175 psi. Since many woods are sensitive to high pressure, especially when hot, the American Wood Preservers Association (AWPA) has set maximum standards for specific species, for example, 150 psi for Douglas fir, 125 psi for redwood, and 100 psi for western red cedar.[1]

Because high temperatures are much more effective than low temperatures for treating wood species that do not readily absorb preservative, the American Wood Preservers Association (AWPA) has set standards requiring an average use temperature between 190^{o} and 200^{o}F for creosote solutions.[1] Higher temperatures can damage the tie's structural properties, leaving the wood susceptible to checking, splitting, and consequent decay. With pentachlorophenol and other waterborne preservatives containing chromium salts, maximum temperatures are set at 120^{o} to 150^{o}F, as higher temperatures cause premature precipitation of the preservatives.

The American Railway Engineering Association Manual gives specific recommendations for preservative penetration of crossties. The recommended penetration varies with the different wood species. For example, a red oak tie should have 65 percent of the sapwood penetrated; for white oak, 95 percent penetration of the sapwood is recommended.[1]

Requirements for preservative retention vary from one railroad to another. Some lines require as low as 6 to 8 pounds of preservative per cubic foot of crosstie volume; others require up to 10 to 12 pounds per cubic foot. Species variation and diverse climatic conditions account for many of these differing penetration and retention requirements.

The use of chemical preservatives has significantly increased the average crosstie life. Before the use of preservatives, crosstie life averaged 6 to 10 years. The current average estimated life for treated crossties is 30 to 35 years. Preservative treatment for crossties has

1. "Preservative Treatment by Pressure Processes," AWPA Standard C6-70 (1970).

proved so effective that all crossties are now treated before use. Figure 3.6 shows pressure-creosoted ties being removed from the treating cylinder. After removal from the treatment area, treated ties are loaded onto tie-carrier cars for shipment to track construction and maintenance projects (Figure 3.7).

There are about 270 companies in the United States that operate pressure treating plants capable of treating crossties. Assuming dedication of one treating cylinder loading per day to crossties, for 300 days a year, the total tie treating capacity is estimated to be 80 million crossties. Theoretically, if treating cylinders were run 365 days per year, 24 hours per day, for crossties alone, 290 million crossties could be treated.[1] We will return to this estimate of treating capabilities of the tie producing industries in Section 9.

3.4 Tie Costs

During the last four years (1972-1976), treated crosstie prices have risen from $5 to $6 per tie to $11 to $13 per tie.[2] If $1 per tie is added for shipping expense and $4 for the cost of installation, the current cost for an installed tie is $16 to $18. This cost is representative for the larger U.S. railroads; however, many of the smaller railroads with more limited purchasing power pay from $20 to $23 each for installed ties. The cost of $16 to $18 per installed tie with an average life of 35 years represents an annual cost per tie of $0.45 to $0.50. At first glance, therefore, it would appear that a renovation process capable of producing a tie resulting in annual cost of less than $0.45 (installed) would be an economical advantage. However, other factors such as initial capitalization costs of a refurbishment facility, the needs of the industry, and degree of industry acceptance of refurbished ties must also be included in an overall assessment.

1. "Industry Capability to Produce Rail and Crossties for Nationwide Railroad Track Rehabilitation," Comptroller General of the United States (September 23, 1976)
2. Data generated by SRI during the course of this study. Appendix D lists key contacts.

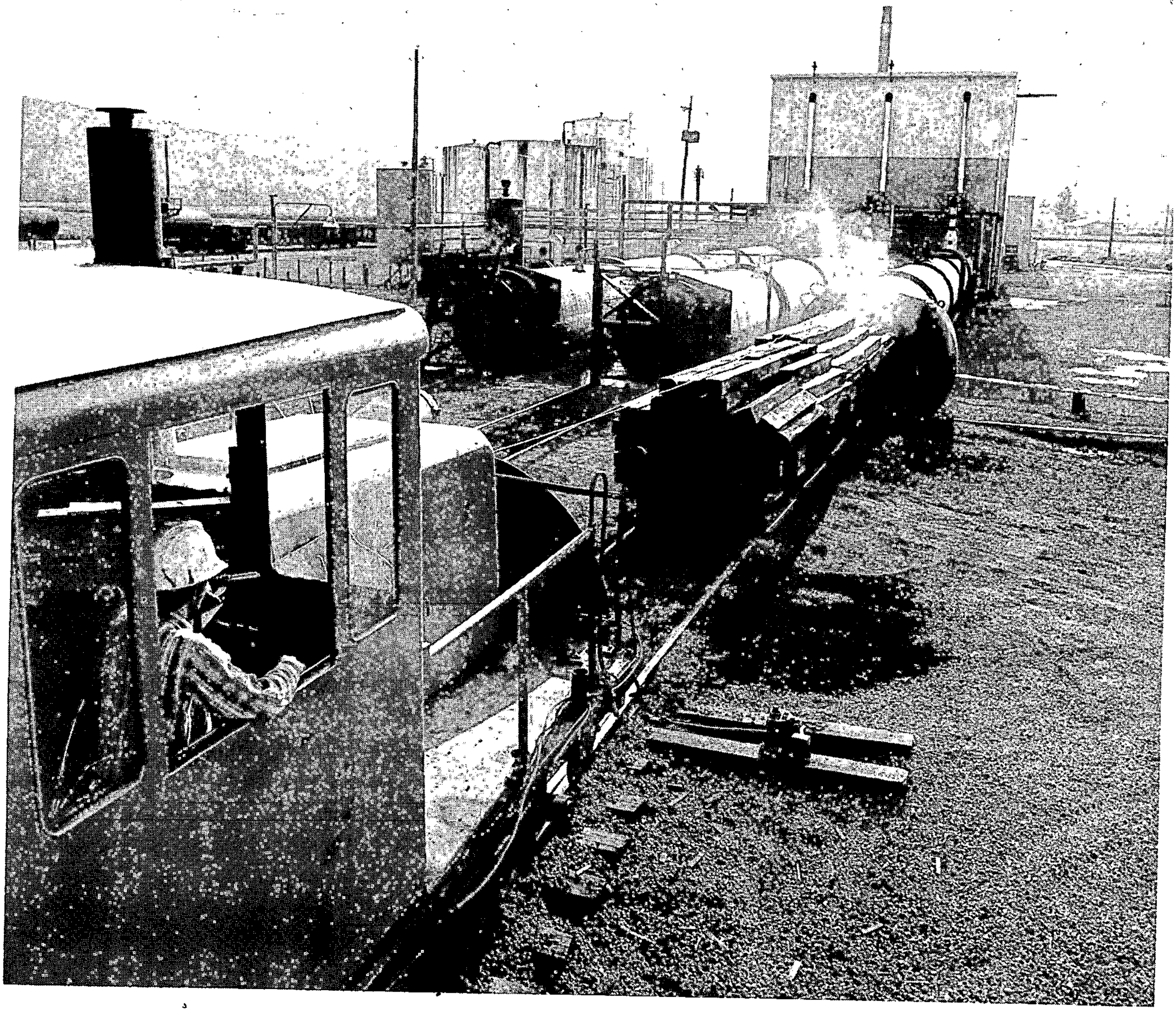

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FIGURE 3.6 PRESSURE-CREOSOTED TIES BEING REMOVED FROM THE TREATING CYLINDER
SOURCE: The Koppers Company

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FIGURE 3.7 TREATED TIES BEING LOADED FOR SHIPMENT
SOURCE: The Koppers Company

4. MODES OF TIE DETERIORATION

The principal modes of deterioration of wooden crossties are mechanical wear, physical damage, termite infestation, and attack by decay fungi.[1,2] These modes and their relationship to the tie service environment are discussed in this chapter. It is these modes of deterioration which a successful tie refurbishment process has to address.

4.1 Attack by Decay Fungi

Living trees are protected from decay fungi by an impervious layer of sapwood. There are almost no wood rotting fungi that can attack the layer of living wood that is present just inside the bark of all trees. Crossties have no such natural protection and so need special treatment to render them resistant to invasion by fungi. As they are normally installed in contact with the ground, moisture cannot be kept low enough or high enough to prevent fungus action. The tendency for crossties to check, opens cracks which serve as an entrance point for fungi attack.

The main requirements of fungi for normal growth are sufficient moisture, air, a favorable substratum, and temperatures of about 50°F to 90°F. Wood with 20 percent moisture or less will not support fungus growth and safe moisture levels are invariably present in air-dry wood. Fungi also have certain special requirements for maximum activity. For instance, many grow only on coniferous wood and others only on hardwoods. Some grow best only on certain species of wood and there are also some which grow well on both hardwoods and softwoods. Some grow mainly on heartwood of certain living trees and others occur only on sapwood of certain dead trees. Since there are so many species of decay fungi, there are species for almost every type of wood under almost any

1. Proceedings of the Wood Pole Institute, Colorado State University, Fort Collins, Colorado (June 1968).
2. Wood Handbook, U.S. Forest Products Laboratory, U.S. Dept. of Agriculture (1974).

condition where the basic favorable requirements of air, moisture, and temperature exist.

Deterioration of wood by fungi is so common that all wood that is to be used in contact with moist soil must be treated with wood preservatives, applied under certain standard procedures, to give satisfactory service. The exceptions are a few durable heartwoods which give satisfactory life without treatment.

Certain selected toxic materials render wood much less favorable to growth of fungi and reduce their susceptibility to a relatively few fungus species. In spite of these treatments, which are usually applied by pressure methods, certain of the fungi are known to be more tolerant to specific treating materials than others. For instance, Letinus lepideus is known for its considerable tolerance to creosote-treated wood. Failures which occur in treated timber are often caused by this decay fungus. Coniophora peteana is resistant to compounds of zinc. Poria monticola and several others are resistant to copper, Lenzites trabea to arsenic, and Polyporus versicolor and P. sanguineus to a number of compounds.

The fungi may be divided into two main groups, depending on whether they cause a brown cubical or checked type of rot or a tough stringy white rot. They may be further classified, depending on whether the decay is in small localized pockets scattered through the relatively sound wood or whether they affect the wood uniformly over the entire infected area. Thus, there can be brown pocket rots or white pocket rots and uniform brown rot. A specific fungus always causes the same type of rot. The rate of decay by different fungi also differs according to species, kind of wood, and on whether the moisture, air, and temperature are favorable. Under outdoor conditions, these factors for growth are often most favorable at or near the soil surface.

Of the two kinds of rot (brown and white), the brown checked type causes greater weakening (breakage across the wood fibers) at an earlier stage than do the white rots. Many of the rots in poles and other products are of this brown type, such as that caused by Lentinus lepideus and Coniophora. Independent of the species of fungus causing tie rot, the process of decay involves the two primary steps of initial infection and continued growth.

Most decay that takes place in trees, logs, or lumber products starts from spores (basidiospores). These spores are one-celled, seed-like bodies ranging in size from about 3μ to 10μ (1μ or micron = 10^{-6} in). Some are round, some are ovoid, and some are more elongated or nearly cylindrical in shape. Some are white (hyaline) and many are dark brown to golden in color. All are so small that they are invisible except where they collect in large quantities as a powder-like mass. A visible layer of such spores may readily be collected in just a few hours from a fruiting body that is actively sporulating.

Spores are disseminated by being forcibly ejected from the sporophore into the air, where their small size and weight enable them to be carried for considerable distances by even slight wind currents. They finally may land on another tree, or a log or pole, and settle in a favorable spot, such as a check, for germination and growth.

There is also the possibility that infection in wood may start from mycelium in the soil or from spores deposited in soil adjacent to wood. However, there is little positive information on decay fungi living and growing in a moist soil in the absence of wood. In any event, decay fungi have seldom been isolated directly from the soil. For this reason and from the general knowledge of the habits of the fungi, we will assume that infection is almost always from direct deposit of spores from the air onto wood which is in favorable condition for germination and growth. This germination process marks the initiation of the growth period, having established the infection in a supporting

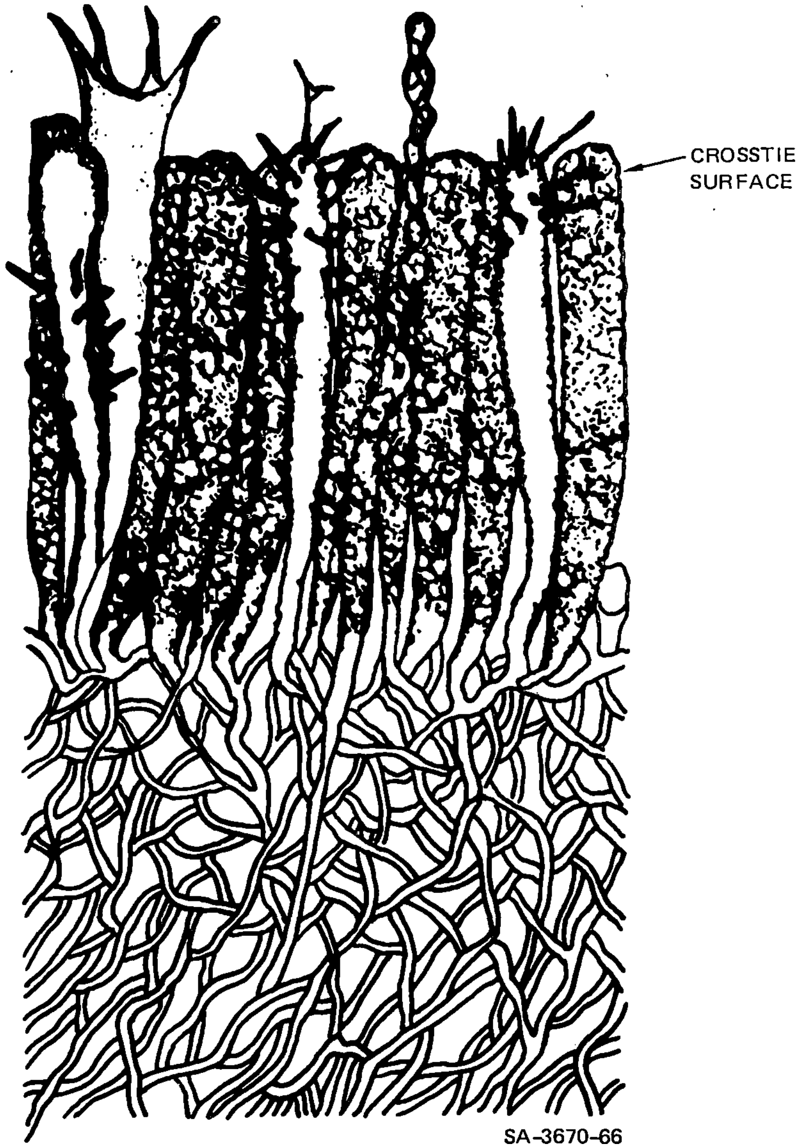

FIGURE 4.1 CROSS-SECTION VIEW OF DECAY FUNGI ATTACK

environment.

A spore is so small that it could support very little subsequent growth. Therefore, on germination the delicate mycelial filaments must grow quickly into the wood (Figure 4.1). They penetrate into and through wood cells by dissolving the cell walls and using the substances thus obtained for further growth and expansion. The penetrating hypae use certain parts of the cell walls and continue to multiply and concentrate action of growth until much of the content of the cell walls are broken down and the wood weakened and largely destroyed. This is the process called decay. Some species of fungi dissolve and utilize mainly the cellulose and much of the lignin (white stringy rots). There are many other fungi (molds) which will grow in sapwood and utilize the cell contents but cause no reduction in wood strength. Such fungi render the sapwood more permeable so it will absorb water or liquid preservatives more readily.

4.2 Attack by Termites

Untreated crossties placed in contact with or near the ground are subject to attack and damage by termites as well as by decay. Such damage is apt to be more severe in the central and southern parts of the country at low elevations than in the more northern parts at higher elevations. However, termites occur to some extent in all of our states except Alaska and have been found at elevations of 7000 feet.

In addition to the damage they cause directly, they make openings in the surface of wood that hasten attack by fungus decay. Also, termites working in partially decayed wood will accelerate its deterioration. Subterranean termites, mainly *Reticulitermes* species, live in the ground where it is moist. Their principal food is cellulose. Thus, moisture and cellulose are their two main requirements. If deprived of either one of them, they will die.

Termites are social insects, like ants, and the reproductive forms have wings, but there the similarity ends. They are not closely related and, in fact, are natural enemies. Although they have been known to live relatively close to one another in wood, they maintain separate colonies. In the winged stage, ants are frequently mistaken for termites. They can be readily identified by making the following observations. In the case of the ant, the body is thin-waisted and the inner pair of wings are smaller than the outer pair and extend no more than one-half their length beyond the body. Also, the ants retain their wings until they have established their new nest. In the case of termites, the body is thick-waisted and both pairs of wings are of equal size and length and extend nearly two-thirds their length beyond the body. Frequently termites shed their wings shortly after emergence, particularly when this occurs inside of a building.

A well established colony of subterranean termites consists of the yellow-brown to black winged reproductives (primary king and queen); from 35 to 100 second- and third-form kings and queens, which spread out in the ground and reproduce; a large number of wingless, grayish white, sterile workers that destroy wood and other cellulose-containing products; and a small number of soldiers with bodies like the workers but with long, brownish, hard heads equipped with sickle-like jaws which they use to attack ants or other enemies that try to invade their nest. The workers care for and feed the reproductives and soldiers, as well as care for the eggs and the young. The soldiers protect and maintain order in the colony.

Subterranean termites follow the grain when extending their channels through the wood. They remove the cellulose from the wide springwood rings and leave the more resinous summer wood alone, penetrating it only when necessary to reach the adjoining springwood. Thus, the damaged wood consists of a series of channels, separated by thin partitions. When present in large numbers, they can honeycomb wood. They dot the sides of their chambers with their soft, grayish excrement, which dries and appears as specks on the surface of the wood. This is characteristic of the work of this type of termite and enables one to determine, with a marked degree of certainty, even small pieces of the damaged wood. Another indication of termite damage is the presence of earthen-like tubes that they build occasionally along the exposed surface of the wood. It requires a year for the subterranean termite to mature and its average life is five years.

Drywood termites (Kalotermes species, particularly K. minor Hagen, the Dark Pacific Coast species) are known to cause serious damage to untreated ties in areas where they are prevalent. Termites in this group have only two forms or castes, the reproductives and the soldiers. The worker caste is absent. The young perform the duties of the worker. The adults emerge and fly at night, whereas the ground-nesting forms normally fly during the day. The winged adults enter crevices in the wood and live there. They do not need any more moisture than normally occurs in wood and buildings or in poles. They make cavities in the wood and seal their eighth-inch entrance holes with tiny impressed pellets which are held together with a glue-like secretion that comes from their mouths. Their pellets are extruded from tiny openings in the wood and are an indication of infestation by this type of termite. Some of these colonies are known to be 15 years old.

For the country as a whole, crossties treated full length by the "full cell" pressure process (at least 6 pounds per cubic foot) in large steel cylinders with coal-tar creosote of standard grade may be expected to make the wood resistant to attack by both drywood and ground-nesting termites for at least 30 years (see Section 3.3). In areas where termites are not much of a problem, it may be possible to obtain all of the protection required with a lighter treatment.

4.3 Mechanical Wear and Physical Damage

This mode of deterioration includes crushing and plate cutting, spike killing, and to some extent checking and splitting.

4.3.1 Plate Cutting

Although steel tie plates considerably reduce the penetration of rails into the tie surface, they do not completely eliminate this cutting action. Even though the tie plates are initially firmly spiked to the ties, lateral plate movement of 0.005 to 0.01 inch takes place under the load of passing trains.[1] As the plate moves, the wood fibers under the plate are gradually abraded and the plate penetrates into the tie surface (Figure 4.2). Railroad engineers state, and tests from the American Association of Railroads' laboratory have shown, that plate cutting damage would be insignificant if this lateral movement of the plates did not occur.[1]

Plate movement alone is not the cause of plate cutting, however. Studies have shown that plate wear on dry, clean wooden ties is insignificant over extended periods.[2] It seems that wear is significant when plate movement is accompanied by the presence of moisture and foreign material such as dirt or rocks. Track curvature also greatly affects plate cutting. In the high tonnage track, ties not only plate cut more rapidly but also suffer other forms of deterioration at higher rates. The rate of plate cutting is considerably higher on curved track than on tangent track.

The wood species used for ties can also significantly influence the rate of plate cutting. The denser hardwoods tend to resist plate cutting or abrasion more than the less dense softwoods. Traffic volume and track curvature also greatly effect plate cutting by significantly

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1. L. G. Collister, A.T.& S.F., private communication.
2. R. W. Pember, "Determining Who Renews Ties," Railway Track and Structures, July 1976, p. 62.

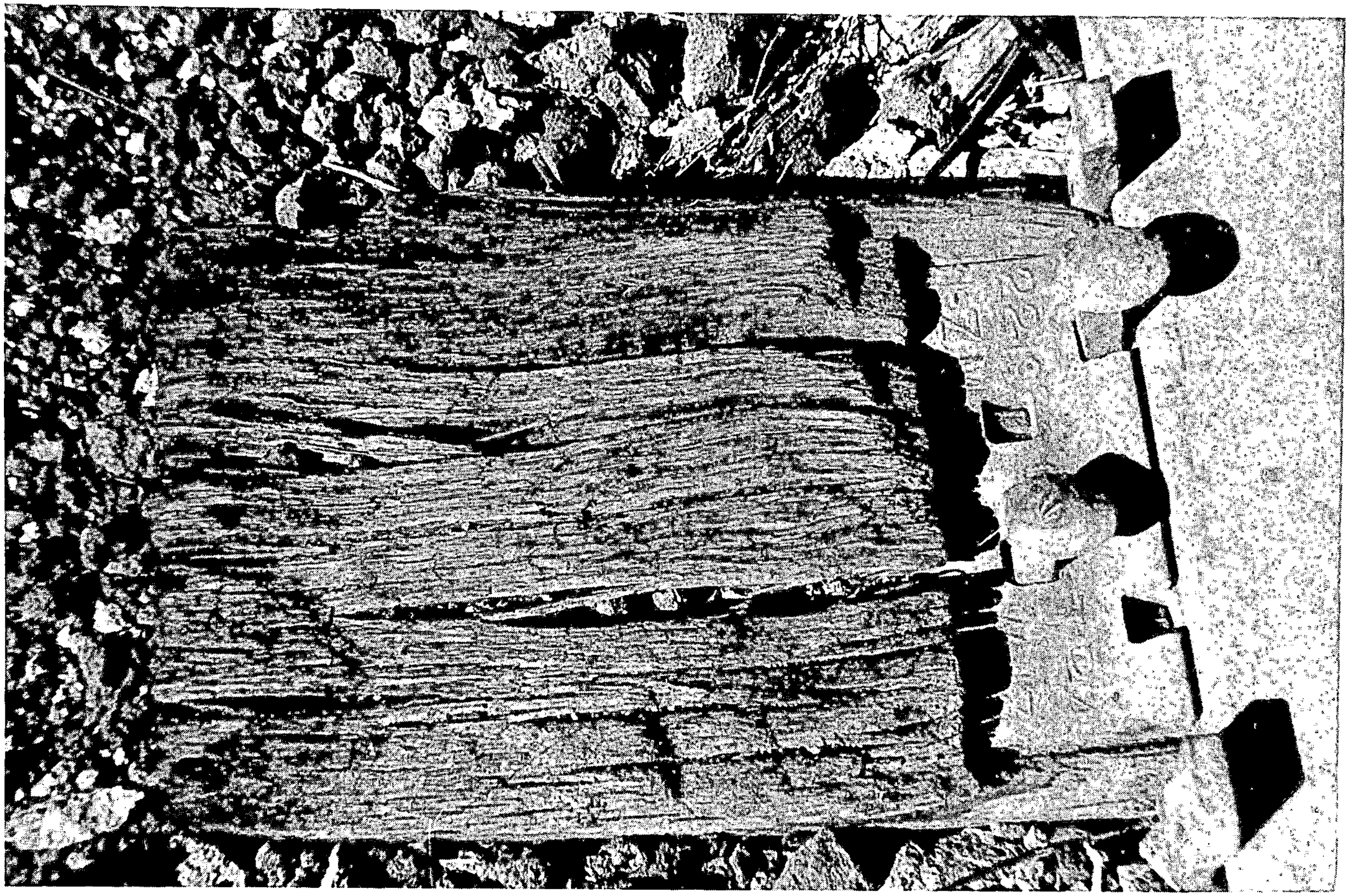

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FIGURE 4.2 SEVERE TIE PLATE CUTTING

affecting the magnitude and frequency of plate loading events.

4.3.2 Crushing

Crushing is the actual destruction of the wood fibers in the plate area (see Figure 4.3). This degradation is caused by moisture entering the area beneath the plate by way of surface checks and splits. The moisture penetrates the wood fibers, causing swelling of the wood cells and appreciable weakening of the fibers. As this takes place, the fibers are further destroyed by the movement of the plate on the tie caused by passing trains.

Although the term "plate cutting," as previously described, is normally used by the industry to include both vertical action and lateral shearing, crushing in the plate area is a special and distinct case, although plate cutting does often occur in conjunction with crushing of the wood fibers. One result of crushing is excessive plate movement due to a loosening of the spikes as the wood fibers weaken and are no longer able to hold them. Crushing will also lead to biological decay of the wood fibers in the plate area and adjacent areas. The main reason for biological decay is loss of preservatives from the crushed area, for as crushing occurs, the wood fibers flex under load and preservative is exuded.

4.3.3 Spike Killing

Spike-killed ties are those that are no longer capable of holding their spikes: the spikes are not solidly in the ties and are able to move, in many cases rising from the tie (Figure 4.4). Spike kill facilitates widening of the rail gauge under applied lateral loading and allows excessive movement of the tie plate.

Spike killing often results from the respiking of the ties when new rail is laid, the track is regauged, or when respiking becomes necessary in the vicinity of insulated joints. Whenever the spikes must be pulled and the ties respiked, tie deterioration takes place and leads

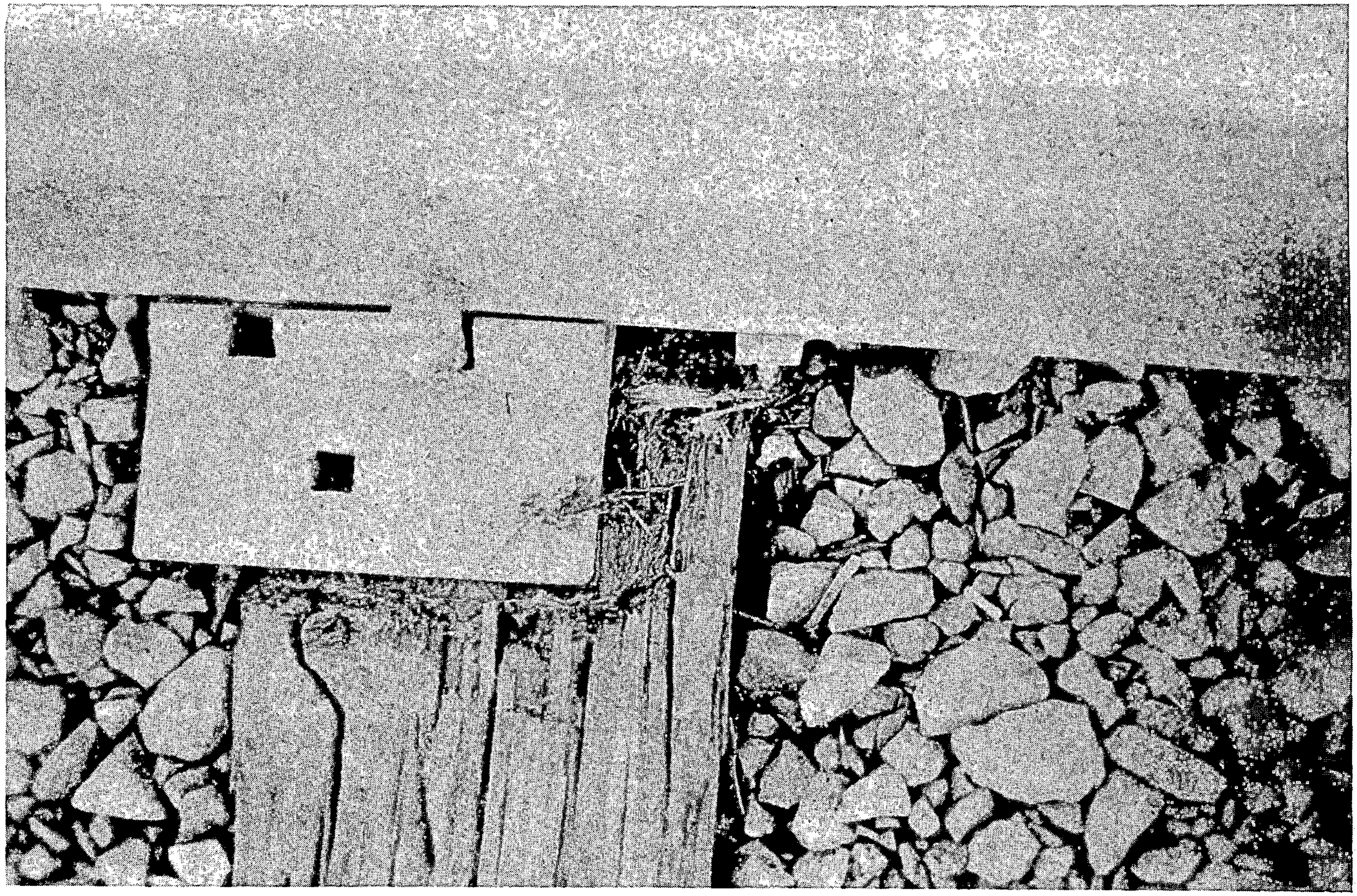

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FIGURE 4.3 CRUSHING UNDER THE TIE PLATE

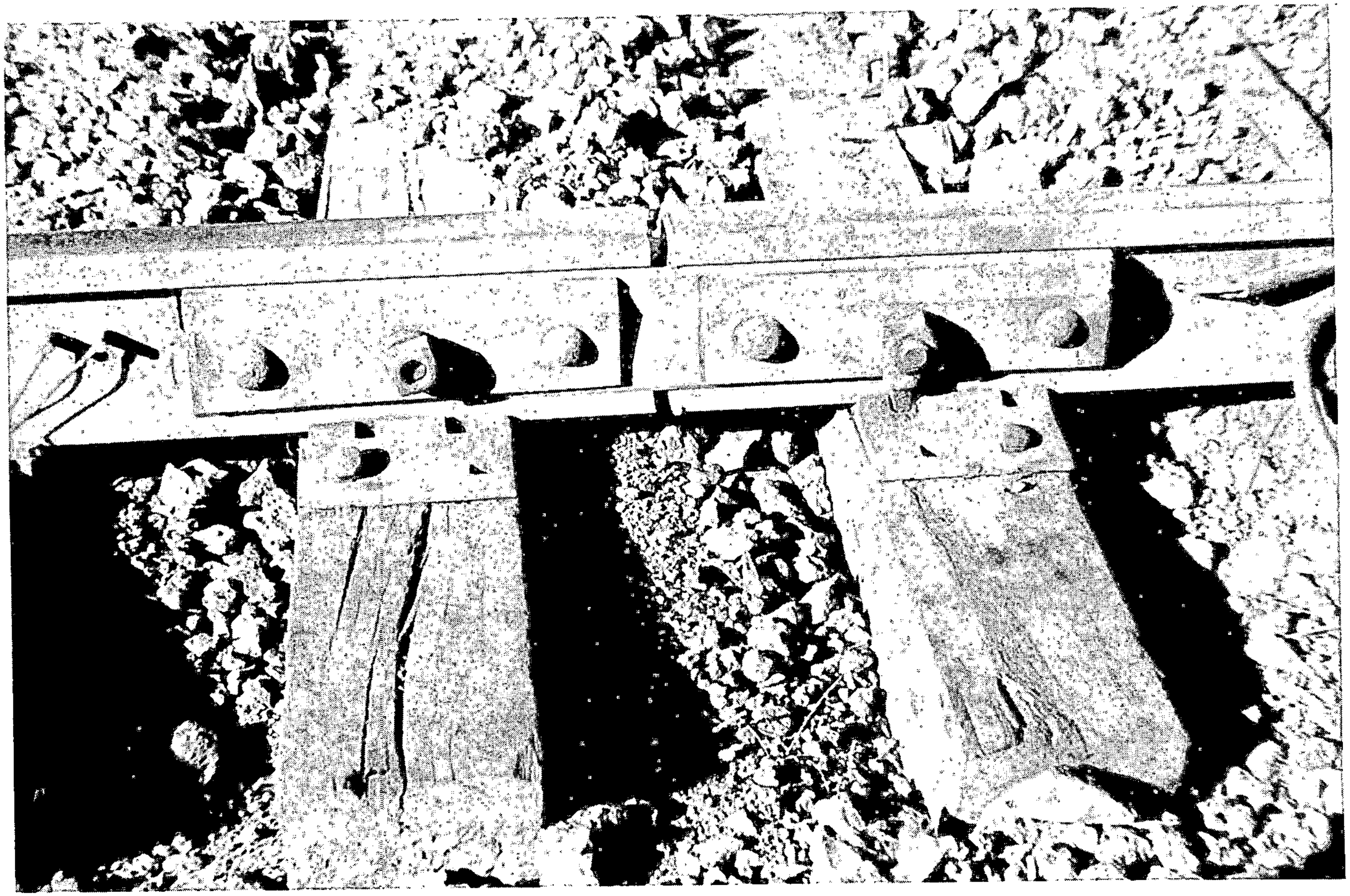

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FIGURE 4.4 SPIKE-KILLED TIES

to weakening of the tie in the tie plate area. Respiking causes spike loosening when the wood fibers around the new spikes are shifted by adjacent fibers being pushed into the voids left by previous spikes.

A second cause of spike kill is the presence of iron, which causes deterioration of the wood fiber around the spike. This wood deterioration is actually a chemical change in the hemicellulose and cellulose that occurs when the oxidation of wood is accelerated by the presence of iron. This form of spike kill is prevalent in oak ties because the presence of tannic acid in this species initiates deterioration.

Another form of spike kill is that caused by the minute movement of the spike under the load of passing trains. This movement allows moisture to migrate into the spike hole and, with time, cause swelling of wood cells. This swelling of the cells will quite rapidly deteriorate the wood fibers in the spike area. The presence of surface checks or splits also allows moisture and fungus to reach the area beneath the tie plate and the area around the spikes. In time, this causes deterioration of the wood and loosening of the spikes.

4.3.4 Checking and Splitting

This deterioration mode has already been described in Section 2.0. Although checking is not normally a cause for crosstie replacement, it is critical to tie decay because it exposes internal portions of the tie and allows biological attack of untreated wood. Checks may also create large splits when the presence of ballast in a check continually enlarges the check under the movement or vibration of passing trains (see Figure 4.5). The entry of water and the freeze and thaw cycle of the winter will also expand checks or splits, allowing entry of decay fungi, ballast, and other foreign materials.

4.3.5 Mechanical Damage

Crossties in service are subjected to varying degrees of mechanical damage. Derailments, equipment dragging from passing trains, vandalism,

FIGURE 4.5 AN IN-SERVICE TIE EXHIBITING CHECKING AND SPLITTING

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and numerous other problems cause ties to be damaged on their surface or, in some cases, broken through. Figure 4.6 illustrates a case wherein a box car in a long freight train jumped the track and was dragged approximately five miles, with a set of its wheels running along the mid-point of the track. The damage inflicted to the ties is evident. Complete replacement of the damaged section is the only remedy for this type of damage.

4.4 Population of Deterioration Modes

Although specific modes of deterioration are not critically cataloged when ties are removed from track, and, more often than not more than one form of deterioration has caused the removal of the tie, detailed interviews with railroad personnel and American Railway Engineers Association (AREA) Committee 3 members were employed to estimate the population of ties in each defect class. This population is shown in Table 4.1.

TABLE 4.1 PERCENTAGE POPULATION OF TIE DETERIORATION MODES

Tie Deterioration Mode	Population (% removed annually)
Decay & wood deterioration (crushing)	43-44
Plate cutting	18-20
Splitting	16-18
Spike killing	14-16
Broken ties	2-3
Other (mechanical damage, such as derailments and rail anchor damage)	2-4

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FIGURE 4.6 TIES DAMAGED BY DERAILED BOXCAR

We assume the above figures to be generally representative of annual tie removals. As no statistical data are kept by the railroads, these represent the average of the best estimates of experts in the field. As Table 4.1 shows, the largest contributers to tie replacement are the closely allied mechanisms of decay, plate cutting, and splitting. Since separation of the replacement causes is difficult at best, and because these mechanisms, as discussed earlier, act in combination to deteriorate ties, the ramifications of these data to the feasibility of reuse are important. A process which could arrest decay and strengthen the wood fibers, while replacing crushed, abraded, or split fibers with sound material, could conceivably take care of nearly 8 percent of the current population of wood ties replaced each year. This factor bears consideration later in Sections 6 and 7 when evaluating processes to achieve these improvements.

5. TIE REPLACEMENT PROCEDURES AND STATISTICS

This section will discuss the procedures involved in the identification of failed wooden crossties, the criteria which require their removal, the methods used for removal and replacement, and the percentage replaced by geographic region and by defect. The mechanics of these procedures and the economic and safety issues associated with them strongly impact the feasibility of refurbishing ties by identifying the conditions of ties when they are scheduled for removal. Shifts in tie inspection procedures and the criteria for removal can substantially impact the nature and the severity of the deterioration ties exhibit at the time refurbishment techniques could be applied. Although they vary from one railroad to another, general trends in tie use can be identified and are reported in this section.

5.1 Tie Inspection and Removal

The only fixed or mandatory requirements on tie condition are set forth in the Federal Railroad Administration (FRA) Track Safety Standards (213.109 Crossties). This standard requires that ties be considered defective and be removed from track if they are (1) broken through, (2) split or otherwise impaired to the extent they will not hold spikes or will allow ballast to work through, (3) so deteriorated that the tie plate or base of rail can move laterally more than one-half inch relative to the crosstie, (4) cut by the tie plate through more than 40 percent of their thickness (5) not spiked as required by 213.127 of the FRA Track Safety Standard.

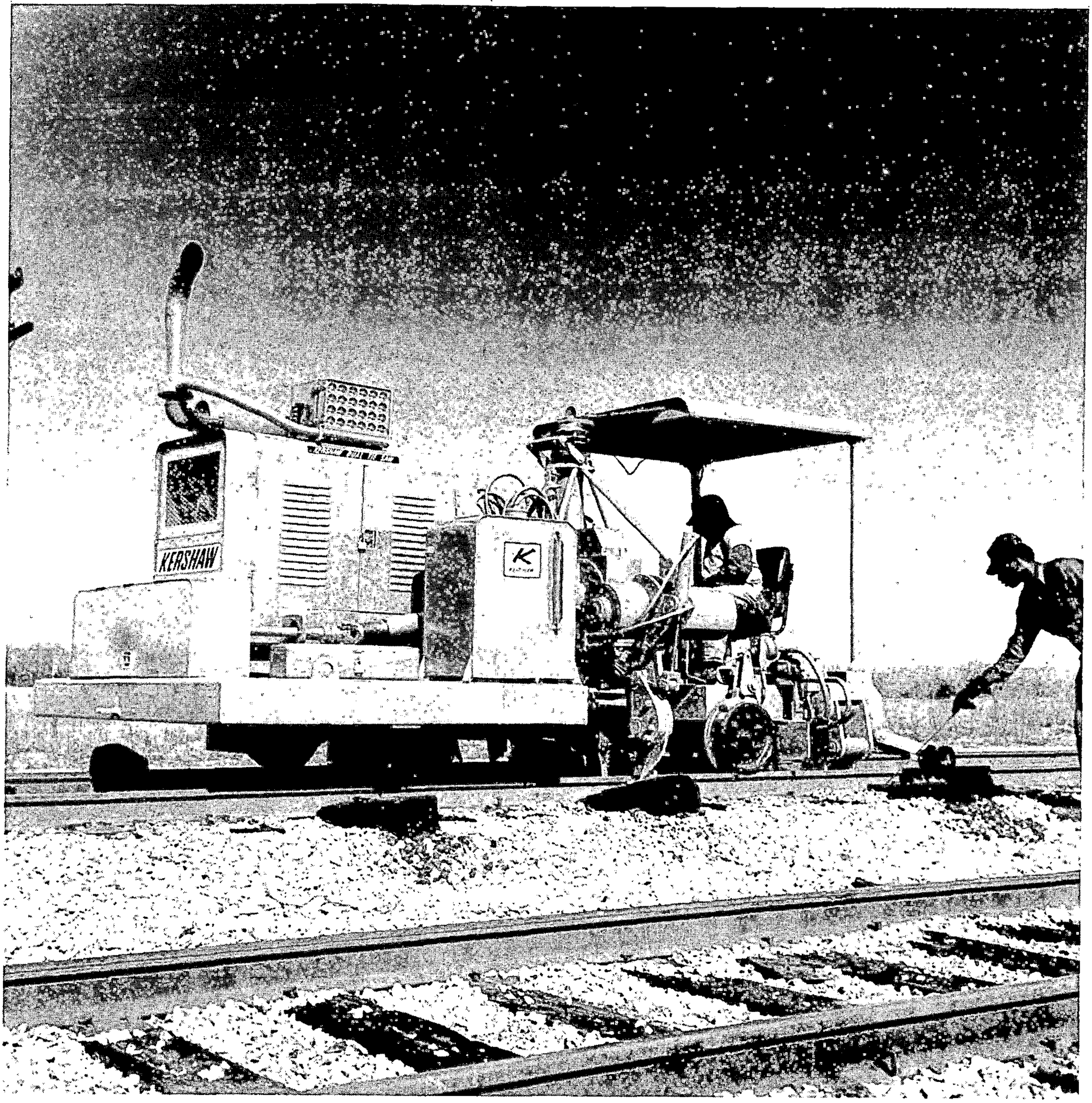
When wooden crossties are used, each 39 feet of track must be supported by nondefective ties as set forth in the standard. In the case of Class I track, the minimum number is 5 spaced at 100 inches, center to center. Spacings and required ties for other classes of track are found in Appendix A.

Inspection of ties is generally accomplished with these standards in mind. Often, however, the first factor to be considered is the condition of the line, surface, and ties in the track to be timbered.[1] Consequently, the track maintenance standards of a given railroad may pose more stringent requirements on tie condition than the minimally acceptable conditions set forth by the Federal standard.

If the track is in poor surface, it is felt that timbering without resurfacing may cause even more rapid deterioration, due largely to the wide variability in support given by the mixture of old and new ties. In this case, a timbering and surfacing operation may be called for, replacing large numbers of ties prior to track surfacing. If surface conditions are acceptable, the more common procedure of spot replacement is followed. In either case, the tie inspector will mark failed ties for removal and replacement if they are cracked to the point of being broken through, exhibit spike kill by either no spikes in the spike hole or spikes obviously loosely held in the spike hole, exhibit plate cutting or crushing under the tie plate through almost half their thickness, or show signs of internal decay on closer examination. These ties are marked in an identifiable manner (such as painting) for subsequent removal by the tie gang.

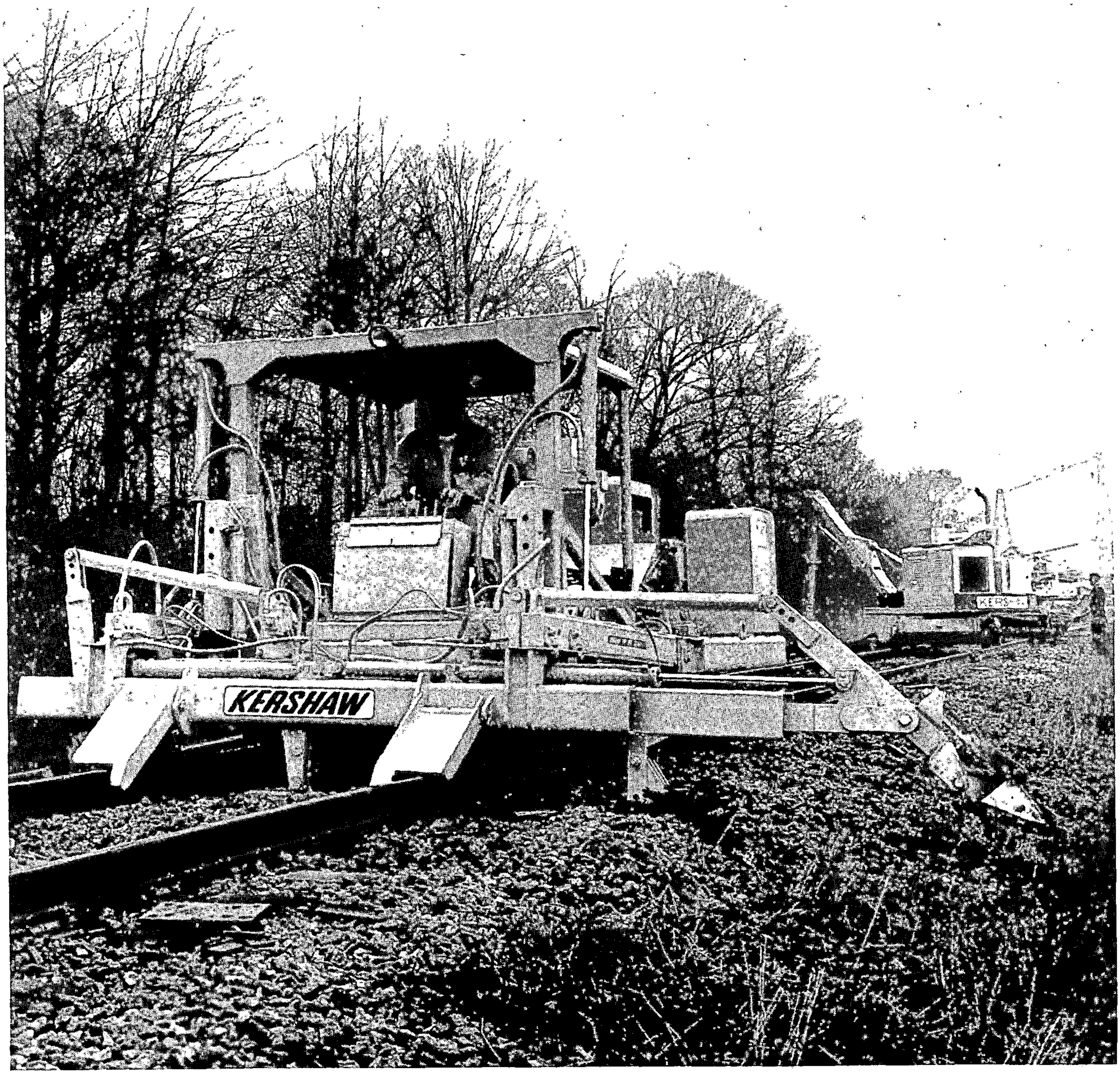
After the defective ties have been marked, replacement ties are brought up and distributed along the right-of-way. When the tie gang arrives, procedures similar to that outlined below are followed. Obviously these vary from railroad to railroad, but generally speaking the procedure entails: (1) removing the rail anchors and pulling the spikes, (2) lifting the rail and removing the tie plates either prior to or after tie removal, (3) removing the tie intact or in some cases cutting the tie into three segments to avoid disturbing the track line and surface (Figure 5.1) (4) scarifing the surface if needed (Figure 5.2) (5) installing

1. R. W. Pember, "Determining Who Renews Ties," Railway Track and Structures, July 1976, p. 62.



SA-3670-72

FIGURE 5.1 A DUAL TIE SAW REMOVING OLD TIES
SOURCE: The Kershaw Company



SA-3670-73

FIGURE 5.2 SCARIFYING THE ROAD SURFACE PRIOR TO NEW TIE INSERTION
SOURCE: The Kershaw Company

the new tie (Figure 5.3) and tie plates, (6) spiking, and (7) replacing the rail anchors. The removed ties are then either gathered for return to a given distribution point or are chipped and spread along the right-of-way.

Following these procedures, typical tie gangs can install between 800 to 2000 ties per day, depending on the size of the gang, the weather, road conditions, etc. Literature references describe instances of tie replacement levels of 2775 per day,[1] but these are felt to be special situations and not generally applicable.

Recently increased interest in 100 percent or complete tie renewal by U.S. railroads has been noted in the trade literature.[1] The complete tie renewal concept is practiced in the Soviet Union (see Section 8.1) and in parts of Western Europe.

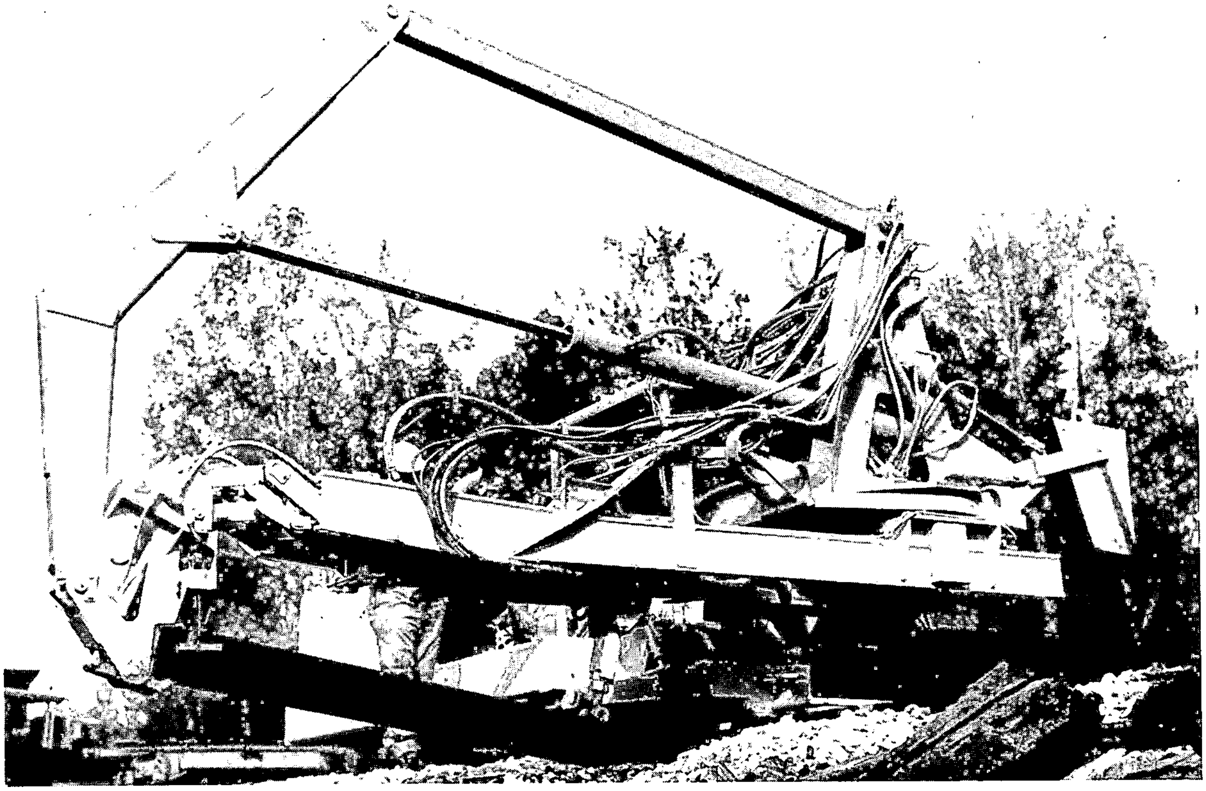
The complete tie renewal process is more costly than existing practice, primarily because it requires more new ties on a shorter cycle (approximately 7 years). However, if complete out-of-face tie renewal is performed together with ballast undercutting and cleaning, track can be restored at a savings of approximately 5 percent per mile compared with normal timbering and surfacing operations, and useful tie life increased by an estimated 25 percent.[2]

As will be shown in Section 8.4, ties removed by this process prior to severe deterioration can be readily refurbished for use in light tonnage track. The primary deterrent for the railroads involvement in the process is the apparent high capital cost of the necessary equipment.

5.2 Tie Population by Defect

During 1975, an estimated 19,300,000 wooden crossties were laid in

1. R. W. Pember, "Determining Who Renews Ties", Railway Track and Structures, July 1976, p. 62.
2. "Complete Tie Renewal," Progressive Railroading, March 1977, pp. 68-69.



SA-3670-74

FIGURE 5.3 INSERTION OF NEW TIES IN TRACK
SOURCE: The Kershaw Company

replacement in Class I Railroads in the United States.[1] Using the data reported in Section 4.2 on modes of tie deterioration, one finds the distribution by defect class as shown in Table 5.1.

TABLE 5.1 TIE POPULATION BY DETERIORATION MODE (1975)

Deterioration Mode	Tie Population (thousands)
Decay and Crushing	8,400
Plate Cutting	3,650
Splitting	3,300
Spike Killing	2,900
Broken Ties	480
Other	570

Estimated crosstie insertions for 1976 have been given as 26,217,000 this being approximately 10 percent below the calculated requirement for 1976 of 29,610,000 based on a 25-year life.[2]

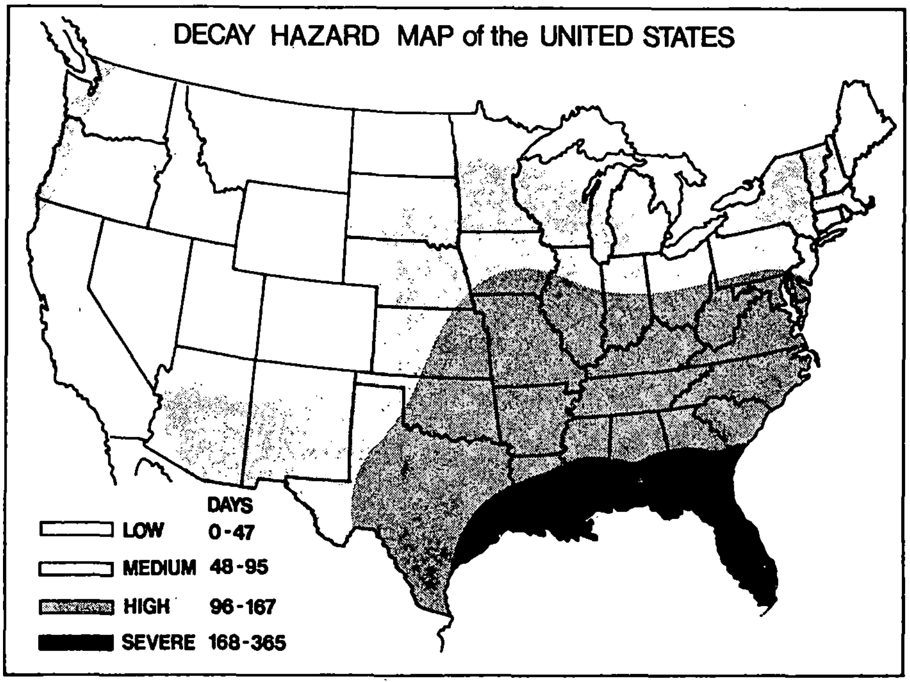
These figures represent national averages and can be expected to vary with geographic area and type of service as a result of varying severity of use and exposure to climatic conditions. One might hypothesize that ties in the eastern and southern states trackage would normally operate under more severe conditions than those in the western states; some statistics are available to verify this hypothesis. Indeed, a comparison of percent renewal to all ties (in-track) for 1975 for Class I Railroads in the United States shows that the Eastern and Southern Districts renewals were 2.41 and 2.32 percent of all ties per mile, respectively, laying 72 and 71 new ties per mile of track, as compared

1. Crossties, October 1976, pp.58-9.

2. Railway Track and Structures, December 1975, pp. 14-15.

to the Western Districts percent renewal figure of 1.94 with only 59 new crossties inserted per mile of track.[1] However, no quantitative report on modes of deterioration has been assembled.

The U.S. Department of Agriculture has developed a decay hazard map for wood at different locations in the United States (Figure 5.4).



SA-3670-75

FIGURE 5.4 DECAY HAZARD MAP OF THE UNITED STATES
SOURCE: U.S. Department of Agriculture

This map shows that decay hazard is generally greater in the southeastern and midwestern U.S., in areas having the most days of warm weather combined with high rainfall. This analysis also fits the tie renewal statistics given above, although it does not clarify the distribution of deterioration by mode. For the purpose of this study, however, it appears apparent that a higher percentage of ties as candidates for refurbishment would be available in the Southeast and Midwest than in the rest of the United States, if renewal were practiced without deferral of the process due to economic constraints.

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1. Crossties, October 1976, pp. 58-59.

Although the climatic factors in the southern and midwestern portions of the nation favor tie decay and deterioration, other factors strongly suggest a large population of candidate ties in the northeast and southwest. Due to the deteriorating financial condition of the railroads in the northeast, tie replacements on the northeastern roads often run far below the projected requirements. Tie deterioration in this regime could be anticipated from checking and unarrested decay.

Conversely, the arid portion of the southwest, while not fostering tie decay, can lead to increased deterioration by tie plate cutting and spike killing. This situation arises from the intrusion of windblown sand under the tie plate acting as an abrasive under the motions induced by train passage. Consequently, mechanical deterioration could be anticipated to dominate tie replacement causes in this region.

All of the above-mentioned factors would significantly impact the utility of a refurbishment operation in these regions.

6. TIE LIFE EXTENSION

The extension of crosstie life has been a major concern of the U.S. railroad industry for many years. In an attempt to maintain crossties in operational condition for as long as possible, workers in the field have employed a number of diverse tie preservative treatments, mechanical anti-splitting devices, fastening devices, and protective coatings. Some have worked, extending tie life to some degree, others have not. The search continues for a solution to this problem.

6.1 Alternative Philosophies of Reuse

Based on conversations with key representatives of the railroad and tie producing industry, two major philosophical approaches to tie reuse have been noted. The first represents the industry's trend to date: "make the tie last as long as possible at the least possible cost." This philosophy visualizes a single-use tie of negligible effectiveness in the latter portion of its life. Based purely on technical and economic constraints, a high percentage of the ties removed from Class I track after 20-30 years of service are usually deteriorated to the degree that refurbishment is not feasible. Although these ties may have some resale value, such as for use as retaining walls in gardens, these applications are of little value to the railroad, often offering only a convenient way to dispose of used ties. In view of the railroad industry's recent financial performance, this approach is understandable and logical.

However, an alternative philosophy is possible, which is operational on some foreign railroads. This second philosophy of tie reuse seen in the industry is similar to tie/track renewal in the Soviet Union and some Western European countries, and involves the concept of "cascading" of ties, i.e., removal of all ties in a given track section after 7 to 10 years of service. This approach, the antithesis of the one previously outlined, takes ties out of track after only a minor amount (presumably) of deterioration has taken place. These ties can then be reused in secondary or lightly loaded track after only minimal refurbishment. In addition, this type of complete out-of-face removal allows refurbishment of ballast and rail (if necessary) at the same time, resulting in more stable, higher capacity track.

The two approaches are sufficiently contradictory in concept and implications that a simple phasing from one to the other would be difficult. For the cascading approach to gain acceptance, major industry-wide committment would be needed in order to insure the effective utilization of the capital intensive equipment.

The following section will discuss the most commonly reported approaches to tie life extension and will attempt to assess their overall feasibility. In Section 8, we will assess the in-plant repair process and discuss its relationship to the cascading approach.

6.2 Technical Feasibility of Crosstie Repair

A major part of the physical deterioration of crossties in service seems to occur as a result of checking and splitting initiated relatively early (first 5-7 years) in the tie's service life.[1] This deterioration mode often seems to contribute to subsequent crushing and spike-kill problems. It therefore appears plausible that if this checking and splitting, usually brought about by surface weathering, could be reduced, the tie's usable life could be extended. This relatively naive approach to the problem ignores other deterioration modes such as crushing due to prolonged heavy tonnage traffic, mechanical damage, and spike kill, but it does offer a basis for a pragmatic technical assessment of currently practiced or proposed repair systems, including coating, spike-hole plugging, and tie impregnation.

6.2.1 Feasibility of In-situ Repair

The concept of being able to repair deteriorated crossties rapidly and in-track, is an attractive one. It would appear to the layman to be

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1. Data generated by SRI during the course of this study. Appendix D lists key contacts.

the simplest and possibly the cheapest means of repair available. An in-situ repair process may be considered technically feasible if it can repair the major crosstie deterioration modes--most importantly splitting, plate cutting, and spike killing. The technical feasibility of a process to accomplish these repairs is discussed below.

6.2.2 Splitting

Over three million ties are removed from track each year because of splitting. In addition, since splitting allows the intrusion of fungi spores into the untreated center of the tie, it may be a major contributor to other modes of deterioration. An effective in-situ repair of a split tie would require the complete closure or filling of the void introduced by splitting. This would require the repair material to: (1) be viscous enough upon application to flow readily into the split, (2) exhibit good adhesion to the inner surfaces of the split, even if these are not clean or are partially coated with creosote, (3) be capable of being hardened or "set" easily, (4) exhibit tensile strength when hardened or set equivalent to that of the tie itself, and (5) exhibit long-term wear in the railroad environment equivalent to that of wood.

The anticipated difficulties in this type of repair include: (1) problems in removing ballast and foreign materials from the splits, (2) difficulty in confirming that the repair material has flowed into split areas under the tie plate, and (3) difficulty in ascertaining whether the inner surfaces of the split tie are dry enough to permit adequate adhesion.

At this time it appears doubtful that any currently available materials of the plastic or resin type would perform adequately to repair this deterioration mode in-situ. In our estimation, materials of the necessary initial viscosity and subsequent toughness for use in the railroad environment could be developed. However, to date the market demand for such materials has been minimal.

6.2.3 Plate Cutting

Plate cutting accounts for the removal of more than 3.5 million ties annually.[1] To repair this type of defect, the deterioration or "plate-cut" area of the tie must be rebuilt. To repair this area, the spikes and tie plate must be removed and the tie moved so that the plate area is accessible. The plate-cut area must then be adzed to present a clean bondable surface, and a plastic or wood insert bonded in-place. The adhesive used to bond the insert must be sufficiently viscous to flow into and repair old spike holes and should harden readily and rapidly when required. The tie could then be reintroduced into service.

Difficulties with this in-situ/on-site approach include: (1) the need to remove spikes and plate and either move the tie laterally or lift the rail to gain access to the tie plate area, (2) the usual problems of cleanliness and surface moisture encountered when a high performance adhesive bond is required, and (3) the need to adze the tie surface in the field, to a standard dimension, so that prefabricated inserts could be used for the repair operation.

These mechanical constraints are sufficiently serious to remove in-situ repair of plate cut ties from consideration.

6.2.4 Spike Killing

Spike killing (loosening of spikes) accounts for an estimated 2.8 million tie replacements yearly.[1] Repair of a spike-killed tie usually requires rework of the old spike hole to allow respiking. Methods used to accomplish this include driving a peg or dowel into the spike hole and respiking, or using one of several commercially available filling materials.

Typical of these materials is a powdered spike hole filler-a free-

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1. Data generated by SRI during the course of this study. Appendix D lists key contacts.

flowing, dry mixture that is poured into the spike holes after the rail and plates have been removed. The compound contains an abrasive material, a bonding substance, and a wood preservative. The heat generated from the friction created during the spiking process causes the compound to liquify enough to penetrate the wood fibers and then to set up. It is claimed that this process is able to restore and retain 80 percent of the original spike-to-tie bond. Cost per tie (labor and material) has been estimated at $0.236. This material is currently being tested by the Santa Fe Railroad, which claims that at a one-mile-per-day work speed, it could realize a saving of $4.50 to $5.00 per reclaimed tie in an additional service life of eight years.[1]

Such materials may be the answer to the spike-kill problem. Difficulties could still be anticipated, however, especially if deterioration has spread so far from the spike hole that inordinate amounts of repair materials are required, or if the spike-killed rail-seat region has been invaded by fungi.

6.2.5 Decay and Crushing

This form of deterioration is the most prevalent cause of tie removal, requiring removal of approximately 8.2 million ties per year or about 44 percent of the tie removals annually.[2] It would appear that treatment of even a portion of these defective ties could offer substantial benefits.

For adequate repair of decayed or crushed ties, the decay may first be arrested by sterilizing the tie and removing excess moisture. This would not be technically possible in an in-situ repair, unless some elaborate form of portable microwave drying equipment were used. Even if such equipment were available, use of this type of equipment at track-side would be highly questionable on a technical basis and is not worthy of further consideration. Failure to achieve sterilization would allow fungi to continue to grow, and the resulting deterioration, even in coated tie,

1. "Santa Fe Expects Spike-Hole Compound to Extend Tie Life," <u>Railway Track and Structures</u>, March 1977, pp. 48-49.
2. Data generated by SRI during the course of this study. Appendix D lists key contacts.

would lead to continued failures.

6.2.6 Materials

Taking into account the operational constraints of the railroad environment (presence of dirt and ballast, and the need to maintain time schedules and minimize service disruptions), a survey of the available literature revealed only three basic types of polymer/resin systems that could be used to repair ties in situ. These are the epoxy resins, furfuryl alcohol-based resins, and solvent-based asphaltic or hot melt resin systems.

The epoxy resin systems cost $0.85 to $1.10 per pound. This cost might be lowered to $0.40 or $0.45 per pound through the use of extenders and fillers. Furfuryl alcohol resins cost approximately $1.00 per pound, which could be lowered to $0.45 or $0.60 per pound through the use of cheap extenders. Solvent-based asphaltic resin systems cost from $0.15 to $0.45 per pound. These resins could probably not be modified or extended other than by formulating for optimum properties such as weathering, adhesion, flow characteristics, and thermal stability.

The nominal weight of a crosstie is 180 pounds. The estimated amount of resin required to repair a defective tie is from 5 to 10 percent of the tie weight. In other words, it would require 9 to 18 pounds of resin to sufficiently fill checks, splits, and deteriorated portions of the tie. This amount of resin would not repair spike-killed or plate-cut areas. We estimate, however, that a coating applied to a tie after approximately five years of service might extend its life approximately 10 to 15 years. If applied properly, this coating would fill any checks and splits already present and help to prevent formation of new ones. The coating would eliminate any further migration of moisture and fungi into untreated areas of the ties, and would also keep ballast and freezing/thawing water out of the checks and decrease leaching of preservative from the tie.

Application of an in-situ coating would require a three-man crew using a conventional spray application process on a powered car. The equipment required for this type of repair is relatively simple and maintenance free. Since fungicidal attack on the interior of the tie would continue unarrested, the effectiveness of such a repair appears to be relatively limited. Consequently in-situ coating is not recommended as a technique for extending tie life. The costs associated with this repair mode are discussed in Section 7.3.2. This analysis shows that use of a protective coating, while technically possible, is not economically feasible.

6.2.7 Assessment of On-Site Repair

On-site repair of deteriorated crossties would involve the removal of a tie from its place in the track and repairing it at track side. Although this type of repair would not require replacement of the tie in its original position in the track, it would require replacing some tie in track within three or four hours to minimize train delays and scheduling difficulties.

The first technical problem in the on-site repair process is that crossties removed from track must be cleaned and allowed to dry for a period of time to remove excess moisture from the surface of the tie, as few of the materials economically feasible for repairing the tie will adhere to a wet surface. Chambers for drying the ties could be used to accelerate the drying process, but the technical (and economic) feasibility of the use of these is doubtful. It would also be necessary to inspect for pieces of metal spikes in the plate areas of each tie. If the cleaning process were done mechanically, it would require large scrubbing brushes or high pressure water. To do this at track side would not only be difficult but also quite costly. Although detection of metal fragments in the ties would be simple, it might be costly at track side because of the labor charges. Impregnation of ties on-site would require continual transportation and mixing of impregnation materials such as resins, fillers, and catalyst systems. Although the transportation of mixing and impregnation equipment is technically feasible, the economics of the situation, as described in Section 7.3.2, mitigate against any further consideration of this repair mode.

7. ECONOMICS OF TIE LIFE EXTENSION

Any discussion of the feasibility of extending tie life must include an examination of the economic advantages or constraints of the materials and/or processes proposed to achieve the extension. As a basis for this study, we have chosen to use the present value (or present worth) method commonly used in the railway industry. An explanation of this method is given in Appendix B.

The cases presented below represent a comparison of various scenarios for the treatment and, as such, provide a basis for the economic evaluation of the feasibility of alternatives strategies. As individual railroads vary widely in their reported costs of capital and return on investment (ROI) requirements (some reporting 10 percent ROI, others 20 percent ROI), we have chosen for the purposes of this study to use a 10 percent ROI (or discount rate) based on figures quoted by the American Association of Railroads (AAR) for the generally accepted cost of capital to the American railroad industry.[1]

7.1 Creosoted versus Untreated Ties

The first case analyzed is possibly the simplest: the economics of using creosoted vs. uncreosoted ties. This constitutes the datum or baseline case of current practice. It also indicates the base from which consideration of other treatments may be evaluated. For this case we assumed that untreated wood ties would have to be replaced on a 10-year cycle, while the treated ties could remain in-track for 30 years. Using the present value (PV) method, illustrated in Table 7.1, one can see that even ignoring anticipated inflation in materials, shipping and installation costs, a treated tie capable of 30 years in-track service, is preferred on an economic basis to insertion of new untreated ties every 10 years. This result validates existing practice and indicates,

1. K. Schoenberg, AAR, private communication.

as well, that treatments extending tie life even beyond the 30 year period may be worthy of consideration.

TABLE 7.1 PRESENT VALUE ANALYSIS/DISCOUNTED CASH FLOW METHOD

Years	Untreated Ties (Installed Cost)	PV @ 10% ROI	Treated Ties (Installed Cost)
0	12.00	12.00	18.00
10	12.00	4.63	-
20	12.00	1.78	-
30	-	-	-
Present Value		18.41	18.00

7.2 Creosoted versus Modified New Ties

We next consider the case wherein new ties, prior to insertion in-track, and most probably prior to creosote treatment, were treated with a polymer or resin in latex form to strengthen the tie, increase its resistance to abrasive wear, and extend its usable life by 10 years. For this example, consider a geographic region in which normal creosoted tie life averages 20 years and a candidate repair process which can modify tie life to 30 years. Table 7.2 shows it is economically feasible to spend as much as $1.95 more per new tie to extend its life--in this case, for 10 years. The analysis assumes that the impregnation step would be included in the normal tie treating process and that equipment costs would be negligible. While this seems, for the most part, to be an acceptable assumption, we feel it would require experimental validation.

TABLE 7.2 PRESENT VALUE ANALYSIS/DISCOUNTED CASH FLOW METHOD

Years	Creosoted Tie (Installed Cost)	PV @ 10% ROI	Modified Tie Installed Cost	PV @ 10% ROI
0	18.00	18.00	19.95	19.95
10	-	-	-	-
20	18.00	2.68	-	-
30	-	-	19.95	1.13
40	18.00	0.40	-	-
60	-	-	-	-
	Present Value	21.08	Present Value	21.08

7.3 <u>In-Situ Repair</u>

Of the tie life extension/repair processes examined in Section 6, only certain in-situ repair processes appeared sufficiently technically feasible for further consideration. These were the repair of spike kill and checking and splitting.

7.3.1 Repair of Spike Kill

As previously discussed in Section 6.2.3, spike-killed ties can be repaired in the field either by driving pegs or dowels into the spike hole and respiking, or by use of filling compounds which set up on spiking, binding the spike tightly to the tie. Estimates by the Santa Fe Railroad on the use of one of these filling materials indicate that at a cost per tie (labor and material) of \$0.236, tie life can be extended approximately 10 years at a savings of \$4.50 to \$5.00 per tie.

A discounted cash flow analysis on a per tie basis (Table 7.3) verifies the economic advantage of the situation, though not the magnitude. For this analysis we have assumed the tie life for the spike-killed tie to be 20 years, with the use of the spike hole filler extending this life to 30 years.

TABLE 7.3 PRESENT VALUE ANALYSIS/DISCOUNTED CASH FLOW METHOD

Years	Installed Tie Cost	PV @ 10% ROI	Installed Tie Cost	Repair Material Cost	PV @ 10% ROI
0	$18.00	$18.00	$18.00	-	$18.00
20	18.00	2.68		0.24	0.04
30	-	-	18.00	-	1.03
40	18.00	0.40	-	-	-
50	-	-	-	0.24	N/A
60	-	-	-	-	-
	Present Value	$21.08	Present Value		$19.07

If plugging the spike hole with pegs or dowels is examined by this method (Table 7.4) and the same assumptions are made as for the previous case, assuming plug cost at $0.75 per tie and labor costs as high as $2.50 per tie (assuming $5.00 man hour cost, 2 ties repaired per hour, as an extreme case), the repair still appears feasible.

TABLE 7.4 PRESENT VALUE ANALYSIS/DISCOUNTED CASH FLOW METHOD

Years	Installed Tie Cost	PV @ 10% ROI	Installed Tie Cost	Plug Cost (incl. labor)	PV @ 10% ROI
0	$18.00	$18.00	$18.00	-	$18.00
20	18.00	2.68	-	3.25	0.48
30	-	-	18.00	-	1.03
40	18.00	0.40	-	-	-
50	-	-	-	3.25	0.03
60	-	-	-	-	-
	Present Value	$21.08	Present Value		$19.54

This analysis indicates the economic feasibility of current spike-kill repair practices. In our estimation it is most effective when the ties under repair exhibit no other deterioration mode than spike kill. If other deterioration modes are present, ties would have to be completely removed from track and presumably transported to a repair facility. This additional activity greatly lessens the in-situ impact of these practices.

7.3.2 Repair of Checking and Splitting

Ties that are not too badly checked or split (as arbitrarily decided by the tie inspector) may possibly be repaired by use of an overcoating which would fill in the checks and splits and stop their further growth. Currently commercially available spray equipment has reached a level of sophistication which allows it to thoroughly coat a tie to the degree desired without overspray. In this way only the tie, and not the ballast, would be treated.

Materials cost for this type of treatment would be relatively low, since the coatings would be based on blends of asphaltics with polymers such as the polyvinyl acetates, dissolved in suitable solvent. Cost is projected at approximately $0.50 per pound.[1] We anticipate each crosstie will need 5 to 7 pounds of coating, at a cost of $2.50 to $3.50. Labor and equipment costs are estimated at $1.05/tie. This estimate is based on recently reported tie gang/equipment costs on using a three-man gang for the coating operation at a rate of 45 ties coated per hour.[2] Table 7.5 illustrates the cost per tie based on these estimates.

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1. Data generated by SRI during the course of this study. Appendix D lists key contacts.

2. D. R. Burns, "Do Track-Renewal Trains Have a Place on American Railroads?," Track and Structures, March 1977, p. 32.

TABLE 7.5 IN-SITU COATING COST PER TIE

	Resin Loading	
	5 pounds/tie	7 pounds/tie
Resin cost/tie @ $0.50/pound resin cost	$2.50	$3.50
Application cost	1.05	1.05
TOTAL COST/TIE	$3.55	$4.55

These cost figures can then be used in a present value analysis to test the economics of this repair mode. Assuming a 7-pound loading/tie, total coating cost per tie is $4.55. If we assume that crosstie life is 20 years under current conditions and that the coating can extend tie life by ten years, then in a present value analysis very similar to that shown in Table 7.2, we find comparison of PVs at $21.08 for noncoated tie costs versus $19.79 for coated ties with a 10-year life extension. This represents a definite economic advantage. The same general advantage is seen in a similar calculation for ties lasting 30 years uncoated and 40 years coated.

However, the major limiting factor to this approach is the assumption that checking and splitting will be the only deterioration mode noted after 20 or 30 years of the tie in service. As previously stated, we feel that checking and splitting tend to initiate other modes of failure such as spike kill and plate cutting, so one may logically expect these to be present as well. If they are, merely coating the tie will not be sufficient, since in-situ coating will do little to improve the other conditions.

7.4 Conclusions

From the technical and economic considerations presented, one can conclude that the life of a wooden tie might be extended by (1) the normal custom of treating it with creosote, (2) treating it, prior to creosoting, with a polymeric latex to increase its strength and toughness, (3) in-situ repair of spike kill by plugging with pegs or dowels, or use of commercially available plugging compounds, and (4) in-situ repair of checking and splitting (if not too severe) by means of overcoating.

Although on a technical and economic basis, all the above seem feasible for use in some areas, all but the first conclusion mut be experimentally verified in laboratory and field trials prior to recommendation for adoption by the industry as standard practice.

8. ASSESSMENT OF IN-PLANT REPAIR

In-plant repair of deteriorated ties has as immediate and obvious advantages: (1) a centralized (or centralizable) location for tie repair in a given geographic or demographic region, (2) round-the-clock availability of equipment specifically designed for the refurbishment operation, (3) availability of crews trained specifically for tie refurbishment, and (4) a centralized distribution point for refurbished or second-use ties. Secondary benefits might arise from the factor that if all grading of ties is accomplished at the refurbishment facility, discarded ties (those too deteriorated for railroad use) would have been removed from the right-of-way, and could be sold from a regionally centralized location. (In the latter case, it has been reported that the calorific worth (heating value) of a shredded tie is $2.85 and the value of a scrap tie for landscaping or fencing is between $4.00 to $7.00.[1])

Possible immediate disadvantages of this approach are: (1) high capitalization costs with unproven technical feasibility, (2) questionable need and/or industry acceptance of refurbished ties at tie costs yielding acceptable ROI values, and (3) difficulties in identifying the segment of industry to be involved (i.e., railroads, tie producers, tie treaters, or others).

In the following chapter, refurbishment plant techniques and processes will be examined. The refurbishment process used in the Soviet Union will be described and illustrated, and contrasted with the American system.

8.1 Tie Refurbishment in the Soviet Union

The most extensive program for the refurbishment and reuse of wooden crossties to date is currently active in the Soviet Union.[1] This system has evolved as part of the Soviet System for periodic capital reconstruction

1. Burns, David R., "Do Track-Renewal Trains Have a Place on American Railroads?," Track and Structures, March 1977, p. 32.

of all principal rail lines after approximately 550 million gross tons (MGT) in service.

Principal rail lines in the Soviet Union are constructed by a highly mechanized track panel laying technique. At an interval which is based on the detection of three rail flaws per kilometer, the track is retired, track panels are removed, ballast cleaned and new track panels installed. On average this occurs at 550 MGT for conventional rail and at 825 MGT for the new Soviet fully heat-treated rails. This process results in the generation of large volumes of used wooden crossties, most of which have seen from 5 to 10 years of service on average.

The Soviets have developed a highly efficient process for refurbishing these crossties and returning them to service, most often in rebuilding secondary lines. This processing is accomplished at regionally located central processing plants adjacent to the major track panel construction stations on each railroad.

Ties are returned to the processing facility on flat cars in the original panel assemblies as shown in Figure 8.1. These panels are disassembled by a rail-mounted mechanized line and the ties sorted into scrap and recoverable tie stockpiles as shown in Figure 8.2. As a close examination of Figure 8.3 and 8.4 reveal, by U.S. standards most of the recoverable ties could be reused with little or no attention other than plugging of the spike holes. The predominant modes of deterioration which are found in these ties are splitting and checking of the tie (12 percent) and mild plate cutting. This would be anticipated considering the length of service the ties have seen, and is consistent with U.S. findings for ties of this age.

The basic refurbishment process adopted by the Soviets involves six principal steps. As the processing plant flow diagram of Figure 8.5 illustrates, these are:

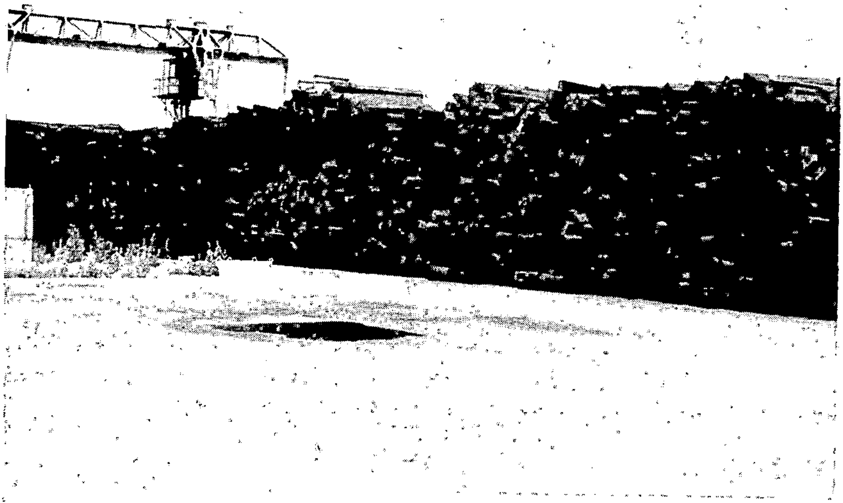

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FIGURE 8.1 RETURNED PANEL ASSEMBLIES

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FIGURE 8.3 RECOVERABLE TIES (TOP VIEW)

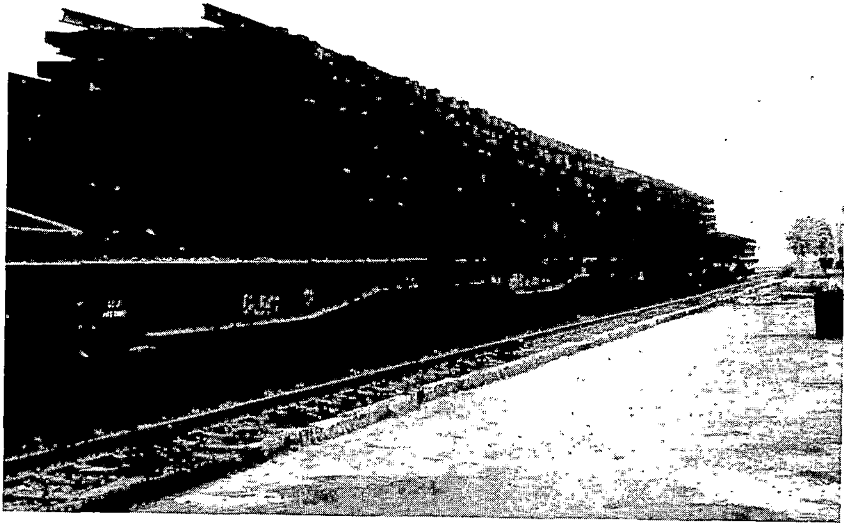

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FIGURE 8.2 RECOVERABLE TIE STOCKPILES

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FIGURE 8.4 RECOVERABLE TIES (END VIEW)

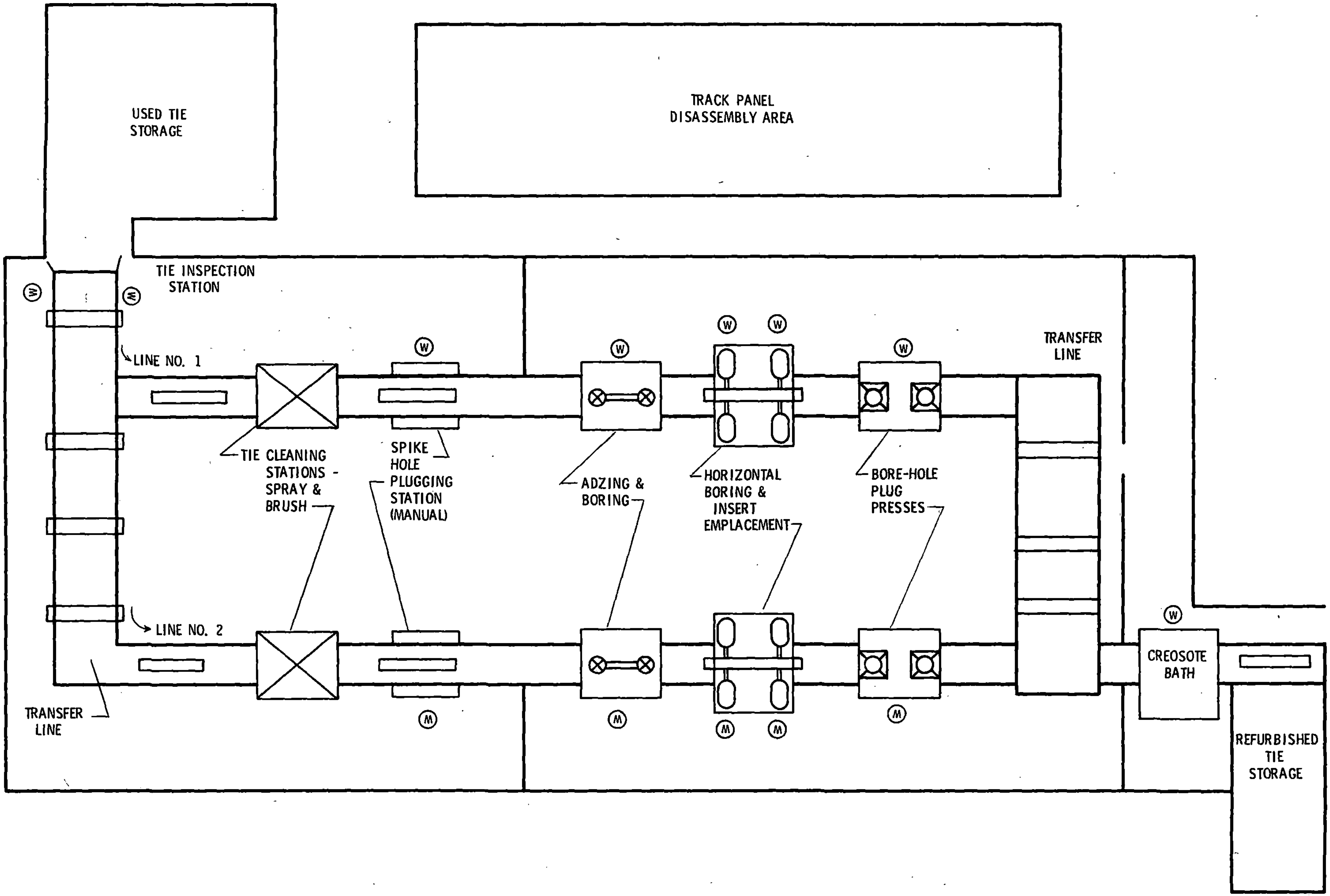

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FIGURE 8.5 SOVIET TIE REPAIR FACILITY

(1) Plugging of existing spike holes

(2) Adzing and reboring

(3) Installation of anti-splitting dowels

(4) Immersion in a creosote bath

A typical Soviet Refurbishment Plant, seen in overview in Figure 8.6, employs double parallel transfer lines with sequential mechanized woodworking operations and requires 16 operators, including foreman and fork lift operators. Ties received for refurbishment are first visually inspected for decay and entrained ballast or fastener parts as they enter the transfer line (Figure 8.7). The ties then flow in two parallel and identical work lines where they are automatically cleaned by pressurized water sprays and wire brushes.

Cleaned ties, tie plate side up, have hardwood plugs manually driven into the spike holes and excess plug material is sheared off. These ties are then received in a combined tie plate adzing and spike hole boring machine, shown in Figure 8.8, where the rail seat is reworked to a new spiking pattern. This corrects the tie plate wear condition and prepares the tie for the insertion of hardwood spike hole liners, shown ready for the bore hole plug press in Figure 8.9. Soviet standards require hardwood inserts to increase the resistance to spike pullout of the soft pines which are utilized for crossties.

In order to arrest the splitting and checking, ties are horizontally bored at each end, as shown in Figure 8.10, and hardwood dowels (Figure 8.11) screwed into place. Soviet experience has shown dowelling to be more effective than the "S" irons used previously, due largely to the ability of the dowels to arrest running splits in the center portion of the ties. The final operation in the process is the non-pressurized treatment of the ties in a rotary bath (Figure 8.12) to coat exposed wood surfaces. Soviet creosoting techniques, even for new ties, shows penetration to depths of less than 0.5 inch. The ties are then stored

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FIGURE 8.6 OVERVIEW OF TYPICAL SOVIET TIE REFURBISHMENT PLANT

FIGURE 8.7 VISUAL INSPECTION OF TIES ENTERING PLANT

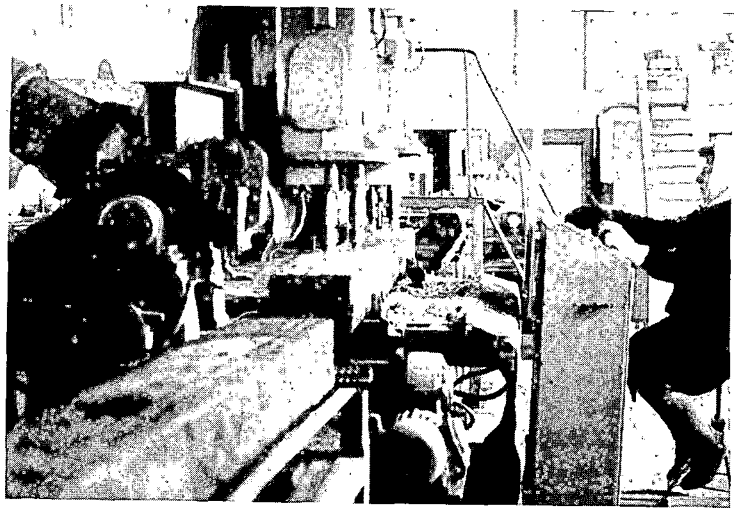

FIGURE 8.8 TIE PLATE ADZING AND SPIKE HOLE BORING

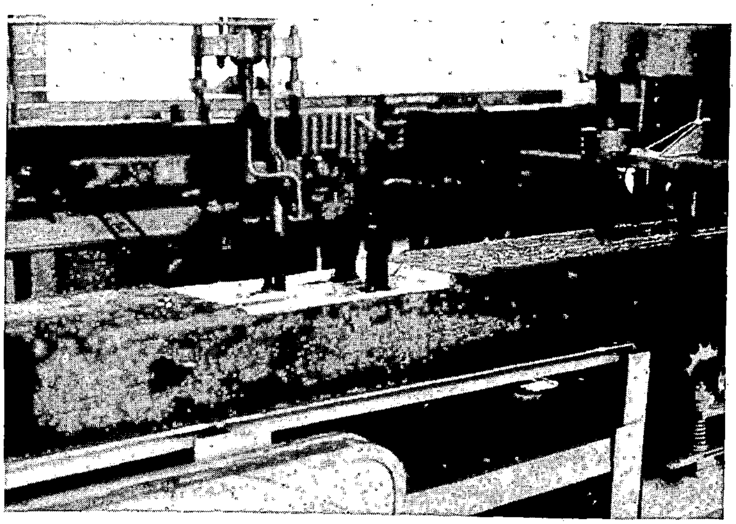

FIGURE 8.9 HARDWOOD SPIKE HOLE LINERS READY FOR BORE HOLE PRESS

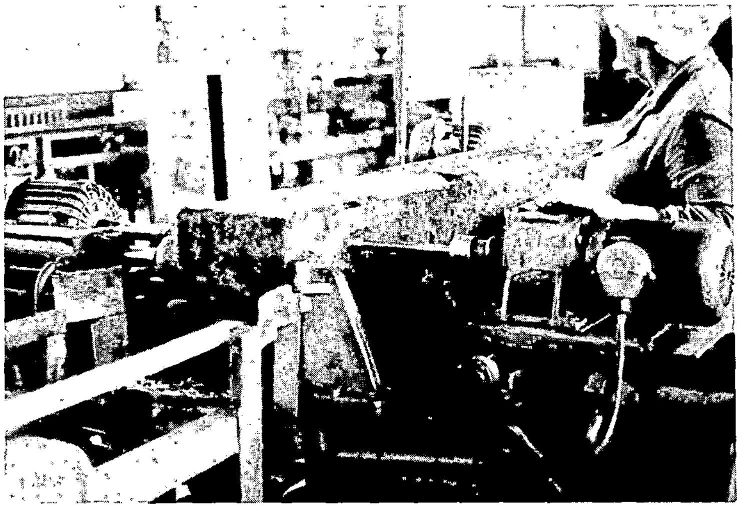

FIGURE 8.10 HORIZONTAL BORING OF TIES

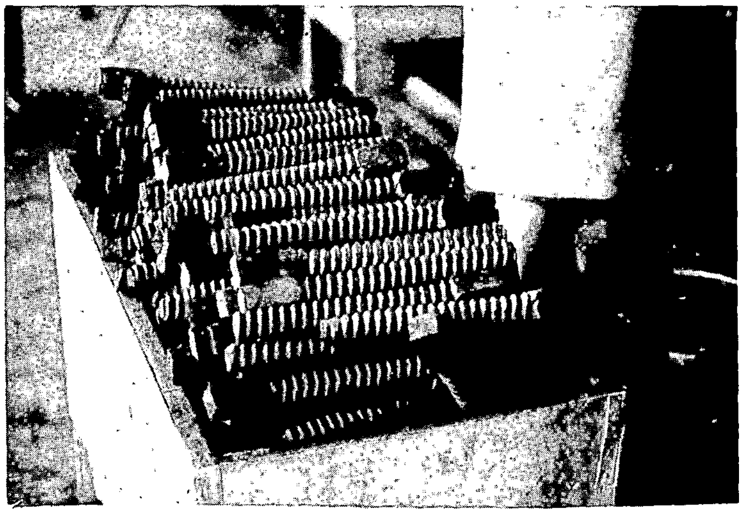

FIGURE 8.11 HARDWOOD DOWELS FOR TIE INSERTION

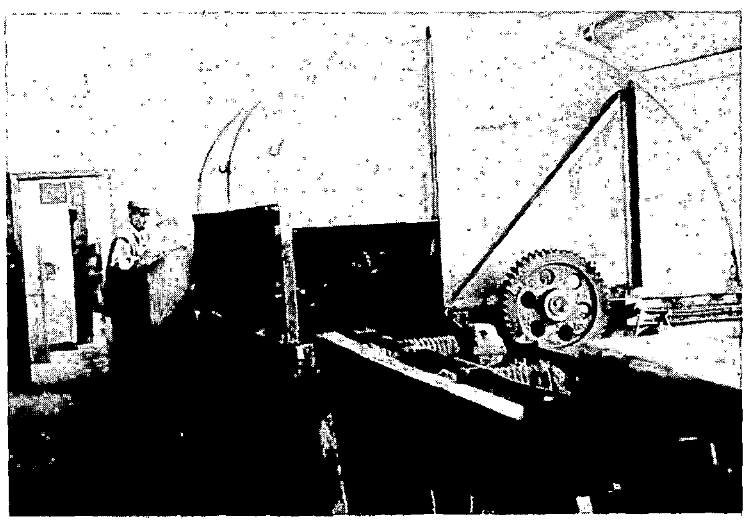

FIGURE 8.12 ROTARY CREOSOTING OPERATION

until required for panel assembly.

It is important to point out some key differences in philosophy and practice between the U.S. and the USSR. In the Soviet case, reliance on the country's rail system for the transportation of goods and people is extremely high. In many cases rail transportation is not only the preferred mode, it is the only mode available, with virtually all freight movements of over 250 miles moving by rail. This reliance on rail transportation necessitates a carefully planned, efficiently executed maintenance of way (M/W) program to ensure the uninterupted flow of goods. Reflecting this extensive M/W activity are the track renewal techniques discussed above in Section 8.1. Crossties are removed from track after having seen only 5 to 10 years of average service. They are removed not singly as is the practice in the U.S. but panel by panel as previously explained. They are treated with only minimum emphasis on the economic constraints involved in the treating process. In the U.S., M/W budgets have lagged behind track maintenance requirements, remaining at a fixed percentage of operating revenues. In addition, the high cost of capital has severely limited new approaches to crosstie utilization. The U.S. practice of replacing defective crossties singly as opposed to entire rail sections has until now strongly influenced the possible refurbishment procedures.

8.2 Tie Refurbishment in the United States

Operating under a different set of technical and economic criteria, in-plant tie refurbishment activities in the United States could follow the sequence of steps identified below.

8.2.1 Tie Collection and Shipping

For the past 150 years, deteriorated ties have been removed singly and either discarded whole along the right-of-way or shedded or chipped by specialized machines. In recent times, some railroads have started to consider out-of-face replacement and cascading of ties. The tie cascading process, entailing the removal of track panels and all the ties in a given track would allow a relatively easy collection of ties that had been in service along the track. This tie cascading approach is very similar to that described in the Soviet case study.

Ties removed from track could be picked up along the track by a dedicated work train or a returning tie train. These could be delivered to the refurbishment facility for inspection and sorting.

8.2.2 Inspection and Sorting

The first likely step in the repair process would be inspection of the returned ties. Criteria for refurbishment would be difficult to specify in great detail; however, one would expect the rejection of ties split over half-way through their thickness, ties exhibiting severe decay or rotting, and ties so severely plate cut that rebuilding of the plate area was not plausible. Inspection procedures and criteria would have to be developed and refined during an experimental or pilot program for tie refurbishment.

Ties determined to be so deteriorated that refurbishment was not considered feasible could be diverted at this point for eventual disposal or resale for landscaping or ornamental use. Repairable ties would be transferred to the next inspection station, where detection and removal of broken spikes, dating nails, etc. could be accomplished. Commercially available metal detectors could be used at this station, although visual inspection might be sufficient.

8.2.3 Cleaning

Although by this point it is anticipated that the heavier accumulations of dirt and debris would have been removed from the ties, more thorough cleaning would be required for ease of repair at later stations. At the cleaning station, therefore, all ballast and foreign material would be removed from the tie surface, spike holes, and checks and splits. This cleaning operation could be done with large rotating brushes and/or high pressure water streams. All the proposed equipment is now commercially available. If water cleaning is used, ties might need to be dried before entering the repair station.

The cleaning operation as described above, especially if a drying step is required, represents a process which appears relatively energy intensive. This may become a determinant factor for subsequent repair operations: i.e., if completely dry clean ties are required for a given repair process, the process may not be feasible for use in this operation for reasons of economy or energy conservation.

8.2.4 Repair Operations

Actual crosstie repair would, of necessity, involve the renovation of ties exhibiting a number of different failure modes. To repair each form of deterioration simultaneously is impossible. Effective repair of all forms of deterioration discussed in this report is even a questionable goal. Repair of a decaying tie for example would require (1) complete sterilization of the tie to arrest the decay process, (2) impregnation of the tie with a monomer or resin system to rebuild its strength or toughness, and possibly (3) rebuilding of the plate or spike areas. Experience suggests *a priori* that a renovation as complex as that outlined would be neither technically nor economically attractive.

Failure modes which may indeed be repairable within the existing (and projected) technical and economic constraints would appear to be:

spike kill

plate cutting

checking and splitting

In the case of the spike-killed tie, previous discussions (Sections 6 and 7) have pointed out that techniques and materials for its repair are currently commercially available. These techniques of plugging with dowels or using reactive materials could be accomplished in-plant as well as in the field and would, as in the Soviet experience, lend themselves well to an integrated repair process.

Plate cutting, if not too extensive (i.e., beyond a predetermined degree as constrained by the dimension of a hardwood insert) might be repaired by an adzing operation followed by the lamination of a hardwood insert to the plate area. This repair method is as yet only a concept, since experimental verification of such a laminated construction has not yet been reported. If currently available adhesive systems could withstand the flexing and bending under load of a tie in service, this repair mode could also lend itself well to the in-plant renovation process. However, further experimental work is required, before any definitive recommendation can be made.

If the returned tie is checked and split through more than half its thickness, it is doubtful that it could be repaired. From a technical point of view, however, if the damage is less than that, monomer impregnation techniques and subsequent curing in-place have been reported to be capable of successfully strengthening and repairing or toughening the tie.[1] Although many of the studies reported described experiments using pristine wood, not deteriorated out-of-service crossties, it is technically feasible to assume that the results using crossties could be very similar to those reported. Polymer systems reported to have been used for strengthening of wood include:

benzoguanimine
poly (dimethyl phenylsiloxane)
poly (phenylsiloxane)
methyl sulfoxide/polyurethane precursors
phenolic resins
lignosulfonic acid polymers
polyester (unsaturated)
methacrylate polymers
polystyrenes

1. Data generated by SRI during the course of this study. Appendix D lists key contacts.

styrene/acrylonitrile polymers
polyester phthalates
epoxy compounds
polyisocyanates
vinylfurans

Techniques for curing these polymers within the wood matrix include the use of gamma radiation, ionizing radiation such as an electron beam, and chemical methods such as the use of peroxides. Microwave and ultra-violet radiation techniques have also been reported.

On a worldwide basis, it is noted that the predominant amount of research effort in this field has been reported by the USSR (approximately one-third of the notations reviewed), closely followed by Western Europe (France and Germany, specifically), and then by Japan and the United States.

Most studies available at this time reported processes similar to those performed at the Brookhaven National Laboratory by Beller and Steinberg.[1] These entail (1) drying or evacuation of the article to remove moisture and air, (2) soaking or spraying with monomer to impregnate the wood and (3) curing the monomer in the wood to convert it to a solid polymer.

Initial evaluation of these processes predict questionable success if creosoted ties are used with radiation treatment by other than the relatively powerful gamma sources used at Brookhaven. It is doubtful that a tie treating facility would care to invest the necessary funds (well over $100,000) and set-up the necessary radiation and safety facilities that this type of repair would require, especially as these constitute only about 16 percent of all deteriorated ties.

8.2.5 Anti-splitting Devices

Installation of anti-splitting dowels or other devices is considered

1. Beller and Steinberg, Composite Materials for Railroad Applications, Brookhaven National Laboratory Report 50371 (1971).

optional, i.e., applied as a matter of choice. Aside from the intuitive feeling that these devices help strengthen the tie laterally, documented evidence as to overall technoeconomic value has not been uncovered. Certainly plate cutting, spike killing, and surface checking would not be affected by use of such devices.

8.2.6 Creosote Treatment

As a final step in the repair operation, the ties would be passed through a preservative dip tank. This would be a non-pressurized operation, since preservatives would remain from the original treatment and it is anticipated that the ties would absorb 3 to 4 pounds of preservative to replace that lost while in service or during repair. The ties could then be moved to a storage area for distribution.

8.3 Proposed Plant Operations: Basic Assumptions and Layout

For the sake of the following economic analyses, assumptions have been made based on the best estimates available from the industry for labor costs, overhead rates, and transportation and materials costs. A number of plant layouts are presented to illustrate repair processes of increasing complexity. The simplest refurbishment case is shown in Layout A (Figure 8.13). This represents the repair process for spike-killed ties and insertion of an anti-splitting device, while Layout D of Figure 8.16 includes repair stations for spike-killed and plate-cut ties and insertion of anti-splitting devices.

Based on industry estimates and comparison with other similar wood processing operations (such as plywood manufacture), the initial capital cost of a crosstie refurbishment plant utilizing a process as described above is estimated to be in the $1.0 million to $1.25 million range. The cost will vary with the specific type of repair operations for which the plant is designed, but equipment costs can be estimated from similar, existing operations. Annual operating costs will vary as well. For the four plant repair processes shown earlier, these costs are given in Tables 8.1 through 8.4. Assumptions made for these analyses were:

Plant capacity:	840 ties/day 210,000 ties/yr
Labor costs/hr	Laborer: $5.00 Supervisor: $8.00
Overhead rate:	40%
Transportation costs of returning ties to plant, per tie:	$1.25
Preservative costs per tie:	$0.60

The economics of various options for in plant refurbishment are compared below with the practice of continued replacement of defective ties with new wood crossties. It is assumed that a refurbishment plant could process some 840 ties per day, resulting in the production of some 210,000 refurbished ties per year. This figure is felt to be reasonable in light of the 790 tie/day capacity of the Soviet plant described earlier and the production capacity of allied woodworking processes in this country.

It is further assumed that used ties processed in such a facility would be interchangeable with new ties: that is, they would be equally sound, structurally and functionally, with a useful life at least equal to the new solid sawn crossties. No assumption on cascading or single use is made, except that the ties are available at a negligible value to the processing plant as a result of already required tie removal, collection, and disposal processes, i.e., as an alternative to chipping or burning. Consequently, only the estimated transportation cost for the used ties is included in the operating costs.

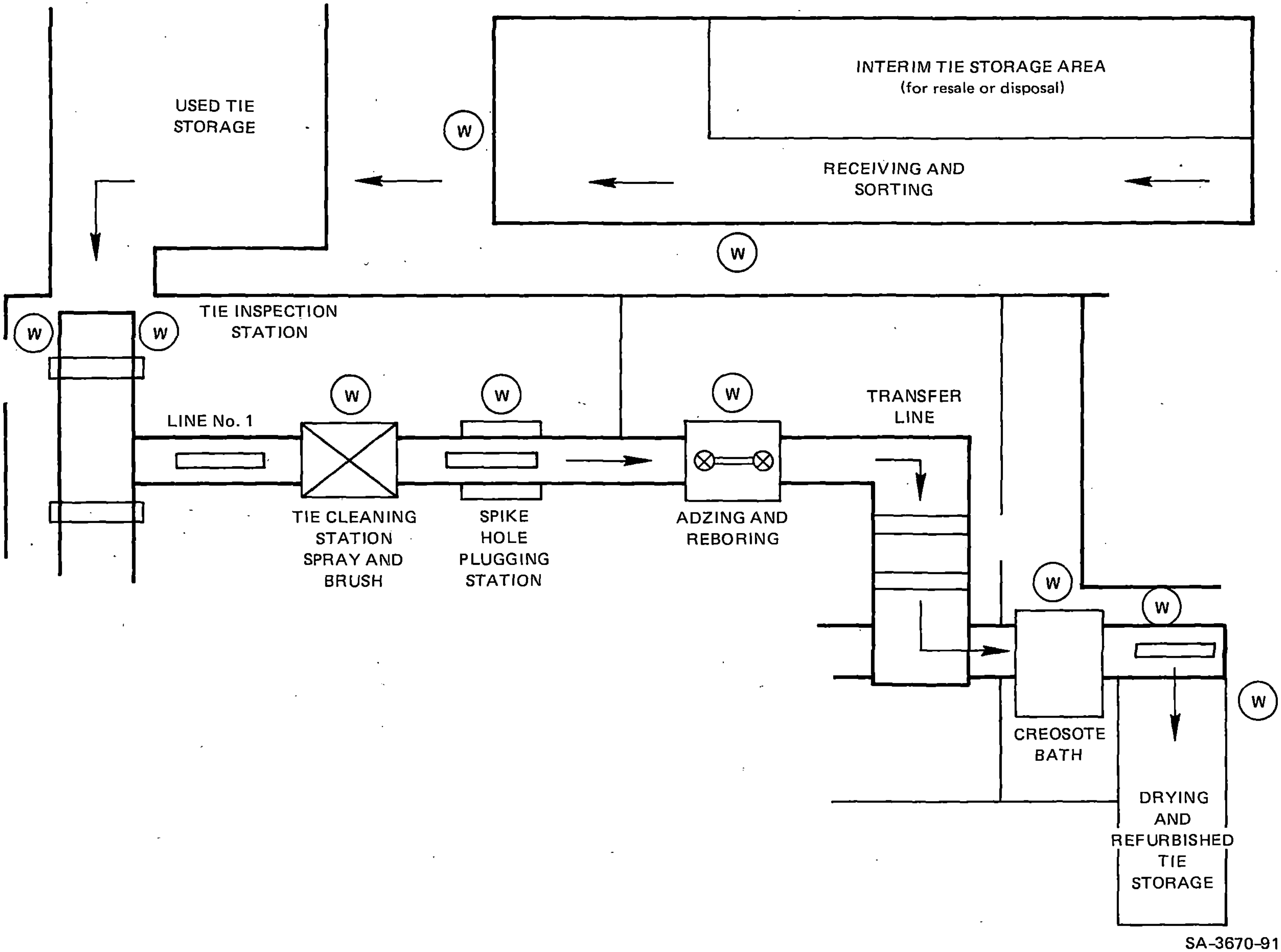

FIGURE 8.13 LAYOUT A: REPAIR LINE FOR SPIKE-KILLED TIES

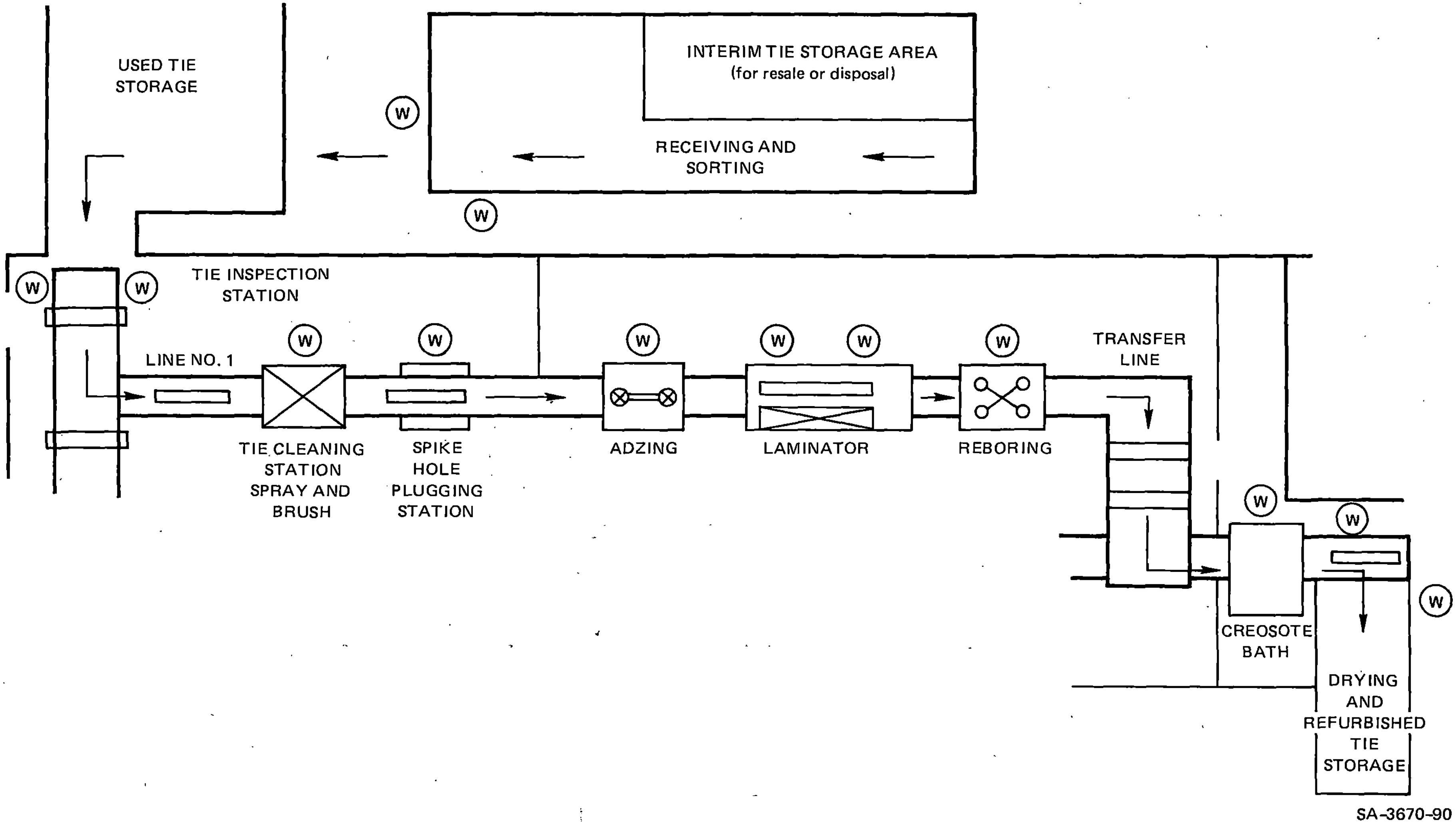

FIGURE 8.14 LAYOUT B: REPAIR LINE FOR SPIKE-KILLED AND PLATE-CUT TIES

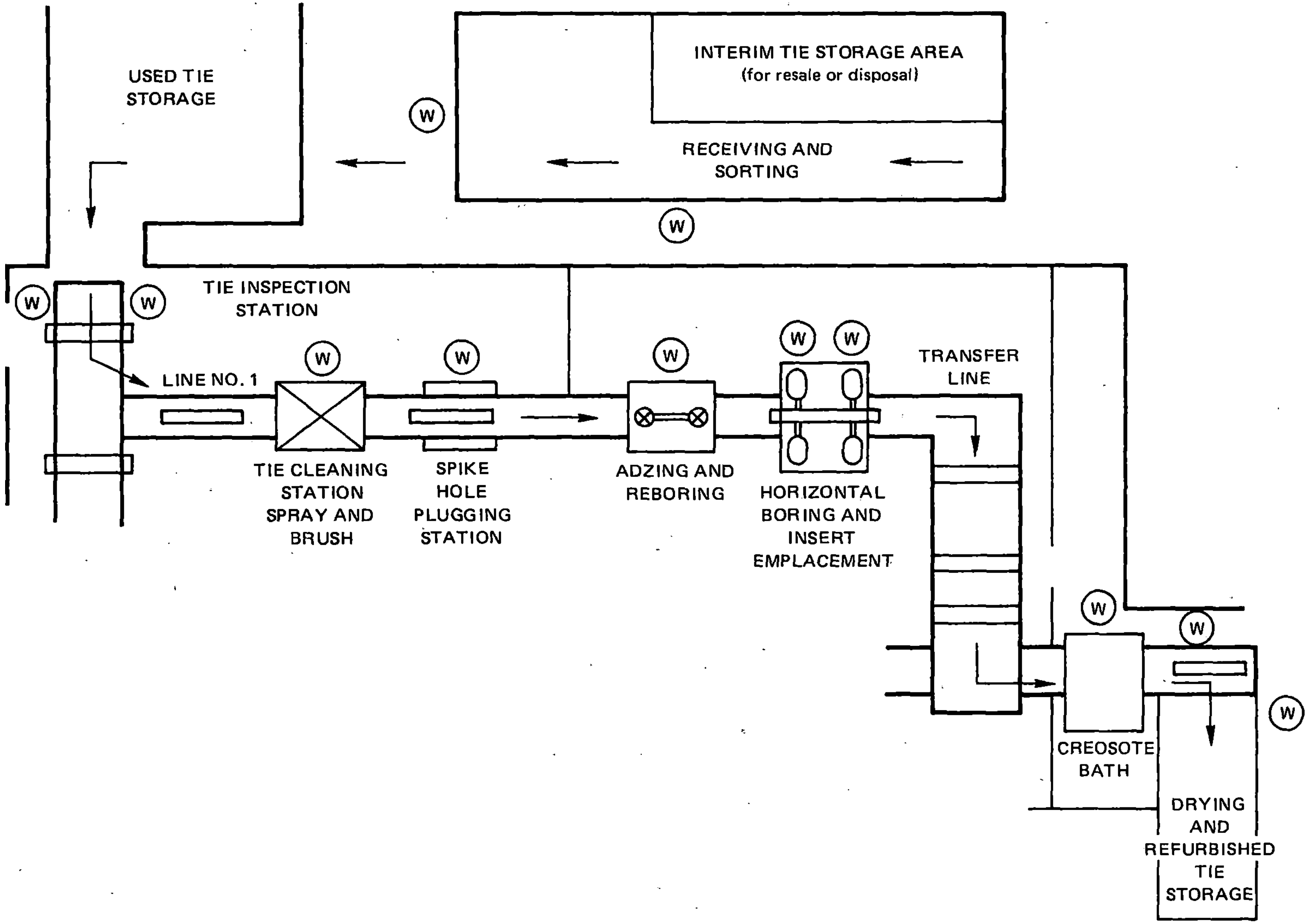

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FIGURE 8.15 LAYOUT C: REPAIR LINE FOR SPIKE-KILLED TIES WITH ANTISPLITTING DEVICE INSERTION

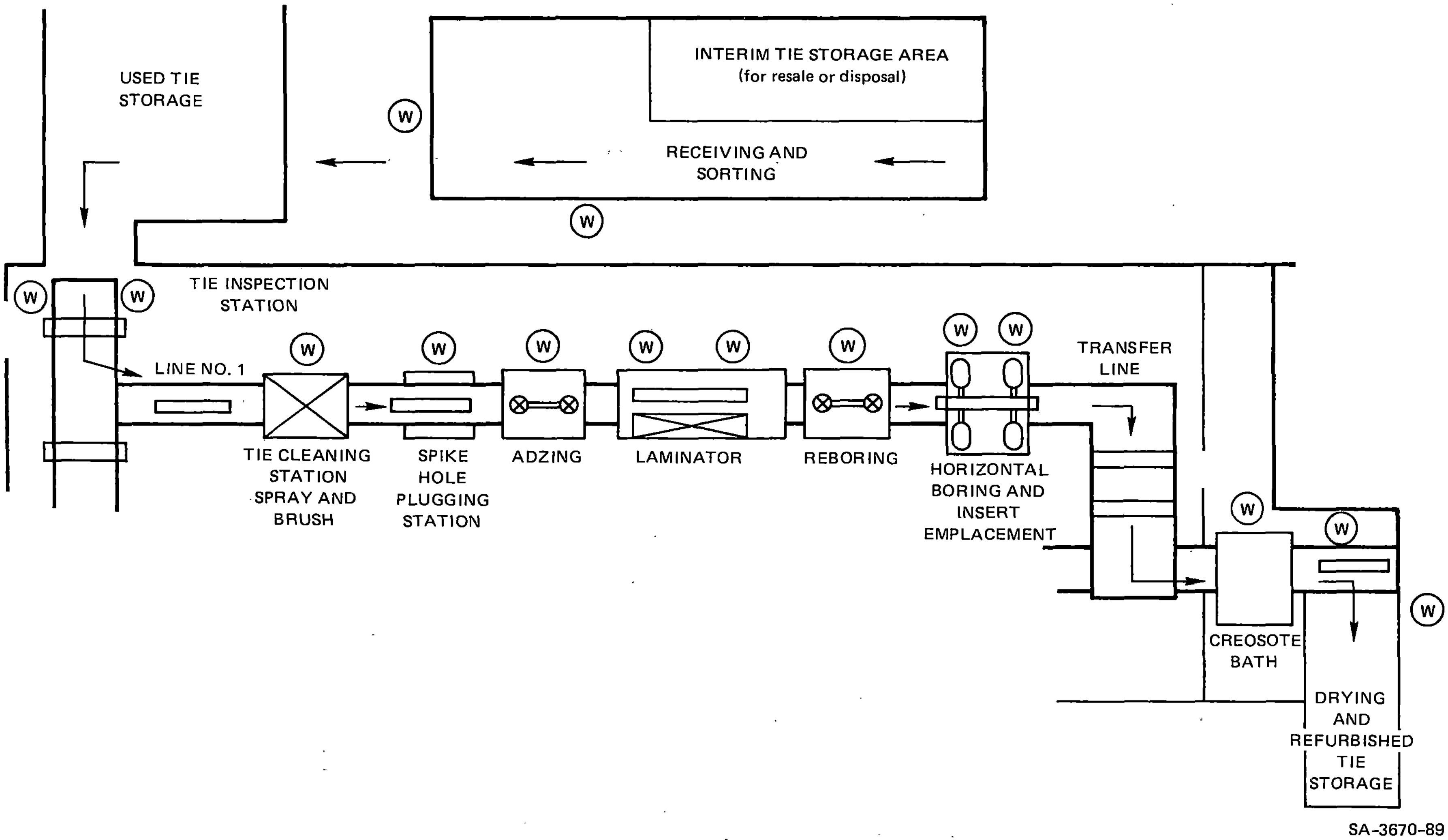


FIGURE 8.16 LAYOUT D: REPAIR LINE FOR SPIKE-KILLED AND PLATE-CUT TIES WITH ANTISPLITTING DEVICE INSERTION

TABLE 8.1 IN-PLANT TIE REFURBISHMENT:
REPAIR SPIKE-KILLED TIES (LAYOUT A)

Labor Analysis

Phase of Operation	People Required
Receiving	2
Inspection	2
Cleaning	1
Plugging and reboring spike hole	1
Adzing	1
Preservative Treatment	1
Drying/Storage	2
	10
Supervisory	1

Cost

Labor Cost/Day	$649.60
Labor Cost/Tie @ 840 ties/day	0.77

Plant Operating Costs

	Cost/tie
Shipping (to plant)	$1.25
Plugs	0.75
Preservative	0.60
Labor	0.77
Direct cost	$3.37
15% Gen. & Admin.	0.51
Total Operating Cost/Tie	$3.88
Total Operating Cost @ 210,000 ties/yr	$814,800

TABLE 8.2 IN-PLANT TIE REFURBISHMENT: REPAIR SPIKE-KILLED AND PLATE-CUT TIES (LAYOUT B)

Labor and Operating Costs

Labor Analysis

Phase of Operation	People Required
Receiving	2
Inspection	2
Cleaning	1
Plugging Spike Hole	1
Adzing	1
Lamination	2
Reboring	1
Preservative Treatment	1
Drying/Storage	2
	13
Supervisory	1

Costs

Labor Cost/Day	$817.60
Labor Cost/Tie @ 840 ties/day	0.97

Plant Operating Costs

	Cost/Tie
Shipping (to plant)	$1.25
Plugs	0.75
Adhesive (based on $.60/lb. industrial grade lamination adhesive)	0.60
Hardwood Plate Inserts	1.25
Preservative	0.60
Labor	0.97
Direct Cost	$5.42
15% G&A	0.81
Total Operating Cost/Tie	$6.23
Total Operating Cost @ 210,000 ties/yr	$1,308,930

TABLE 8.3 IN-PLANT TIE REFURBISHMENT: REPAIR SPIKE-KILLED TIES AND ANTI-SPLITTING DEVICE INSERTION (LAYOUT C)

Labor and Operating Costs

Labor Analysis

Phase of Operation	People Required
Receiving	2
Inspection	2
Cleaning	1
Plugging and Reboring Spike Hole	1
Adzing	1
Horizontal Boring and Insert Emplacement	2
Preservative Treatment	1
Drying/Storage	2
	12
Supervisory	1

Costs

Labor Cost/Day	$761.60
Labor Cost/Tie @ 840 ties/day	0.91

Plant Operating Costs

	Cost/Tie
Shipping (to plant)	$1.25
Plugs	0.75
Anti-splitting Devices	1.50
Preservative	0.60
Labor	0.91
Direct Costs	$5.01
15% G&A	0.75
Total Operating Cost/Tie	$5.76
Total Operating Cost @ 210,000 Ties/yr	$1,209,600

TABLE 8.4 IN-PLANT TIE REFURBISHMENT: REPAIR SPIKE-KILLED, PLATE-CUT TIES AND ANTI-SPLITTING DEVICE INSERTION (LAYOUT D)

Labor and Operating Costs

Labor Analysis

Phase of Operation	People Required
Receiving	2
Inspection	2
Cleaning	1
Plugging Spike Hole	1
Adzing	1
Lamination	2
Reboring & Horizontal Boring and Insert Emplacement	2
Preservative Treatment	1
Drying Storage	2
	14
Supervisory	1

Costs

Labor Cost/Day	$873.60
Labor Cost/Tie @ 840 ties/day	1.04

Plant Operating Costs

	Cost/Tie
Shipping (to plant)	$1.25
Plugs	0.75
Adhesive	0.60
Hardwood Plate Inserts	1.25
Anti-splitting Devices	1.50
Preservative	0.60
Labor	1.04
Direct Costs	$6.99
15% G&A	1.04
Total Operating Cost/Tie	$8.03
Total Operating Cost @ 210,000 ties/yr	$1,688,085

TABLE 8.5 COMPARISON OF ALTERNATIVE APPROACHES TO CROSSTIE REPLACEMENT
(Via Discounted Cash Flow Method)

Plan of Operation	Cost ($)	Initial Plant Cost	Total Present Worth @ 10%		% Savings	
			30-year cycle	7-year cycle	30 yr	7 yr
A. Buy and Install 210,000 New Ties Each Year	3,780,000		35,634,000	18,401,104	-	-
B. Renovate* and Install 210,000 Ties Each Year	2,697,133[1]	1,250,000	26,675,872	14,379,643	23	19
C. Renovate** and Install 210,000 Ties Each Year	1,831,467[2]	1,000,000+	18,265,239	9,915,580	42	50

* Repairing spike kill, plate cutting and inserting anti-splitting devices.
** Repairing spike kill only.
+ Plant costs for spike-kill repair only, estimated @ $1,000,000.

[1] <u>Plan B Calculation</u>

Cost: $1,688,800 operating expense - $41,667 plant depreciation + $1,050,000 ties installation cost = $2,697,133 per year

PV @ 10% = 25,425,872 + 1,250,000 initial plant cost = $26,675,872

[2] <u>Plan C Calculation</u>

Cost: 814,800 operating expense - $33,333 plant depreciation + $1,050,000 tie installation cost = 1,831,467

PV @ 10% = 17,265,239 + 1,000,000+ initial plant cost = 18,265,239

8.4 Economic Feasibility of In-Plant Repair

The success of an in-plant repair operation in the United States is far more predicated on favorable economics of operation than in the Soviet Union. These economics are controlled to a high degree by tie removal techniques employed--simple or cascade, anticipated (or needed) additional service life, anticipated tie costs, and overall operating costs, to name a few.

The information in Tables 8.1 through 8.4 makes it possible to perform a discounted cash flow analysis of the various repair plant operations. The results are summarized in Table 8.5. This table illustrates the economic advantage to be gained from the refurbishment of ties, assuming equal life of the refurbished tie to the new tie. No attempt was made to estimate the refurbished value of ties lasting for shorter periods than new ties. The anticipated variability in such an analysis would make it meaningless.

Examination of both the most costly process repair of spike killed, plate-cut ties with insertion of anti-splitting devices (Layout D, Table 8.4) and the most inexpensive repair of spike kill only (Layout A, Table 8.1) show that in either case the use of refurbishment techniques as compared with new tie purchase could potentially save the railroad industry \$200,000 to \$600,000 annually (based on repair of only 210,000 ties/yr).

In the event the U.S. rail industry decided to adopt the practice of cascading ties, as practiced in the Soviet Union and in parts of Western Europe, and 30-year in-service life is not a necessary criterion, then the discounted cash flow analysis in Table 8.5 would be of interest. The table shows costs and savings associated with two repair modes: Plan B--renovation of ties exhibiting spike kill and plate cutting, and then insertion of anti-splitting devices, and Plan C--renovation of spike-killed ties only. The operating expense of \$1,688,800 used in

Plan B was based on the figures developed in Table 8.4. The $41,667 plant depreciation was based on an arbitrarily chosen 30-year straight line depreciation of the initial $1,250,000 plant cost. Installation cost per tie was assumed to be $5.00. Plan C calculations were based on similar assumptions.

Table 8.5 illustrates the relatively high degree of savings achieveable by the use of refurbished ties. Based on a plant size of only 210,000 ties per year, it appears that the railroads could realize a 20 to 50 percent savings over the cost of new ties by investing in/ and operating such a facility. In fact, it appears that in every case examined, in-plant tie renewal operations are economically feasible and, most likely, technically sound.

Refurbished ties could conveniently find use in branch track or in track carrying lighter loads; new ties could be reinserted more often to provide a more stable, higher capacity roadbed. However, further research will be needed to prove the technical feasibility of some of the refurbishment techniques outlined in this report. The completion of such research may provide a greater incentive to the tie treating industry.

8.5 Financial Analysis of Investment Conditions

Once market demand for refurbished crossties has been firmly established and the technical and economic constraints and benefits of the repair operation validated, new business opportunities will exist. In an attempt to identify potential investors/operators of a tie refurbishment plant, the tie supply industry has been profiled and an attempt has been made to assess the financial risk or return for investment in a refurbishment facility.

Tie suppliers range in size from those reporting sales under $50,000 per year to those reporting sales of over $1,000,000 annually.[1]

1. Thomas Register of American Manufacturers (Thomas Publishing Company, New York, 1976).

Over 50 suppliers of wooden crossties are listed in the 1976 Thomas Register of American Manufacturers, while 1975 statistics revealed that there were over 200 wood preserving plants in the United States. Many of these firms appear on the tie suppliers list as well. We have also noted 27 firms supplying ties in the United States with sales greater than $1,000,000 per year. These firms are listed in Appendix C.

The Railway Tie Association (RTA) is the trade association of this industry. It's membership, numbering over 400, includes lumber companies, wood treating firms, railroads, railroad contractors, chemicals suppliers, and others working in the field.

Tie suppliers include lumber yards, treating facilities or, as is the case with some of the railroads, an in-house tie production facility. All these have tie handling equipment which might be integrated into a tie refurbishment operation. The degree to which each would be willing to divert this equipment from the processing of new ties is a matter of individual choice. Capitalization requirements for construction of a refurbishment facility are expected to remain in the $1 million to $1.25 million range, however, even if some equipment costs are minimized. For this reason, it has been estimated that the only suppliers that can be considered candidates for operation of a refurbishment plant are those with annual sales greater than $1 million or railroads with existing tie producing facilities.

Up to this point, we have considered only the potential savings to the railroads resulting from the use of refurbished crossties. In considering crosstie refurbishment as a business, potential sales prices of the refurbished crossties as well as return-on-investment considerations must be reviewed, to determine the market competiveness of the refurbished ties. For this analysis we have assumed a plant overhead rate of 15 percent, an annual tax on gross profit of 50 percent, and a simplified calculation for after-tax profit of:

Income

-Cost of Goods Sold

Gross Profit

-Overhead and Depreciation

Pretax Profit

-50%

NET PROFIT AFTER TAXES

Table 8.6 gives the plant costs, operating costs, and depreciation figures used in the following calculations.

TABLE 8.6 TIE REFURBISHMENT PLANT COSTS

Repair Mode	Plant Cost	Operating Cost/Tie	Annual Operating Cost	Depreciation*	Initial** Investment Costs
Spike kill	$1,000,000	$3.88	$814,800	$33,333	$1,937,020
Spike kill & plate cut	1,250,000	6.23	1,308,930	41,667	2,755,270
Spike kill & anti-splitting device insertion	1,250,000	5.76	1,209,600	41,667	2,641,040
Spike kill, plate cut & anti-splitting device insertion	1,250,000	8.03	1,688,085	41,667	3,191,298

* 30 year straight line depreciation.
** plant cost + annual operating cost + 15% overhead.

Using these figures, we have calculated the required sales price of a refurbished tie if either 20 percent ROI or 10 percent ROI is to be achieved. We have included the 20 percent ROI figure to illustrate the financial advantage of the refurbishment operation as described so far. The results of these calculations are shown in Table 8.7. From this analysis it would appear that the investor seeking a 20 percent ROI would be limited to repair of spike-killed ties only, if a competitive price with the new tie were held. As this repair can even now be readily accomplished in the field, the construction of a centralized facility seems pointless.

TABLE 8.7 REQUIRED TIE SALES PRICE TO MEET ROI CRITERIA

Repair Mode	10% ROI	20% ROI
Spike kill	6.45	8.30
Spike kill & plate cut	10.00	12.60
Spike kill & antisplitting device insertion	9.35	11.90
Spike kill, plate cut & anti-splitting device insertion	12.50	15.55

At a lower return on investment, refurbished ties can be attractively and competitively priced and could probably find a high degree of market acceptance. However, it must be pointed out that in all calculations to date, we have assumed no cost for the returned tie itself. This would mean that the "owner" of the deteriorated tie would either have to assign a zero value to the tie (as is common railroad practice) and repair it in-house, or give it free-of-charge to a firm involved in tie repair, under some kind of payment or lease-back agreement.

Once one does assign a value to a removed tie, however, the cost of the refurbished tie will rise correspondingly. For example, if a value of $1.00 were placed on the retained tie, the sales price would rise $1.00; if it were given a value of $2.00 to maintain an equivalent ROI, the sales price would have to increase by $2.00. Referring back to Table 8.4, a returned tie value of $1.00 would eliminate the repair mode encompassing spike kill, plate cut and insertion of the anti-splitting device. A returned tie value of $2.00 would remove the repair of a spike-killed/plate-cut tie from consideration. Obviously the higher the returned tie price, the less economical the repaired tie will be.

The implications of this analysis are significant. Barring a substantial increase in the cost of timber, the attractiveness of refurbished crossties in the marketplace is going to be strongly influenced by the dollar value railroads attach to their discarded ties. It could be argued that since railroads will ultimately control both the volume and initial costs for used crossties, the railroads themselves would profit most by direct involvement in the establishment of a refurbishment plant. Drawing upon the investment capital and inherent expertise of the wood processing industry, and the materials supply of the railroads, an economically sound partnership could be envisioned.

An alternative to this approach would be for railroads in effect, to subsidize a tie refurbishment facility by supplying ties at no cost, as an alternative to their destruction, under some kind of payment or lease-back agreement. With either arrangement, the railroads could anticipate the reduced operating costs associated with refurbished tie usage.

9. CONCLUSIONS AND RECOMMENDATIONS

The data generated in this study on the technical and economic feasibility of refurbishing wood crossties have shown that tie replacement costs are still one of the largest single railroad maintenance expenditures, and that these must be reduced for the railroads to improve their financial viability. In light of this situation, and the increasingly stringent demands made on crossties in service, tie life extension and/or refurbishment is still a topic of considerable importance. Inherent in any discussion of tie refurbishment is a consideration of tie renewal practices and the contrasts between those now considered standard (i.e., spot replacement of failed ties) and out-of-face replacement techniques coupled with surfacing operations. The latter approach to tie renewal lends itself much more favorably to the refurbishment approach.

Recent estimates by the General Accounting Office report that the supply of hardwood for crosstie use will exceed demand until at least the year 2000. Competing wood products such as pallets and wood pulp could however result in higher tie prices. If refurbishment techniques could be developed that supplied second-use ties, equivalent in service life to new ties, at prices no less than currently available ties, a savings on tie costs of 20 to 50 percent over that of new ties could be realized by the railroads.

The principal modes of tie deterioration, in service, are mechanical wear, physical damage, termite infestation, and attack by decay fungi. Included in the mechanical wear and physical damage categories are defects such as plate cutting, spike kill, crushing, and checking and splitting. The modes most repaired are spike kill and plate cutting. These account for approximately 35% of all tie removals in the United States.

Tie repair, on-site, appears only feasible from a technical and economic point of view with spike-killed ties. Overall tie refurbishment, especially of spike kill and plate cutting may be technoeconomically feasible in a batch plant operation specifically designed for tie refurbishment. Other modes of deterioration may be either too expensive to repair, or may not lend themselves to a repair process (such as ties exhibiting severe termite damage).

Alternative tie renewal techniques such as tie cascading would allow ties only minimally damaged to be returned for minor refurbishment and subsequent use in lighter load trackage. The technoeconomic aspects of combining tie cascading practices with in-plant refurbishment appears quite attractive at this point. From a strictly economic view, however, for this scheme to remain attractive, returned ties (those removed from track) must be assigned a zero dollar value if any refurbishment technique is to be considered. This indicates that the railroads must either operate such refurbishment facilities themselves, or at least supply the ties to such a facility at no cost.

Plant refurbishment of spike-killed and plate-cut ties appears most feasible from a technical and economic point of view. Savings to the railroads of 20 to 50 percent are possible by purchasing second-use ties, if such ties can be shown to exhibit similar in-service life to new ties. The latter assumption would have to be experimentally verified before industry approval could be obtained.

Based on these conclusions, one can recommend that experimental work to verify the feasibility of repairing spike-killed and plate-cut ties should be initiated. This experimental program should investigate not only currently available repair techniques, but should also consider accelerated testing of such repaired ties to determine actual life in service. In addition, a technoeconomic survey on the benefits/constraint of tie cascading practices in the United States should be carried out. One U.S. railroad has initiated some tie cascading practices and could possibly be used as a model for the industry.

If these recommendations appear technically feasible, a pilot refurbishment facility might be designed and constructed to assess the overall benefits to be gained from such an operation.

Appendix A

CROSSTIE SPECIFICATIONS

The following is an outline of the specifications for wooden crossties set forth in the AREA Manual, Bulletin 645, Volume 75.

Physical Requirements

General Quality

Except as hereinafter provided, all ties shall be free from any defects that may impair their strength or durability as crossties, such as decay, large splits, large shakes, slanting grain, or large or numerous holes or knots.

Resistance to Wear

When so ordered, ties from needleleaved trees shall be of compact wood throughout the top fourth of the tie, where any inch of any radius from the pith shall have six or more rings of annual growth.

Design

Dimensions

(a) Before manufacturing ties, producers shall ascertain which of the following lengths, shapes, or sizes will be accepted, and whether ties are to be hewed or sawed, and in either case whether on the sides as well as on the top and the bottom.

(b) Except as hereinafter provided, standard-gage railway ties shall be 8 ft, 8 ft 6 in, or 9 ft long.

(c) Except as hereinafter provided, ties shall measure as follows throughout both sections between 20 in and 40 in from the middle of the tie:

Size	Sawed or Hewed Top, Bottom and Sides	Sawed or Hewed Top and Bottom
1	6 in thick by 6 in wide on top	6 in thick by 6 in wide on top
2	6 in thick by 7 in wide on top	6 in thick by 7 in wide on top
3	6 in thick by 8 in wide on top	6 in thick by 8 in wide on top 7 in thick by 7 in wide on top
4	7 in thick by 8 in wide on top	7 in thick by 8 in wide on top
5	7 in thick by 9 in wide on top	7 in thick by 9 in wide on top

Manufacture

Except as hereinafter provided, all ties shall be straight, well hewed or sawed, cut square at the ends, have bottom and top parallel, and have bark entirely removed.

Inspection

Decay

The following decay will be allowed; in cedar and in cypress, "pipe or stump rot" and "peck", respectively, up to the limitations as the holes. "Blue stain" is not decay and is permissible in any wood.

Holes

A large hole, other than one caused by "pipe or stump rot" in cedar, is one more than 1/2 in. in diameter and 8 in deep within, or more than one-fourth the width of the surface on which it appears and 3 in deep outside, the sections of the tie between 20 in and 40 in from its middle. A cedar tie with a pipe or stump rot hole more than 1/2 in. in diameter and 15 in deep will be rejected. Numerous holes are any number equaling a large knot in damaging effect.

+ Railways which specify both 6-in x 8-in and 7-in x 8-in ties sawed or hewed on top and bottom only, and which desire to separate the 6-in from the 7-in ties will designate the 7-in x 7-in as Size 3A.

Shake

One which is not more than one-third the width of the tie will be allowed.

Split

One which is not more than 5 in long will be allowed. The purchaser shall specify what antisplitting devices are to be applied, if any.

Slanting Grain

Except in woods with interlocking grain, a slant in grain in excess of 1 in 15 will not be permitted.

Manufacture

(a) A tie will be considered straight: (1) when a straight line along the top from the middle of one end to the middle of the other end is entirely within the tie; and (2) when a straight line along a side from the middle to one end to the middle of the other end is everywhere more than 2 in from the top and bottom of the tie.

(b) A tie is not well hewed or sawed when it surfaces are cut into with scoremarks more than 1/2 in deep or when its surfaces are not even.

(c) The top and bottom of a tie will be considered parallel if any difference in the thickness at the sides or ends does not exceed 1/2 in.

Dimensions

(a) The lengths, thicknesses and widths specified are minima for the standard sizes. Ties over 1 in longer, thicker or wider than the standard size ordered will be rejected.

(b) All thicknesses and widths apply to the sections of the tie between 20 in and 40 in from the middle of the tie. All determinations of width will be made on the top of the tie, which is the narrower of the horizontal surfaces, or the one with narrower or no heartwood if both horizontal surfaces are of the same width.

The following are specifications for crossties in track as stated in the FRA Track Safety Standards (213.109 Crossties):

(a) Crossties may be made of any material to which rails can be securely fastened. The material must be capable of holding the rails to gage within the limits prescribed in 213.53 (b) and of distributing the load from the rails to the ballast section.

(b) A timber crosstie is considered to be defective when it is

  (1) Broken through.

  (2) Split or otherwise impaired to the extent it will not hold spikes or will allow the ballast to work through.

  (3) So deteriorated that the tie plate or base of rail can move laterally more than one-half inch relative to the crosstie.

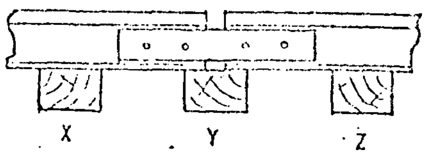
  (4) Cut by the tie plate through more than 40 percent of its thickness.

  (5) Not spiked as required by 213.127 of FRA Track Safety Standard.

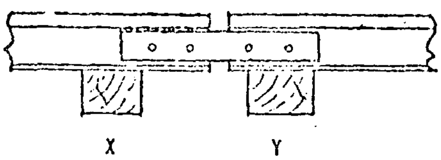
(c) If timber crossties are used, each 39 feet of track must be supported by nondefective ties as set forth in the following table:

Class of Track	Minimum Number of Nondefective Ties	Maximum Distance Between Nondefective Ties (Center to Center) (inches)
1	5	100
2, 3	8	70
4, 5	12	48
6	14	48

(d) If timber ties are used, the minimum number of nondefective ties under a rail joint and their relative positions under the joint are described in the following chart. The letters in the chart correspond to letters underneath the ties for each type of joint depicted.



Supported joint



Suspended joint

Class of Track	Minimun Number of Nondefective Ties Under a Joint	Required Position of Nondefective Ties	
		Supported Joint	Suspended Joint
1	1	X,Y, or Z	X or Y
2,3	1	Y	X or Y
4,5,6	2	X and Y or Y and Z	X and Y

(e) Except in an emergency or for a temporary installation of not more than six months duration, crossties may not be interlaced to take the place of switch ties.

Appendix B

PRESENT VALUE/DISCOUNTED CASH FLOW ANALYSIS

A number of criteria are used by various industries for determining capital investment priorities. The typical industry which operates in terms of specific plans for finite intervals of time customarily sees the future in terms of a finite capital supply: limited capacity to generate funds internally, limited borrowing capacity, and limited capacity to raise new equity as imposed by considerations of control or market conditions. Thus, when considering new investment, if a ranking to investment alternatives can be applied, the choice of where such an industry should put its money can be somewhat simplified. One such method of ranking is the use of ROI or return-on-investment standards. These ROI criteria are minimum acceptable rates of return on new investments, which every alternative must meet in order to be considered.

One method to assess the ROI on long range investments, such as those discussed in this report, is the present value (or worth)/discounted cash flow method. This method basically says that an industry would not ordinarily relinquish today's dollar in exchange for a promise that it will be returned a year from now. It will want its dollar back plus some payment for its use. For example, if an acceptable ROI is 10 percent, $1.00 invested at 10 percent today would be worth $1.10 a year from now. To put it another way, the present value of $1.10 a year from now, discounted at 10 percent is $1.00. Or conversely, we might want to know what amount invested at 10 percent will cumulate to $1.00 a year from now. This amount is $0.909 ($0.909 + 10% x 0.909) = $1.00. In other words, the present value of $1.00 a year from now, discounted at 10% is $0.909.

This latter approach to investment strategy was used for this report. One final point: If today's dollar is worth $1.10 a year from now, it should be worth even more two years from now. Today the dollar is invested at 10 percent; at the end of the first year, \$1.10 is invested at 10 percent. At the end of year two, at a rate of 10 percent compounded annually, a dollar is worth \$1.21. <u>Alternatively we say that \$1.00 two years from now has a present value of \$0.826</u>.

By these means projected future costs may be assessed and compared with what they would be if the money were invested now at an acceptable ROI. This comparison has allowed us to compare refurbishment techniques and their projected costs with the costs of replacing defective ties with new ones in the future.

Appendix C

TIE SUPPLIERS WITH SALES OVER $1,000,000/YR.

American Creosote Works, Inc.
New Orleans, LA

Atlantic Creosoting Co., Inc.
Menlo Park, NJ

Baxter, J. H. & Co.
San Mateo, CA

Boise Cascade Corp.
Portland, OR

Brand-S Corp.
Corvallis, OR

Dant & Russell, Inc.
Portland, OR

Foster, L. B. Company
Pittsburg, PA

Georgia-Pacific Corp.
Portland, OR

Gibraltar Equipment & Mfg. Co.
Alton, IL

Gross & Janes Co.
St. Louis, MO

International Paper Co.
Deridder, LA

Jennison-Wright Corp.
Toledo, OH

Kirby Lumber Corp.
Silsbee, TX

Koppers Company, Inc.
Pittsburg, PA

Louisiana-Pacific Corp.
Portland, OR

Marmon Transmotive
Knoxville, TN

McCormick & Baxter Creosoting Co.
Portland, OR

Midwest Steel Division
Charleston, W VA

Moss-American Inc.
Oklahoma City, OK

Pacific Wood Treating Corp.
Ridgefield, WA

Potomac Supply Corp.
Denison, TX

Smith, W. J. Wood Preserving Co.
Denison, TX

Southern Wood Preserving Co.
East Point, GA

Southern Forest Industries, Inc.
Phoenix, AZ

St. Regis Paper Co.
New York, NY

Taylor-Piedmont Co.
Pittsburg, PA

Western Tar Products Corp.
Terre Haute, IN

Source: Thomas Register of American Manufacturers and Thomas Register Catalog File, 1976.

Appendix D

CONTACTS MADE DURING THE COURSE OF THE STUDY

American Wood Preservers' Association
Washington, DC

Association of American Railroads
Washington, DC

Atchison, Topeka & Santa Fe Railroad
Chicago, IL

J. H. Baxter & Company
San Mateo, CA

R. Bescher (Retired Koppers)
Orrville, OH

Brookhaven National Laboratories
Upton, Long Island, NY

Canadian Pacific
Windsor Sta., Montreal

Daubert Chemical Company
Chicago, IL

Diversified Products
Hacketstown, NJ

Dow Chemical
Midland, MI

Forest Products Laboratory
Princeton, W VA

G. W. Lumber Company
Stover, MO

Koppers Company
Monroeville, PA

Missouri Pacific Railroad
St. Louis, MO

Osmose Wood Preserving Co.
Madison, WI

Pennsylvania Central Railroad
Philadelphia, PA

Portland Cement Laboratory
Skokie, IL

Racine Railroad Products
Racine, WI

Southern Pacific Transportation Company
San Francisco, CA

Southern Railway
Atlanta, GA

Southern Wood Piedmont
Spartenburg, SC

The Railway Tie Association
St. Louis, MO

Union Pacific Railroad
The Dalles, OR

U.S. Bureau of Mines
Washington, DC

Appendix E

REPORT OF INVENTIONS

This report contains the results of a systematic review of the causes of wooden crosstie deterioration and the feasibility of repairing deteriorated crossties for reuse. It suggests the transfer of processes common to other wood refurbishment operations to wooden crosstie rehabilitation, describing possible processing plant flow diagrams.

Because of the nature of the technology transfer of this report, a diligent review of this material disclosed no new novel or patentable process or device as a result of this work. Rather, the report describes the economic and technical framework within which new approaches to tie refurbishment must function.