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RTA

RTA TieReports

Table of Contents

Thank you for your interest in RTA's TieReports. The Railway Tie Association has developed TieReports as a one-stop resource of the highest quality technical information. The technical materials in this binder will be valuable to all in the wood crosstie industry, including engineers, specifiers and users of wood crossties.

Research on a variety of important topics is listed on the Table of Contents page in this compilation. Individual documents on the subjects listed on the Table of Contents page also are available online at the RTA website **(www.rta.org)** on the Publications page.

TieReports will be updated frequently with new papers, research reports and other materials. Those who may have ideas for additional reports are encouraged to contact the RTA.

RTA TieReport #1

Update on Wood Tie Life: Part 1

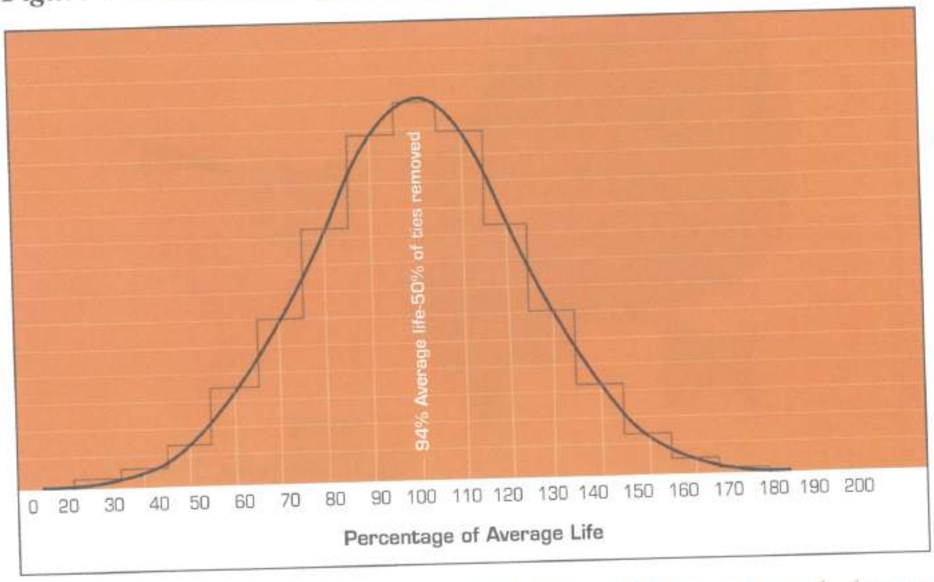
Wood crossties represent the predominant type of tie in use in North America. The life of the wood crosstie will vary significantly based on track, roadway, traffic and environmental conditions [1,2]. This TechNote will present the most current experience of wood crossties life as a function of such key parameters as track curvature, environmental conditions, and traffic density.

The lives presented here are for conventional creosote-treated hardwood crossties with cut-spike fasteners. This system represents the dominant tie and fastener system used on North American freight railroads. The effect of alternate, non-conventional fastener types, such as elastic fasteners, and treatments will be presented in a later TechNote.

These tie lives are calculated based on the RTA's SelecTie model as calibrated to tie lives reported by several major US Class 1 railroads. While other wood tie life models have been developed over the years [1,3] the SelecTie model has been found to represent a realistic assessment of conventional wood tie life in North American freight railroad service.

It should be noted that ties, even when installed at the same time under identical operating conditions, do not all fail at once. Rather, there is a statistical distribution of tie failure and hence replacement, around an "average" tie life, as shown in Figure 1 for wood ties with cut spike fasteners.

Figure 1: *Factors that Affect Tie Life*



Frequency curve showing successive percentage tie replacements for 10 percent intervals of average life. Symmetrical form- Original taken at 94 percent.

Tie Report #1: *Update on Wood Tie Life: Part 1 (continued)*

Such statistical distribution curves have been developed by the USDA Forest Products Laboratory [4] and the Association of American Railroads [5]. This average tie life model is a convenient reference value to use, and as such can be related directly to the key track, traffic, and environmental parameters that reflect tie life variability. As can be seen in Table 1, Tie Life is related to a range of track, traffic and environmental factors.

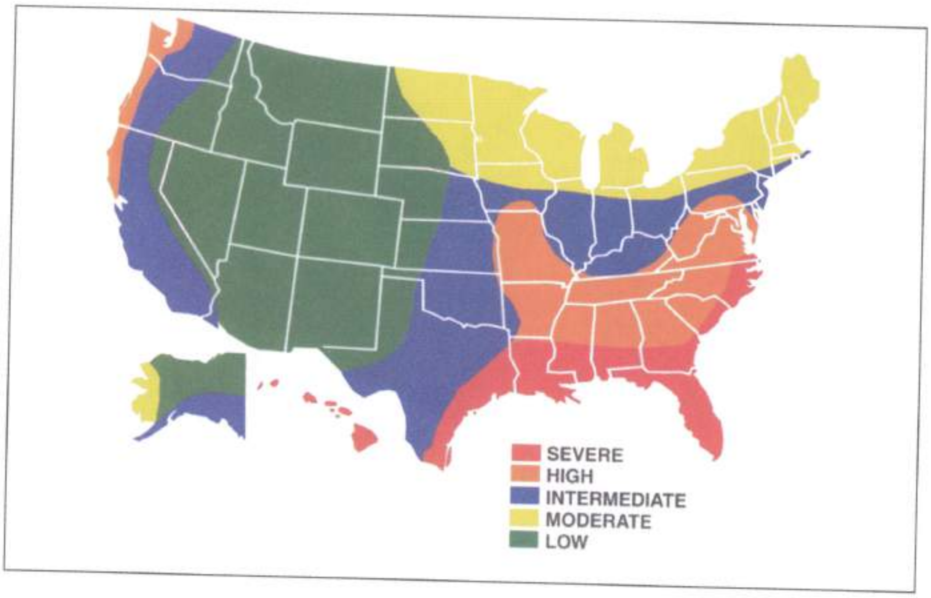
Table 1: *Tie Life Factors*

Traffic Characteristics	• Traffic Density or Tonnage (Annual MGT) • Axle Load • Speed • Traffic Type
Track Geometry	• Curvature • Grade
Track Type and Condition	• Rail Section (weight) • Welded Rail (CWR) vs. Jointed Rail • Fastener Type • Ballast/Track Support
External Factors	• Environment (climate, temperature, humidity, decay hazard) • Biological factors (termites, fungi, etc.) • Wood type (e.g., hardwood vs. softwood)

Of these factors, three can be considered to be the dominant factors for conventional wood tie, cut spike track:

- Tonnage
- Curvature
- Environmental Conditions (Decay Hazard) [Figure 2]

Figure 2: *Decay Hazard Map of U.S.*



The first two factors directly affect the rate of mechanical degradation of the ties. The third factor directly affects the rate of decay of the tie.

Tie Report #1: Update on Wood Tie Life: Part 1 (continued)

The actual mode of failure, mechanical vs. decay, is a function of the severity of the service environment (tonnage, curvature, etc.) and the rate of decay or environmental degradation (which also includes biological degradation such as through termite infestation, etc.). On average, the distribution of failure between mechanical and environmental decay is illustrated in Figure 3 [1,6]. However, This distribution can change significantly as a function of the parameters noted above. This can be seen in the following Figures.

Figure 3: *Tie Failure Distribution by Defect Mode. (Mainline Case)*

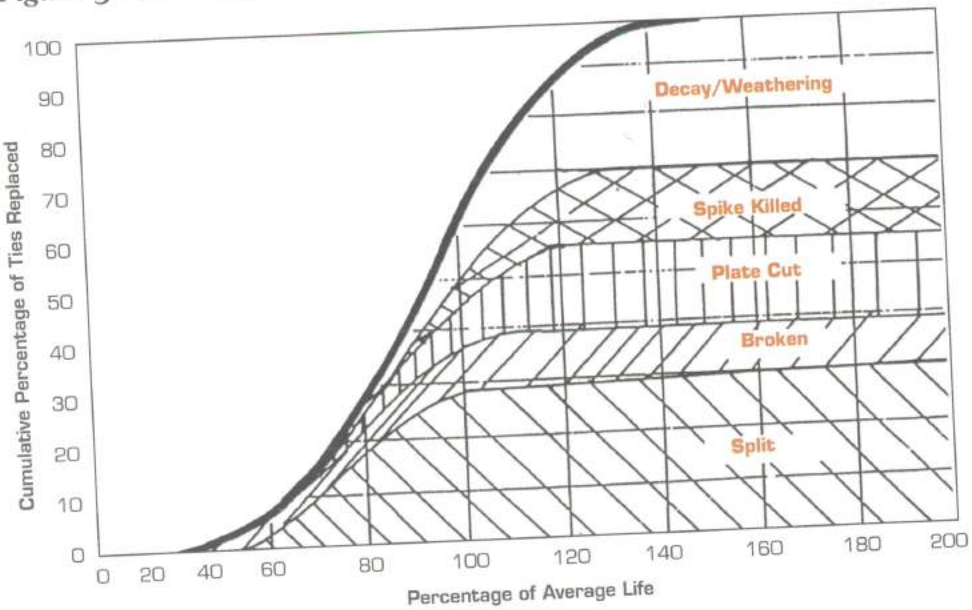


Figure 4: *Curvature Sensitivity*

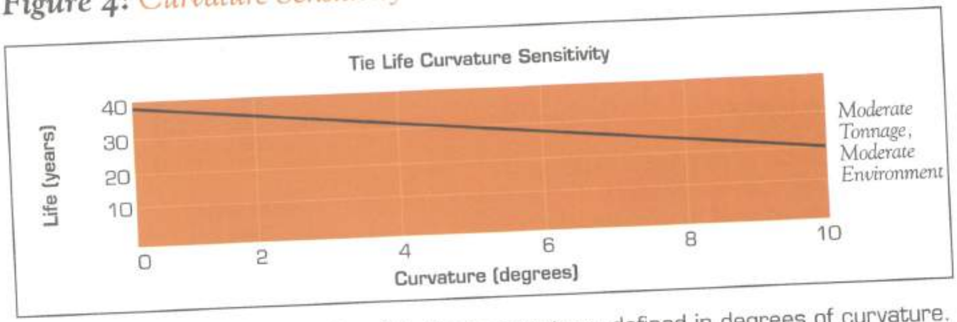


Figure 4 presents the sensitivity of tie life to curvature, defined in degrees of curvature.

Figure 5: *Tonnage Sensitivity*

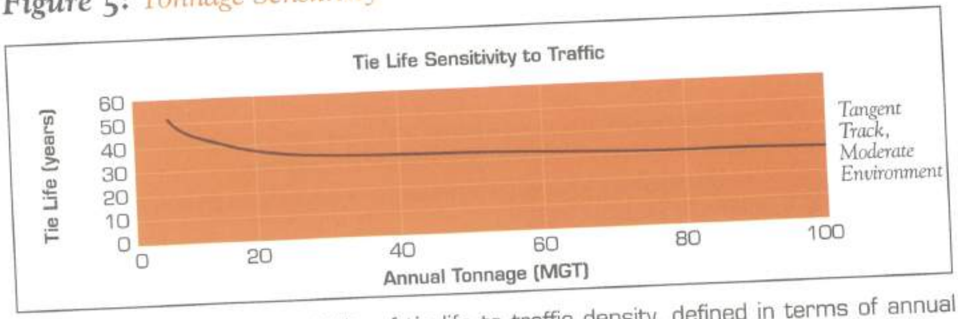


Figure 5 presents the sensitivity of tie life to traffic density, defined in terms of annual tonnage of MGT per year.

Tie Report #1: Update on Wood Tie Life: Part 1 (continued)

Figure 6: Environmental Sensitivity

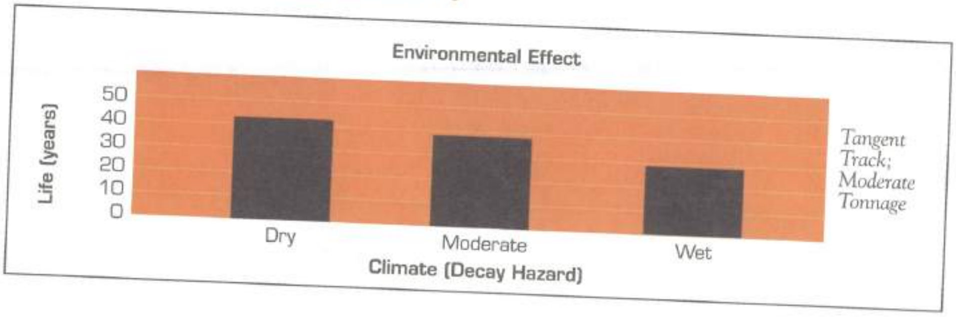


Figure 6 presents the sensitivity of tie life to environmental or climatic condition. This is directly related to the Decay Hazard map presented in Figure 2 and can be simplified as follows:

- "Dry" Climate Track: Representative of Western U.S.
- "Moderate" Climate Track: Representative of Northern U.S.
- "Wet" Climate Track: Representative of Southeastern U.S.

Table 2 presents a tabular summary of tie life by major category [2] as follows:

Annual tonnage:

• Low:	10 MGT per year
• Moderate:	25 MGT per year
• High:	50 MGT per year

Curvature:

- Tangent
- Moderate (defined as 4 degrees)
- Composite curvature (80% tangent and 20% to curves reflect a distribution identified on selected US railway routes)

Climatic condition:

- "Dry" Climate Track: Representative of Western U.S.
- "Moderate" Climate Track: Representative of Northern U.S.
- "Wet" Climate Track: Representative of Southeastern U.S.

Table 2: Wood Tie Life

"Dry" Climate Track	Curve (deg)		
MGT	0	4	Aggregate
10	50	39	47.8
25	40	33	38.6
50	36	28	34.4

Moderate Climate Track	Curve (deg)		
MGT	0	4	Aggregate
10	45	36	43.5
25	38	30	36.2
50	33	26	31.5

"Wet" Climate Track	Curve (deg)		
MGT	0	4	Aggregate
10	34	27	32.8
25	29	22	27.3
50	25	19	24

REFERENCES

1. Zarembski, A. M. and Holfeld, D. H., "On the Prediction of the Life of Wood Cross Ties," American Wood Preservers Association, Annual Conference, Pittsburgh, PA, April 1997.

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3. Zarembski, A. M., "Forecasting of Track Component Lives and its Use in Track Maintenance Planning," International Heavy Haul Railways Association/Transportation Research Board Workshop, Vancouver, B.C., June 1991.

4. MacLean, J. D., "Percentage Renewals and Average Life of Railroad Ties," Forest Products Laboratory, USDA Forest Service Report No. 866, November 1957 (Reaffirmed 1965).

5. Wells, T. R., "Tie Failure Rate Analysis and Prediction Techniques," Association of American Railroads Report R-515, October 1982.

6. Davis, D. D., and Shafarenko, V., "Tie Condition at Des Plaines: A Progress Report," Bulletin of the AREA, Bulletin 713, December 1987.

RTA TieReport #2

Cost Comparison of Alternate Crosstie Materials

While wood cross-ties continue to represent the dominant tie material installed in the United States and Canada with a 95% share of all ties purchased in 2005 [1], other cross-tie materials in active use include:

Concrete | Steel | Composite/Plastic

In order to examine the economics of these alternate materials as compared to wood cross-ties, several detailed studies have been undertaken and computer models developed. The original focus of these analyses was on the comparison of wood vs. concrete cross-ties, where a new generation life cycle cost model, the "SelecTie" model, was developed to examine the full spectrum of purchase, installation and maintenance costs associated with these different tie types [2,3]. Table 1 illustrates the range of parameters used in such a detailed life cycle cost analysis.

Table 1: SelecTie Analysis Factors

Costs

- Component (material) Costs
  - Tie
  - Fasteners and Fastener Components
- Labor Costs

Tie Life as a Function of Track and Traffic Characteristics

- Track Characteristics
  - Curvature
  - Grade
  - Climatic Condition
  - Track Design
  - Track Components
- Traffic Characteristics
  - Operating Speed
  - Axle Load
  - Traffic Density (annual tonnage)

Economic Characteristics

- Interest Rate

Maintenance Activities

- Rail Replacement Costs
- Tie Replacement Costs
- Concrete Tie Repair Costs
- Surfacing Costs
- Other Maintenance Costs

The results of these life cycle cost analyses showed that for the vast majority of track, wood is the economic choice. However, there are locations and conditions where concrete is an economically attractive alternative [2,3]. Thus, these analyses must be updated as a function of the respective costs and life cycles of the alternate materials.

Such an updated analysis was recently performed which analyzed the costs and associated "values" of several of these alternate tie materials as a function of traffic and service [4]. Specifically, the study calculated the "value" of wood ties on a cost per ton mile basis as compared to these alternate tie materials, looking at respective costs, service life and performance.

Noting that the service lives vary as a function of traffic density, climatic conditions, curvature, etc., a set of comparisons was performed using current costs for tie materials (to include fasteners and installation, as presented in Table 2), wood tie service lives (as presented in the previous Tech Note number I), and service lives for the alternate tie materials (as presented in Table 3).

Tie Report #2: Cost Comparison of Alternate Crosstie Materials (continued)

Table 2: Tie Costs to Include Fasteners and Installation [4]

	Wood	Concrete 1	Concrete 2	Composite/Plastic	Steel 1*
Unit Cost	$95.00	$250.00	$200.00	$135.00	$140.00
Ties/Mile	3,250	2,640	2,640	3,250	3,250
Cost/Mile	$308,750	$660,000	$528,000	$438,750	$455,000

Notes:

- Concrete 1 represents costs of complete out-of-phase installation of concrete track as part of new construction, based on the costs of a major U.S. Class 1 railroad.
- Concrete 2 represents 2/3 of the labor and equipment costs reported for Concrete 1 and is considered a "lower bound" cost for cases with very high rates of tie installation productivity.
- Steel 1 is based on a standard tie spacing of 19½ inches.

**Steel ties are sensitive to the cost of steel, which varies with demand.*

Table 3: Service Lives of Alternate Tie Materials [4]

Concrete

	Curve (deg)		
MGT	0	4	Aggregate*
10	60	53	58.6
25	51	45	49.8
50	46	41	45

*Aggregate life is for a composite curvature (80% tangent and 20% curves) which reflects a distribution identified on selected U.S. railway routes.

Composite/Plastic Tie Life**

	Curve (deg)		
MGT	0	4	Aggregate
10	50	39	47.8
25	40	33	38.6
50	36	28	34.4

**Composite/plastic tie life assumed to be comparable to dry climate track wood tie life. This performance has not yet been confirmed by field experience.

Steel Tie Life***

	Curve (deg)		
MGT	0	4	Aggregate
10	55	46	53.2
25	45.5	39	44.2
50	41	34.5	39.7

***Steel tie life assumed to be an average of concrete and dry climate track wood tie life. This performance has not yet been confirmed by field experience.

Three distinct cost/benefit analysis approaches were used to examine the respective values of the different tie materials,

1. **Simplified Analysis of Unit Costs** (all materials)
   Tie material and replacement (labor and equipment) costs used to calculate a cost/mile/MGT based on a full, one-time replacement of all of the cross-ties.
2. **Tie Replacement Life Cycle Costs** (Steel and Composite/Plastic vs. Wood)
   Tie material and replacement (labor and equipment) costs used to calculate a cost/mile/MGT, based on a 100-year life cycle using conventional cyclic tie gangs[1].

---

[1] This analysis is not appropriate for concrete ties because of the significant difference in tie gang cycles, due to the fact that concrete ties are replaced out of face (100% replacement).

3. Full SelecTie Life Cycle Cost Analysis (Concrete vs. Wood)
Full life cycle analysis performed using the RTA SelecTie model, including all of the major maintenance activities (to include tie replacement, rail replacement, surfacing, grinding, etc.). Cost/mile/MGT calculated based on life cycle cost analysis.

Because of the difference in time horizons, the actual costs per unit of traffic ($/mile/MGT) differ significantly among the three methods. However, the relative rankings and ratio are appropriate for comparison of wood against the other tie materials.

In all cases, the cost/mile/MGT for each analysis pair; wood vs. alternate tie material, was converted to a value ratio, the ratio of wood tie to alternate tie cost/mile/MGT. Note: When this ratio is less than 1, it means that the unit cost of the wood ties is less than the alternate ties. If it is greater than 1, it means the cost of the alternate ties is less.

For the simplified analysis, based on tie installation costs and total tie life in MGT (not accounting for the time value of money), the results are presented in Table 4. In this analysis, tie material and replacement (labor and equipment) costs were used to calculate a cost per mile of track, based on a full, one-time replacement of all of the cross-ties. Using the tie life in years, annual MGT, the defined replacement unit cost defined here, $/mile/MGT was calculated together with the ratio of wood tie to alternate tie cost.

Table 4: *Simplified Unit Cost Analysis (All Materials)*

For "Dry" Climate Track
(Western U.S.)

Wood/Concrete 1		Tangent	Mod Curve
Low Tonnage	10	0.56	0.64
Med Tonnage	25	0.60	0.64
High Tonnage	50	0.60	0.68

Wood/Concrete 2		Tangent	Mod Curve
$/Mile/MGT	MGT		
Low Tonnage	10	0.70	0.79
Med Tonnage	25	0.75	0.80
High Tonnage	50	0.75	0.86

Wood/Plastic		Tangent	Mod Curve
Low Tonnage	10	0.70	0.70
Med Tonnage	25	0.70	0.70
High Tonnage	50	0.70	0.70

Wood/Steel 1		Tangent	Mod Curve
Low Tonnage	10	0.75	0.80
Med Tonnage	25	0.77	0.80
High Tonnage	50	0.77	0.84

For Moderate Climate Track

Wood/Concrete 1		Tangent	Mod Curve
Low Tonnage	10	0.62	0.70
Med Tonnage	25	0.63	0.71
High Tonnage	50	0.65	0.74

Wood/Concrete 2		Tangent	Mod Curve
Low Tonnage	10	0.77	0.87
Med Tonnage	50	0.79	0.89
High Tonnage	50	0.82	0.93

Wood/Plastic		Tangent	Mod Curve
Low Tonnage	10	0.77	0.77
Med Tonnage	25	0.74	0.78
High Tonnage	50	0.77	0.76

Wood/Steel 1		Tangent	Mod Curve
Low Tonnage	10	0.82	0.88
Med Tonnage	25	0.82	0.89
High Tonnage	50	0.84	0.91

Tie Report #2: *Cost Comparison of Alternate Crosstie Materials (continued)*

For "Wet" Climate Track
(representative of Southeastern U.S.)

Wood/Concrete 1		Tangent	Mod Curve
Low Tonnage	10	0.82	0.92
Med Tonnage	25	0.83	0.94
High Tonnage	50	0.86	0.98

Wood/Plastic		Tangent	Mod Curve
Low Tonnage	10	1.02	1.02
Med Tonnage	25	.98	1.04
High Tonnage	50	1.02	1.01

Wood/Concrete 2		Tangent	Mod Curve
Low Tonnage	10	1.02	1.15
Med Tonnage	25	1.04	1.18
High Tonnage	50	1.08	1.23

Wood/Steel 1		Tangent	Mod Curve
Low Tonnage	10	1.09	1.16
Med Tonnage	25	1.08	1.18
High Tonnage	50	1.12	1.20

For the life cycle cost analysis based on tie material and installation costs and total tie life, the results for the moderate tonnage case are presented in Table 5. In this analysis, tie material and replacement (labor and equipment) costs were used to calculate a cost per mile of track, based on a 100-year life cycle cost analysis. The wood, steel and plastic ties were replaced using conventional tie gangs, based on 25% replacement of ties per cycle and a cost of money of 8%.

Table 5: *Tie Replacement Life Cycle Costs Analysis*

(Steel and Composite/Plastic vs. Wood)

Moderate Tonnage
(25 MGT) Tangent Track

For "Dry" Climate Track (Western U.S.)

wood-"dry"/Plastic	0.70
wood-"dry"/Steel 1	0.75

For Moderate Climate Track

wood-mod/Plastic	0.77
wood-mod/Steel 1	0.83

For "Wet" Climate Track (e.g., Southeastern U.S.)

wood-"wet"/Plastic	0.89
wood-"wet"/Steel 1	0.96

Moderate Tonnage
(25 MGT) Curved Track

For "Dry" Climate Track (Western U.S.)

wood-"dry"/Plastic	0.70
wood-"dry"/Steel 1	0.75

For Moderate Climate Track

wood-mod/Plastic	0.77
wood-mod/Steel 1	0.82

For "Wet" Climate Track (e.g., Southeastern U.S.)

wood-"wet"/Plastic	0.96
wood-"wet"/Steel 1	1..02

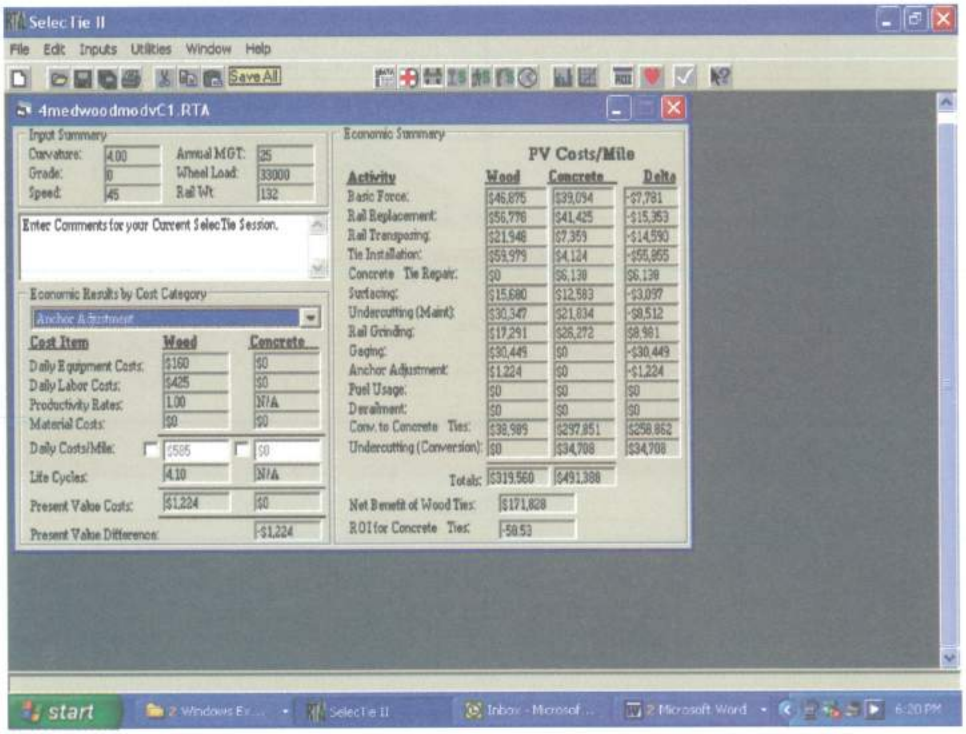
The analysis of Concrete vs. Wood ties was performed using the RTA SelecTie model [2,3], where all of the major maintenance activities addressed by the SelecTie model (to include tie replacement, rail replacement, surfacing, grinding, etc.) costs were used to calculate a cost per mile of track, based on a life cycle cost analysis. Maintenance cycles were activity-specific based on internal SelecTie life models. Most recent updated costs were used in SelecTie.

**Note: This analysis was limited to the Wood vs. Concrete tie analysis.*

Tie Report #2: Cost Comparison of Alternate Crosstie Materials (continued)

Figure 1: *SelecTie Analysis Wood ("dry" climate track) vs. Concrete, Moderate Density, Curved Track*

Figure 1



Input Summary

Curvature: 4.00
Grade: 0
Speed: 45
Annual MGT: 25
Wheel Load: 33000
Rail Wt: 132

Enter Comments for your Current SelecTie Session.

Economic Results by Cost Category

Anchor Adjustment

Cost Item	Wood	Concrete
Daily Equipment Costs:	$160	$0
Daily Labor Costs:	$425	$0
Productivity Rates:	1.00	N/A
Material Costs:	$0	$0
Daily Costs/Mile:	☐ $585	☐ $0
Life Cycles:	4.10	N/A
Present Value Costs:	$1,224	$0
Present Value Difference:		-$1,224

Economic Summary

PV Costs/Mile

Activity	Wood	Concrete	Delta
Basic Force:	$46,875	$39,094	-$7,781
Rail Replacement:	$56,776	$41,425	-$15,353
Rail Transposing:	$21,948	$7,359	-$14,590
Tie Installation:	$59,979	$4,124	-$55,855
Concrete Tie Repair:	$0	$6,138	$6,138
Surfacing:	$15,680	$12,583	-$3,097
Undercutting (Maint):	$30,347	$21,834	-$8,512
Rail Grinding:	$17,291	$26,272	$8,981
Gaging:	$30,449	$0	-$30,449
Anchor Adjustment:	$1,224	$0	-$1,224
Fuel Usage:	$0	$0	$0
Derailment:	$0	$0	$0
Conv. to Concrete Ties:	$38,989	$297,851	$258,862
Undercutting (Conversion):	$0	$34,708	$34,708
Totals:	$319,560	$491,388	

Net Benefit of Wood Ties: $171,828
ROI for Concrete Ties: -58.53

Figure 1 illustrates a sample SelecTie analysis comparing wood vs. concrete tie track in a dry environment, moderate tonnage and moderate curvature.

The results of the SelecTie analysis for moderate tonnage (25 MGT) tangent and curved track are presented in Table 6.

Table 6: *SelecTie Life Cycle Costs Analysis* (Concrete vs. Wood)

Moderate tonnage (25 MGT) **tangent track**

For "Dry" Climate Track (Western U.S.)

wood-"dry"/Concrete Tangent Track	0.57
wood-"dry"/Concrete Curved Track	0.65

For Moderate Climate Track (Western U.S.)

wood-moderate/Concrete Tangent Track	0.58
wood-moderate/Concrete Curved Track	0.66

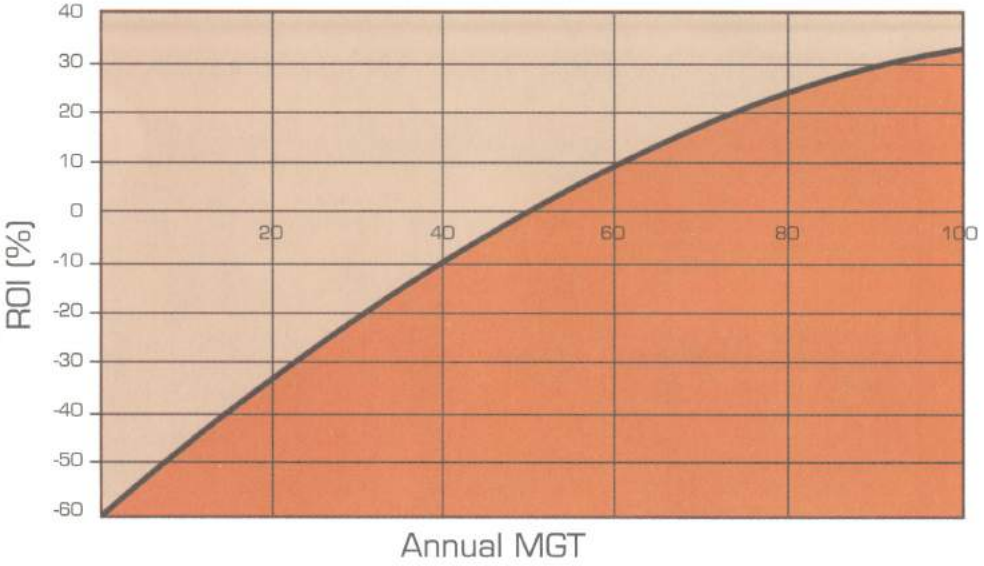
For "Wet" Climate Track (e.g., Southeastern U.S.)

wood-"wet/Concrete Tangent Track	0.62
wood-"wet"/Concrete Curved Track	0.71

However, as noted in earlier analyses, as the annual tonnage increases, the relative benefit of the wood cross-ties changes, with the benefit (defined in terms of Return on Investment or ROI) decreasing, in some cases, at higher annual tonnage levels as illustrated in Figure 2.

Figure 2: SelecTie Sensitivity Analysis for ROI of Concrete (vs. Wood) Track [3]

Figure 2



Based on these analyses, it can be seen that in general, wood ties have a lower cost per mile per MGT than any of the alternate tie configurations, except for applications in wet climates where the tie life is significantly reduced or for high-curvature high-density applications.

In general, for moderate-density tangent track of the order of 25 MGT per year located in a moderate climate zone of the U.S., wood tie costs ($/mile/MGT) are of the order of 60 to 80% of concrete tie track; 70 to 75% of plastic (composite) ties, and 80 to 85% of steel tie track costs.

For moderate-density moderate-curvature track (25 MGT per year) located in a moderate climate zone of the U.S., wood tie costs ($/mile/MGT) are of the order of 65 to 85% of concrete tie track; 70 to 80% of plastic (composite) ties, and 80 to 90% of steel tie track costs.

For dry climates, the wood tie costs represent a corresponding smaller percentage of the costs of alternate tie types; for wet climates, they represent a correspondingly higher percentage of the costs of alternate tie types.

**Note: Analysis shows Return on Investment (ROI) of concrete tie track as compared to wood tie track. Negative or low ROI indicates wood tie is more advantageous.*

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RTA TieReport #3

Modern Cross-Tie Inspection and Planning Tools

In order to effectively and efficiently maintain the railroad's track structure, railroad maintenance officers must have accurate knowledge of the exact condition of the track and its key components. However, while inspection tools used for measurement of rail and track geometry condition have been around for many years, inspection tools for cross-ties are only now becoming available to supplement and complement the traditional tie inspector's "calibrated eye." This is in spite of the fact that cross-ties represent the second largest cost area, accounting for between 20% and 40% of railroad track maintenance costs.

The traditional method of cross-tie inspection makes use of tie inspectors who walk the track, visually inspecting the condition of the ties, and in some cases supplementing the visual inspection by "kicking" the ties and/or fasteners and observing any movement. Bad ties are "counted" using simple mechanical counters which keep track of the number of bad ties in each mile, a number that is written down and ultimately introduced into the railroad database. Since the tie inspectors can range from experienced, full-time tie inspectors to local inspectors, roadmasters or supervisors who generate tie counts upon request, the ability of the tie inspectors to accurately and consistently identify bad ties has always been in question. The ability to categorize ties into more than two simple categories (good vs. bad) simply did not exist.

In recent years, however, several new systems for monitoring and recording tie condition have come into widespread use. In addition to providing detailed and accurate information about tie condition, they also collect a sufficient level of data as to allow for accurate planning of tie maintenance and replacement activities.

TieInspect®

One such new-generation tie inspection system is the *TieInspect®*[1] cross-tie inspection system that has been actively used by railways to accurately "map" the track's tie condition and plan replacement activities based on this condition mapping [1, 2, 3]. TieInspect is a hand-held (computerized) data collection and analysis system that allows the tie inspector to record the condition of each tie individually, thus providing a complete database of current tie condition and allowing for analysis of these collected data. While still based on the tie inspector's visual observations, the ability to categorize tie condition into 4 or 5 categories, and to accurately map the condition of all of the ties, individually, provides the railroad with a powerful tool to accurately determine which ties have to be replaced and when.

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[1] *TieInspect and its associated software products TieReplace, TieMark, TiePrioritize, etc. are products of ZETA-TECH Associates, Inc.*

Figure 1: *TieInspect Tie Inspection System*

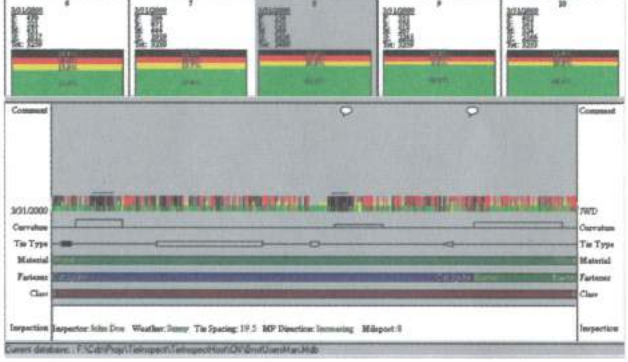
TieInspect consists of a palmtop computer (PDA) and an ergonomically designed handgrip input device (Figure 1) designed to accommodate the tie inspector's traditional inspection technique while giving him the flexibility to record a whole range of important additional information. Thus, the unit records tie condition data for every tie, together with information about location, curvature, tie type, tie material, events, notes, etc.

Because it can categorize tie condition into four or five categories, railway users have been able to develop standardized tie rating systems, such as the system shown in Figure 2, which is currently used by BNSF to inspect and plan tie replacements on over 6,000 miles of track annually [2,3]. Using the TieInspect units and working in two-person teams, BNSF field inspectors average 40 miles of track inspected per team per week.

Figure 2: *BNSF Tie Condition Rating System*

The collected TieInspect data are downloaded to a data base which can be resident on a stand-alone Windows-based computer or a computer network, for analysis, display, and storage. The data can then be viewed in both a summary and detailed format, such as the mile by mile summary distribution and counts of good, marginal, and bad ties (shown in Figure 3). The bar chart on the top of Figure 3 shows the summary data for each mile in that segment, to include tie count and percentage of ties in each condition category. For each individual milepost, a detailed graphical representation of the tie inspection data or tie condition map is presented for each inspection.

	TIE CLASS			
CONDITION	1 FRA Defective BLACK	**2 BNSF Defective RED**	**3 Moderate YELLOW**	4 Good GREEN
Broken	Broken through - separated	Broken through – Not separated	Not broken through	No Breaks
Split or Otherwise Impaired	To the extent the crossties will allow ballast to work through, or will not hold spikes or rail fasteners	Will not hold spikes or rail fasteners. *Loose spikes in curves greater than 2 degrees.*	Tie holds spikes, some splits deep enough to allow water into tie. *Tie can be plugged and respiked if in tangent or curves 2 degrees and less.*	Slight weather splits but integrity not compromised
Deteriorated	So that the tie plate or base of rail can move laterally more than ½ inch relative to the crosstie	So that the tie plate or base of rail can move laterally more than ¼ inch but less than ½ inch relative to the crosstie	Less than ¼ inch of lateral plate or rail movement	No plate movement or cut and no sign of deterioration
Plate Cut	More than 40% of the ties' thickness	More than 1 inch but less than 40% of the ties' thickness	Greater than ¼ inch, up to 1 inch in depth	¼ inch plate cut or less.
Wheel Cut		More than 2 inches deep within 12 inches of the base of the load-bearing area, not broken through the tie.	½ inch to 2 inches deep not broken through the tie	½ inch or less with no structural damage to tie
Rotted or Hollow		Substantial amount of wood decayed or missing. Hollow under plate area.	Some rot over tie and on ends. Not hollow under plate area.	None
Expected Remaining Life			Less than 20 years	20 years or greater



Find By: ● Div & Sub ○ Line Seg
Rail Road: RR
Div: Div
Sub: Sub
Dates After: 1/1/2000
Track: 1
MP Start: 6
MP End: 10
3/31/2000
Inspection: Inspector: John Doe Weather: Sunny Tie Spacing: 19.5 MP Direction: Increasing Milepost: 8

Figure 3: *TieInspect Tie Condition Data Display*

There data are then used in the analysis of the tie condition and planning of the tie maintenance activities, as described later in this note.

Tie Report #3: Modern Cross-Tie Inspection and Planning Tools (continued)

Track Strength Measurement

A second approach to measuring tie condition is based on the measurement of the lateral or gage holding strength of the track, and in particular of the tie and fastener system. This approach, which is based on research and development activities by the AAR and VTSC in the late 1970s and 1980s, makes use of a gage spreading force to apply lateral (and restraining vertical) loads to each rail and simultaneously measure the lateral movement of the two rails, i.e., the gage widening under load of the track. Extensive research has shown that the resistance to this lateral movement or deflection under load is directly related to the condition of the ties and fasteners and represents the gage strength of the track. By monitoring this lateral or gage strength, from a continuously moving track strength testing vehicle, it is possible to identify weak spots in the track due to poor or inadequate tie and/or fastener condition. It is also possible to identify clusters of bad ties that need to be replaced, based on inadequate gage strength, thus forming the basis for a tie replacement program [4].

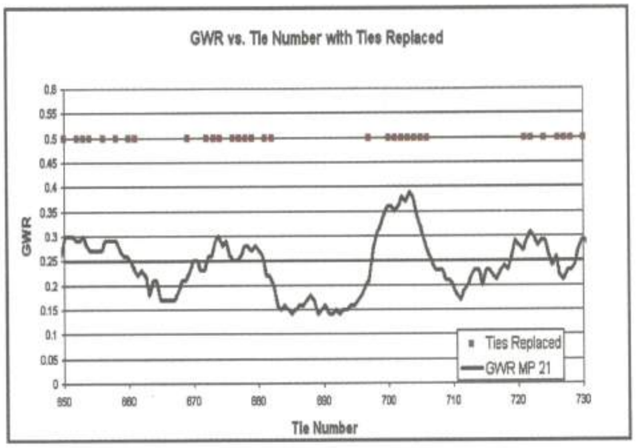
One commercially available track strength system is shown in Figure 4A. This Gage Restraint Measurement System[2] (GRMS), which is mounted under a rail bound inspection vehicle, uses split-axle technology coupled with an instrumented wheel set to apply and measure vertical and lateral loads on the railhead. A second system consists of a hi-rail based inspection vehicle using a split axle type of loading system as shown in Figure 4B.

Figure 4A: *GRMS Inspection Vehicle*

Figure 4B: *TrackStar Hi-Rail Inspection Vehicle*[3]

These systems can conduct continuous track strength testing, which tests speeds of 30+ mph. Using real time measurement of the track deflection under load, various track strength indices are calculated to include Loaded Gage, Projected Loaded Gage (PLG), and Gage Widening Ratio (GWR), which in turn are used to identify ties with inadequate lateral gage strength that must be replaced (see Figure 5) [5].

Figure 5: *Track Strength Output Report and Identified Ties to be Replaced*



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[2] *GRMS is a product of ENSCO Inc.*

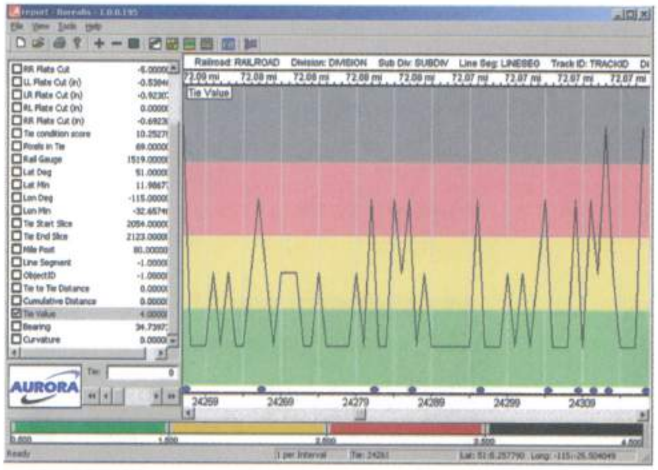
[3] *TrackStar is a product of Holland Company.*

Tie Report #3: Modern Cross-Tie Inspection and Planning Tools (continued)

Automated Machine Visual Tie Inspection

A third approach that has recently been introduced to automatically inspect ties in track makes use of machine vision technology and associated image processing techniques. While several generalized machine vision systems for track inspection have been tried, the new Aurora[4] tie inspection system has developed a level of technology necessary to inspect tie condition. Using this technology, data are gathered at speeds of up to 30 miles per hour and then analyzed, off line, based on visual tie condition criterian to include location, length and width of splits, depth of plate cutting, spike uplift, etc. Both two-level tie condition (good vs. bad) and four-level tie condition (Figure 6) reports can be generated and presented in a report format.

Figure 6: Aurora Four Level Tie Condition



Railroad: RAILROAD Division: DIVISION Sub Div: SUBDIV Line Seg: LINESEG Track ID: TRACKID

☐ RR Plate Cut -6.0000
☐ LL Plate Cut (in) -0.5304
☐ LR Plate Cut (in) -0.9230
☐ RL Plate Cut (in) 0.0000
☐ RR Plate Cut (in) -0.6923
☐ Tie condition score 10.2527
☐ Pixels in Tie 69.0000
☐ Rail Gauge 1519.0000
☐ Lat Deg 51.0000
☐ Lat Min 11.9867
☐ Lon Deg -115.0000
☐ Lon Min -32.6574
☐ Tie Start Slice 2054.0000
☐ Tie End Slice 2123.0000
☐ Mile Post 80.0000
☐ Line Segment -1.0000
☐ ObjectID -1.0000
☐ Tie to Tie Distance 0.0000
☐ Cumulative Distance 0.0000
☑ Tie Value 4.0000
☐ Bearing 34.7397
☐ Curvature 0.0000

1 per Interval Tie: 24261 Lat: 51:6.257790 Long: -115:-26.504049

Tie Maintenance Management and Planning

As noted earlier, the availability of tie condition data allows for a more effective tie maintenance management and planning activity than that allowed by the traditional "bad tie per mile" count. This ranges from a relatively simple exception reporting approach to more sophisticated tie replacement logic approach as well as prioritization of tie replacement activities and scheduling of tie maintenance gangs.

The exception report approach is currently used with track strength data such as illustrated in Figure 5 for Gage Widening Ratio (GWR). By defining a strength threshold level, the number of locations (and ties) that exceed that threshold can be identified and counted. Figure 6 extends this approach to four levels, again providing a count of ties in each condition category.

A more sophisticated approach to identification of ties to be replaced, based on the severity of service and the condition of the ties adjacent to the tie in question, is built into the TieReplace logic of the TieInspect system. This represents a tie replacement decision process based on key track and operating factors such as:

- Condition of tie
- Number of adjacent good and/or marginal ties
- Curvature
- Class of track (speed)
- Proximity to crossings, turnouts and bridges

It also allows for single bad ties to remain in track, where appropriate. Figure 7 illustrates the replacement logic approach. The TieReplace logic determines the specific individual ties that are to be replaced each mile based on the inspected condition of the ties as recorded in the database. The result is a complete data file of replacement ties for each mile of track inspected and analyzed and represents the required tie replacement program for the inspected track. This tie replacement file can then be loaded back into the hand-held computer units and used to identify the ties to be replaced.

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[4] *Aurora is a product of Georgetown Rail Equipment Company*

Tie Report #3: Modern Cross-Tie Inspection and Planning Tools (continued)

Figure 7: TieReplace Replacement Logic

Tie Replacement Logic

Select Track Type and Specify Maximum Allowable Single Bad Ties

Class: 4

Curvature: Moderate

Maximum number of single bad ties to be left per mile: 0 ☐ No Maximum

Replacement Logic for Above Track Type

Maximum number of consecutive marginal (or worse) ties to be left: 7 ☐ No Maximum

Maximum number of consecutive bad ties to be left: 3 ☐ No Maximum

Maximum number of ties that can be replaced in a row: 3 ☐ No Maximum

Replace all bad ties within 16 ties of all crossings, turnouts, and bridges

Acceptable condition of ties within 4 tie(s) of a single bad tie to be left:

☑ 4G/0M ☑ 3G/1M ☑ 2G/2M ☐ 1G/3M ☐ 0G/4M

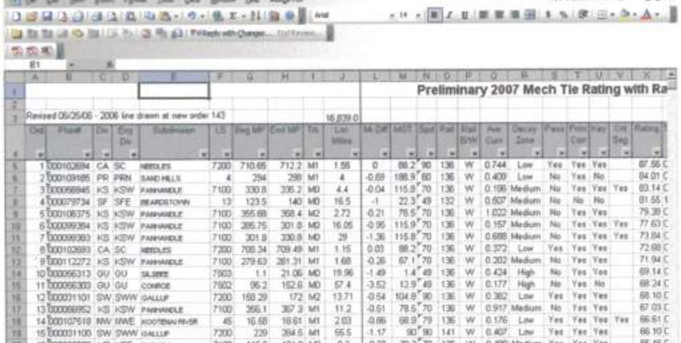
Notes: G = Good Tie, M = Marginal Tie

Check mark indicates an acceptable distribution of ties adjacent to a single bad tie

Prioritization

Accurate and complete tie condition information, such as provided by a detailed tie condition map, can be used to effectively set tie replacement budgets and prioritize tie replacement activities. One example of a prioritization approach, currently used by BNSF, calculates a Prioritization Index[5] for tie segments that forms the basis for which tie gangs can be authorized [7]. In addition to the total number of bad ties per mile in the segment, this Prioritization Index (also referred to as a Condition Index) incorporates other information that is relevant to defining the priority of a tie program to include Clustering, Annual Tonnage (MGT), Climate, traffic, time since last inspection, track quality, etc. The result is a Priority Rating for each proposed tie replacement segment, as illustrated in Figure 8, which can then be used as an objective basis to set tie programs using defined cut-off limits.

Figure 8: BNSF Tie Prioritization and Budgeting Report Using Prioritization Index [7]



Preliminary 2007 Mech Tie Rating with Ra

Revised 06/25/06 - 2006 line drawn at new order 143

16,639.0

Ord	Plan#	Div	Eng Div	Subdivision	LS	Beg MP	End MP	Trk	Lin Miles	M Diff	MGT	Spd	Rail	Rail B/W	Ave Curv	Decay Zone	Pass	Prim Corr	Key	CW Seg	Rating
1	000102694	CA	SC	NEEDLES	7200	710.65	712.2	M1	1.55	0	88.2	90	136	W	0.744	Low	Yes	Yes	Yes		87.56 C
2	000109185	PR	PRN	SAND HILLS	4	294	298	M1	4	-0.69	188.9	60	136	W	0.408	Low	No	Yes	No		84.01 C
3	000066845	KS	KSW	PANHANDLE	7100	330.8	335.2	M0	4.4	-0.04	115.8	70	136	W	0.196	Medium	No	Yes	Yes	Yes	83.14 C
4	000079734	SF	SFE	BEARDSTOWN	13	123.5	140	M0	16.5	-1	22.3	49	132	W	0.507	Medium	No	No	No		81.55 1
5	000106375	KS	KSW	PANHANDLE	7100	355.68	358.4	M2	2.72	-0.21	78.5	70	136	W	1.022	Medium	No	Yes	Yes		79.39 C
6	000099384	KS	KSW	PANHANDLE	7100	285.75	301.8	M0	16.05	-0.95	115.9	70	136	W	0.157	Medium	No	Yes	Yes	Yes	77.63 C
7	000099383	KS	KSW	PANHANDLE	7100	301.8	330.8	M0	29	-1.36	115.8	70	136	W	0.688	Medium	No	Yes	Yes	Yes	73.84 C
8	000102693	CA	SC	NEEDLES	7200	708.34	709.49	M1	1.15	0.03	88.2	70	136	W	0.372	Low	Yes	Yes	Yes		72.68 C
9	000112272	KS	KSW	PANHANDLE	7100	279.63	281.31	M1	1.68	-0.26	67.1	70	136	W	0.202	Medium	No	Yes	Yes		71.94 C
10	000056313	GU	GU	SILSBEE	7503	1.1	21.06	M0	19.96	-1.49	1.4	49	136	W	0.424	High	No	Yes	Yes		69.14 C
11	000056303	GU	GU	CONROE	7502	95.2	152.6	M0	57.4	-3.52	12.9	49	136	W	0.177	High	No	Yes	No		68.24 C
12	000031101	SW	SWW	GALLUP	7200	158.29	172	M2	13.71	-0.54	104.8	90	136	W	0.382	Low	Yes	Yes	Yes		68.10 C
13	000066952	KS	KSW	PANHANDLE	7100	356.1	367.3	M1	11.2	-0.51	78.5	70	136	W	0.917	Medium	No	Yes	Yes		67.03 C
14	000107519	NW	NWE	KOOTENAI RIVER	45	16.58	18.61	M1	2.03	-0.86	68.9	79	136	W	0.176	Low	Yes	Yes	Yes	Yes	66.61 C
15	000031100	SW	SWW	GALLUP	7200	229	284.5	M1	55.5	-1.17	90	90	141	W	0.407	Low	Yes	Yes	Yes		66.10 C
16	000066986	KS	KSE	EMPORIA	7100	115.6	124.8	M3	9.2	-0.37	30.3	79	136	W	0.409	Medium	Yes	Yes	Yes		65.16 C
17	000083224	KS	KSW	PANHANDLE	7100	236.2	243.56	M2	7.36	-0.39	67.1	70	136	W	0.716	Medium	No	Yes	Yes	Yes	65.07 C
18	000109826	SW	SWW	SELIGMAN	7200	425.5	448.25	M2	22.75	0.52	86.6	79	136	W	0.375	Low	Yes	Yes	Yes		64.47 1
19	000031106	SW	SWW	SELIGMAN	7200	329.1	362.3	M1	33.2	[illegible]	93.8	79	136	W	0.643	Low	Yes	Yes	Yes		64.25 1
20	000068871	CH	CHE	AURORA	3	142.3	171.4	M1	29.1	-2.06	55.8	60	112	W	0.923	Medium	No	Yes	Yes		64.13 C
21	000108848	CA	NC	BAKERSFIELD	7200	892.45	916	M0	23.55	-1.03	55.3	79	141	W	0.203	Low	Yes	Yes	Yes		64.04 C
22	000112601	KS	KSW	HEREFORD	7100	633.8	635.2	M2	1.4	0.06	93	70	136	W	0.960	Low	No	Yes	Yes		63.51 C
23	000069199	MT	MTS	DICKINSON	39	166.5	187.71	M0	21.21	-2.38	68.5	60	132	W	0.777	Low	No	Yes	No		62.26 1
24	000066980	TX	TX	RED RIVER VALLEY	495	197	208	M0	11	-0.35	59.8	60	132	W	0.386	Medium	No	Yes	No		62.01 C

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[5] *Developed and implemented by ZETA-TECH Associates, Inc.*

Gang Planning

In addition to providing immediate information for next year's program, accurate tie condition data also allow for the analysis of long-term (future) tie requirements on both a local and large scale level [5,6]. Using tie condition data in conjunction with tie degradation models allows for the calculation of a rate of tie degradation and a forecast of required tie gang cycle dates.

In all cases, availability of accurate tie condition data allows for more accurate tie replacement decision making, to include replacement of sufficient but not excessive ties, effective prioritization of locations where tie replacement is required, better tie budgeting, and more effective tie gang scheduling.

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RTA TieReport #4

Optimizing Tie Maintenance Using Track Strength Information

During the last several decades, the introduction and growing use of lateral track strength measurement techniques has led to a better understanding of the gage holding strength condition of track [1,2,3]. This in turn has led to the development of standards and procedures for monitoring track strength from inspection vehicles and identifying locations of potential weakness of the track structure [3,4]. It has also led to a better understanding of the potential for using these track strength data to determine tie replacement requirements and to better manage the tie replacement process [5].

A recent major study, directed by the Railway Tie Association and performed in conjunction with the Federal Railroad Administration, CSX Transportation, and ZETA-TECH Associates, Inc., examined the potential for optimizing crosstie upgrade and maintenance practices by using track condition information. Specifically, the focus of this study was to compare tie replacement strategies based on conventional visual inspection with strategies based on objective tie condition measurements. Thus, the existing visual inspection and tie replacement practices of CSX were compared to one based on measured track strength values, as taken by CSX's Track Geometry Car mounted Gage Restraint Measurement System (GRMS) [6]. A third set of replacement strategies, based on the TieInspect data collection and analysis system, was also examined [7].

This comparison was conducted on four test miles on CSX, near Washington, DC, all FRA Class 4 track with both freight and passenger operations (79 mph passenger speed). Each test mile had tie upgrade (major replacement) and tie maintenance activities based on one of the above defined approaches:

- Conventional visual inspection and tie selection
- GRMS-based tie selection[1]
- TieInspect-based tie selection

The actual number of ties installed as part of either the upgrade or maintenance activities is presented in Table 1 for each of the four miles and associated maintenance approaches.

Table 1: *Test Miles and Corresponding Upgrade/Maintenance Approaches*

MP	Upgrade	Upgrade Ties Installed	Maintenance	Maintenance Ties Installed
10	*TieInspect*	888	*TieInspect*	184
21	GRMS	878	GRMS	162
22	Conventional	838	Conventional	352
23	GRMS	356	Conventional	551

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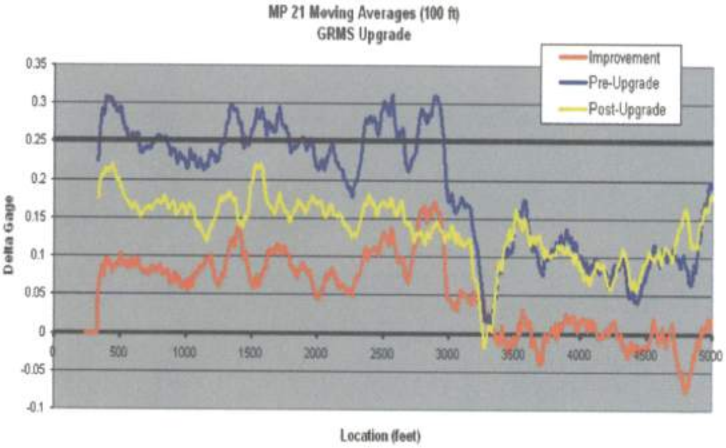
[1] *The GRMS location data were supplemented by tie-specific TieInspect data to allow for accurate location of specific ties.*

Tie Report #4: Optimizing Tie Maintenance Using Track Strength Information (continued)

The strength of the track was used as a measure of the track condition, both before and after tie replacement. The measurement used to represent the track condition (strength) was the GRMS-based Gage Widening Ratio (GWR), which is related to the amount of rail head lateral movement (gage widening) under the applied GRMS loading. Analysis of GRMS data showed that the average or mean GWR is representative of the track strength across each test zone (one mile each) and thus formed the basis for evaluation of tie replacement performance.

Figure 1 illustrates the effect of the tie replacement during the upgrade of one of the test miles (MP 21). As can be seen in this Figure, there was a distinct improvement in measured track strength (GWR), particularly in the first 3500 feet where the majority of the ties were installed.

Figure 1: *Improvement in Track Strength Due to Selective Tie Replacement*



By comparing the rate of track degradation, both before and after the upgrades, for the different test sections, the relative effectiveness of the upgrades (and maintenance cycles) could be evaluated. Table 2 summarizes the behavior of the two GRMS track upgrade sections as compared to the conventional upgrade section, looking at mean GWR after upgrade.

Table 2: *Post-Upgrade Comparison of GRMS vs. Conventional Tie*

	Mean GWR (in.)		Degradation Rate	
MP (Upgrade)	**May '04**	**June '05**	**in./yr.**	**Upgrade Ties**
21 (GRMS)	0.216	0.275	0.054	878
22 (Conv)	0.195	0.260	0.060	838
23 (GRMS)	0.184	0.237	0.049	356

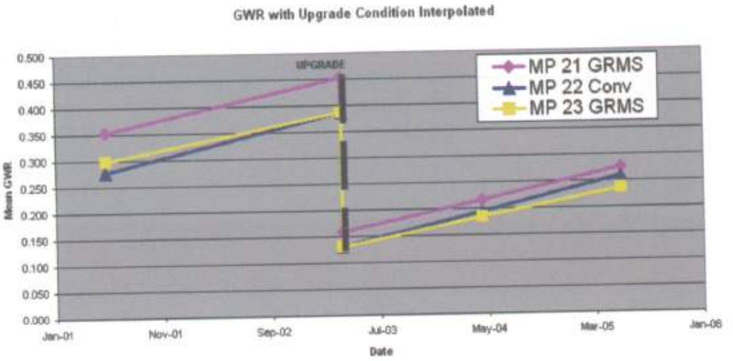
Installation

As can be seen in Table 2, the GRMS miles outperformed the conventional mile in the effectiveness of the tie replacement/upgrade as defined by the corresponding mean GWR degradation rate. The lowest degradation rate (best-performing track) corresponds to the GRMS upgrade mile (Mile 23) with the lowest number of ties installed; 356 vs. 838 for the conventional mile. Furthermore, examination of the GWR standard deviation shows that the GRMS miles had higher pre-upgrade standard deviations, which indicates a wider scatter of tie condition, but ended up with lower standard deviations (more uniform) after the upgrade. This illustrates the ability of the GRMS-based upgrade approach to provide a more uniform, stronger condition, based on track gage strength.

Tie Report #4: Optimizing Tie Maintenance Using Track Strength Information (continued)

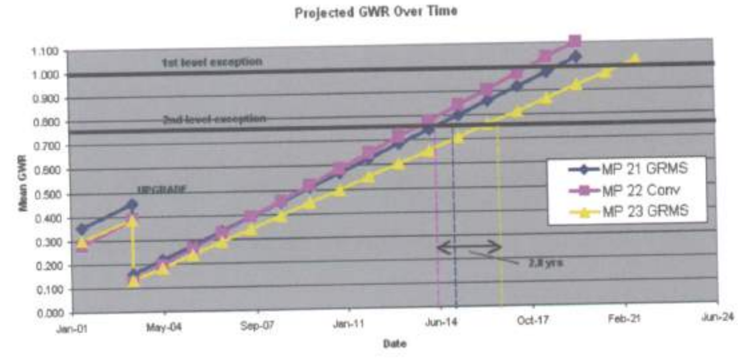
Figure 2 presents the relative behavior of the three test miles graphically. As can be seen in this Figure, the conventionally upgraded mile (Mile 22) started off (pre-upgrade) with the best gage strength, as defined by mean GWR, but was outperformed by the GRMS miles, particularly MP 23. This is in spite of the fact that MP 23 had 58% fewer crossties installed. The other GRMS mile, MP 21 (GRMS), registered the largest improvement in mean GWR, again, due to successful targeting of weak spots.

Figure 2: Mean GWR as a Function of Traffic and Upgrade



The effects of these relative degradation rates on the time it takes for the track to reach the GWR threshold levels was calculated and presented in Figure 3 below. Note, the threshold used is the FRA's second-level exception, which can be considered a maintenance limit of 0.75 inches. A GWR value between 0.75 and 1 inch represents a second-level exception and track speed must be set at the maximum allowed for class 3 track (*FRA Track Safety Standards Part 213, pg. 38*). A GWR reading of 1 inch or more represents a first-level exception and track speed is to be reduced to 10 mph (*FRA Track Safety Standards Part 213. pg. 37*). Noting the above, the conventional mile on average reaches a second-level exception 2.8 years earlier than the best-performing GRMS mile. This is a direct function of the higher degradation rate shown above. By averaging the two GRMS mile degradation rates and using the second-level exception threshold, it was seen that the GRMS upgrade approach provided an additional 2.1 years to reach the threshold. Extending this improvement to overall tie life, and noting average tie life for this location was 23 years[2], this represents a 9.1% extension in tie life.

Figure 3: Projected GWR Over Time



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[2] *Average tie life was calculated using the RTA SelecTie Model II, for the track and operating conditions of the Metropolitan Sub.*

Tie Report #4: Optimizing Tie Maintenance Using Track Strength Information (continued)

In addition to the GRMS vs. conventional tie installation comparison, MP 10 employed the *TieInspect* system and replacement logic for both the upgrade and maintenance cycle. Inspectors looked for all tie failure mechanisms including the ties' ability to hold line and surface, splitting, breaks, plate cutting, plate movement, wheel cuts, decay or hollowness, and the ability to hold cut spikes. The inspections provided a full condition map and allowed for strategic tie replacement. Comparing this approach, using the *TieInspect* tie replacement logic and data, to the conventional CSX approach, tie requirements were reduced by 9.8% using the *TieInspect* system and replacement logic.

Maintenance ties were installed in October 2005 with a post-maintenance GRMS run conducted in April 2006. Similar to the upgrade findings, the GRMS maintenance mile outperformed the conventional maintenance miles in average GWR improvement, with much fewer ties installed. Table 3 shows the direct comparison of average GWR improvement (From June 2005 to April 2006) and the number of ties installed for the maintenance cycle. The GRMS replacement methodology was once again successful in targeting and reducing GWR peaks.

Table 3: GWR Maintenance Results

MP	Maintenance	Average GWR Improvement	Ties
21	GRMS	0.046	162
22	Conventional	0.030	352
23	Conventional	0.019	551

In total, over a 5-year test period, 4,209 crossties were installed in this study. The GRMS miles outperformed the conventional mile in the effectiveness of the tie replacement/upgrade as defined by the corresponding mean GWR degradation rate. The GRMS-based tie replacement generated a stronger track structure than conventional techniques, while using fewer ties, using its more targeted tie replacement. The GRMS test miles also showed a lower degradation rate with a lower number of upgrade ties installed; as compared to the conventional mile, with an overall extension in tie life. The GRMS miles had the lowest total ties (upgrade plus maintenance) installed (907 vs. 1,190) yet provided a more uniform, superior condition, based on the lateral gage strength of the track. An economic analysis of the benefits of strategic tie replacement showed that using a GRMS- or TieInspect-based tie replacement strategy can reduce system tie costs on the order of $27 to $47 million annually.

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RTA TieReport #5

Material Properties of Wood Crossties

Wood is an extremely versatile and effective material for use as a railroad track crosstie. However, the key properties of wood will vary with class of wood type. In order to allow for the potential use of a broad range of wood types, the wood tie properties presented here have been divided into six (6) categories of wood as presented in Table 1.

Table 1: Tie Life Factors

Tie Category
Oak
Northern Mixed Hardwoods
Southern Mixed Hardwoods
Southern Yellow Pine (SYP)
Softwoods
Douglas Fir (DF)

The material properties presented herein are based on a collection of material property data, to include data from standardized tests on small clear specimens and full tie test data (with adjustment to compensate for wood category differences) and are consistent with those presented in the Manual for Railway Engineering of the American Railway Engineering and Maintenance of way Association (AREMA) [Reference 1].

Table 2 presents the full set of wood property values as follows:

1. Dimensions are for a standard main line wood crosstie (in inches) and are based on the AREMA specification [1] that allows a 1/4 inch reduction in width and depth. Unit of measure is inches.

2. Volume is defined as the total amount of space occupied by the crosstie and is calculated based on the dimensions shown. Unit of measure is cubic feet.

3. Density is mass per unit volume and is derived from testing of small clear specimens of wood using ASTM procedure D-143 and U.S. Forest Service data. Actual whole tie values may differ [1]. Unit of measure is pounds per cubic foot.

4. Weight is the density multiplied by the volume. Unit of measure is pounds.

5. Moment of Inertia (MOI) is a measure of the rectangular shape of the crosstie and is calculated around its neutral axis calculated based on the defined dimensions and a rectangular cross-section. Unit of measure is inches^4.

6. Section modulus is a measure of the shape of the crosstie and is calculated by dividing the MOI by the greatest distance of the section from the neutral axis and is calculated from dimensions and rectangular cross-section. Unit of measure is inches^3.

7. Modulus of Elasticity (MOE) is the rate of change of unit stress with respect to unit strain under uniaxial loading within the proportional (or elastic) limits of the material. It is a measure of the stiffness of the crosstie, i.e. the relationship between load (stress) and deflection (strain). Values derived from testing of small clear specimens of wood using ASTM procedure D-143 and U.S. Forest Service data. Actual whole tie values may differ [1]. Unit of measure is pounds per square inch.

8. Modulus of Rupture (MOR) is a measure of the maximum load-carrying capacity or strength of the crosstie and is defined as the stress at which the material breaks or ruptures (based on the assumption that the material is elastic until rupture occurs). Values derived from testing of small clear specimens of wood using ASTM procedure D-143 and U.S. Forest Service data. Actual whole tie values may differ [1]. Unit of measure is pounds per square inch.

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[1] *Eastern and Western Softwoods*

Tie Report #5: Material Properties of Wood Crossties (continued)

9. Rail Seat Compression Test is a measure of the crushing strength or load-carrying capacity of the crosstie at the rail seat (under the tie plate) and is defined as load per unit area at which compression of the wood occurs. Values derived from testing of small clear specimens of wood using ASTM procedure D-143 and U.S. Forest Service data. Actual whole tie values may differ [1]. Unit of measure is pounds per square inch.

10. Material Surface Hardness (Janka Ball) Test is a measure of the surface hardness of the crosstie and is defined as load necessary to push a two-inch-diameter steel ball 0.25 inch into the tie surface. Values derived from testing of small clear specimens of wood using ASTM procedure D-143 and U.S. Forest Service data. Actual whole tie values may differ [1]. Unit of measure is pounds.

11. Static Bending Strength is a measure of the strength of the crosstie and is based on a load deflection test carried out to failure of the wood material (test similar to C-Stiffness Load/Deflection test, shown in 12 below). Unit of measure is inch-kips.

12. C-Stiffness Load Deflection is a measure of the flexibility of the crosstie and is based on a load deflection test in which a load of 10,000 lbs is applied to the center of the crosstie which is supported from below at two points 60 inches apart. The deflection is measured. Unit of measure is inches.

17. Single Tie Lateral Push Test is a measure of the lateral resistance of a single crosstie in ballasted track and is representative of the relative resistance of the track to lateral movement in the ballast. Values are based on field tests taken by U.S. Department of Transportation and are based on "minimum" value for consolidated track adjusted to account for differences in density (weight) of the different crosstie wood materials. Unit of measure is pounds.

Table 2: Material and Tie Strength Preliminary Values

		Oak	Northern Mixed Hardwoods	Southern Mixed Hardwoods	Southern Yellow Pine	Softwood	Douglas Fir
1. Dimensions	nominal						
Length (in)	102	102	102	102	102	102	102
Width (in)	9	8.75	8.75	8.75	8.75	8.75	8.75
Depth (in)	7	6.75	6.75	6.75	6.75	6.75	6.75
2. Volume (ft^3)		3.49	3.49	3.49	3.49	3.49	3.49
3. Density (pcf) [lbs/ft^3]		68.4	65.3	58.9	62.1	53.4	59.7
4. Weight (lbs)		238	227	205	216	186	208
5. Moment of Inertia (in^4)		224	224	224	224	224	224
6. Section Modulus (in^3)		66.4	66.4	66.4	66.4	66.4	66.4
7. Modulus of Elasticity (MOE)	10^6	1.22	1.28	0.95	1.49	1.07	1.60
8. Modulus of Rupture (MOR) in psi	72 F	8392	8893	6810	10508	7144	9299
9. Rail Seat Compression Test (psi)		670	418	523	632	430	594
10. Material Surface Hardness Test (pounds)	Janka Ball	883	690	587	565	371	556
11. Static Bending Strength (in-kips)		558	591	453	698	475	618
12. Stiffness; Load/Deflection (inches)		0.165	0.157	0.212	0.134	0.187	0.125
17. Single tie lateral push test (lbs)		1950	1900	1800	1850	1700	1800

[a] *50% lateral resistance was varied linearly as a function of the weight of the ties, using mixed hardwoods as the base reference. To account for the non-weight-related component of lateral resistance (due to side and end effects that do not change with weight) only 50% of the lateral resistance was varied with weight, with the remaining 50% held constant.*

REFERENCES

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RTA TieReport #6

Performance Requirements for Wood Crosstie Fasteners: Part I, Track Strength

The performance requirements for a freight railway elastic fastener system can be divided into two broad categories [1, 2, 3]:

- Track strength requirements
- Track performance requirements

The track strength requirements relate directly to the ability of the fastener/tie system to adequately and effectively perform its functions under the defined traffic and environmental loading conditions. This is the "strength", or load-carrying capacity, of the system, and includes the full range of track loadings: longitudinal; lateral (both gage widening and lateral track); and vertical.

The track performance requirements refer to those factors (often non-quantifiable) that relate to the ability of the system to accommodate itself to railroad practices and operations. These include system life requirements, maintenance considerations, economic and operating considerations.

This Tie Report will focus on the first category, the track strength requirements. In general, it is necessary to first define the load environment under which the fastening system must perform. Based on this load environment, the actual "strength" requirements can then be defined. As used here, the fastener "strength" or load-carrying capacity refers to the fastener's ability to carry the vehicle and environmental loading without "excessive" deflection or deformation.

There are three basic areas of fastener strength performance, corresponding to the three principal loading directions [1]. These are:

A. Longitudinal Strength
The resistance of the fastener system to longitudinal loading, both mechanical and environmental (thermal).

B. Lateral Strength
The resistance of the fastener system to lateral loading. From the fastener perspective, this consists primarily of gage widening resistance, the resistance of the fastener system to static or dynamic gage widening.

C. Vertical Strength
The resistance of the fastener system to vertical loading. This is to include the ability of the fastener to attenuate dynamic impact loading and to resist uplift forces.

For each of these strength areas, a performance requirement, defined as an ability of the fastener system to resist external loading, can be specified, either in the form of maximum allowable load or as a maximum allowable deflection for a given level of loading.

It should be noted that the strength characteristics of the fastener systems under long-term traffic loading will degrade after time and/or traffic. Thus, any final performance specification must take this degradation behavior either by defining a single set of performance values that the system must always exceed or alternately by defining both a "new" strength value and an "old" strength value, reflecting the requirements in both states. Note: any such "old" value" must be based on the life of the fastener/tie system, which is of the order of 20,000,000 to 40,000,000 loading cycles, (where each cycle represents a single passing axle).

Tie Report #6: Performance Requirements for Wood Crosstie Fasteners (continued)

A. Longitudinal Strength

Longitudinal fastener strength is the ability of the fastener system to provide longitudinal restraint to the rail and prevent rail movement or creepage under all loading conditions. As noted previously, longitudinal loading can be due to train action, such as train or engine braking and/or acceleration, and to environmental action, specifically the variation in temperature, both rail and ambient.

The function of the fastener is to provide longitudinal restraint to prevent any movement of the rail with respect to the ties. Under mechanical loading, this is simply the case of each fastener picking up a portion of the load, up to its maximum capacity, until the entire longitudinal load is restrained. In the case of thermal loading, the distribution of longitudinal consists of two distinct loading zones, the two end zones or "breathing" zones in which longitudinal movement of the rail takes place and the center "constrained" zone in which no longitudinal movement occurs. Therefore, the fastener longitudinal restraint is most critical in these end or "breathing" zones. These zones are at the ends of the Continuously Welded Rail (CWR) strings or at each side of a rail gap, such as occurs during a rail pull-apart or break. Good longitudinal restraint strength is required to prevent development of an excessive rail end opening or "gap" at any discontinuity in the CWR or in the event of a pull-apart or rail break where the break or gap must be controlled to avoid an excessive gap in the rail.

AREMA specifies 2400 lbs. (2.4 Kips) fastener restraint for passing of the fastener longitudinal restraint test and 2500+ lbs. (2.5+ Kips) in its rail fastening system performance table, which is included in Table 1 below [4]. For wood ties at 19.5-inch spacing, this corresponds to a longitudinal restraint of the order of 1500 lb./ft. Most elastic fastener systems meet or exceed these limits.

In the case of wood tie/cut spike/rail anchor system, rail anchors have longitudinal restraint values (new) of the order of 5000+ lbs. (AREMA requires a minimum of 5000 lbs.). This, when placed in a conventional box anchor, every other tie configuration, corresponds to a longitudinal strength of 1500 lbs./ft., corresponding to the elastic fastener values.

B. Lateral Gage Strength

As noted earlier, lateral gage strength refers to the ability of the fastener system to limit the amount of gage widening, both static and dynamic. This is an important parameter, since a key fastener function is to maintain track gage under loading, i.e., to prevent dynamic gage widening. Gage widening is defined to be any increase in the standard gage of the track structure.

Gage widening is associated with three distinct mechanisms as follows:

A. **Rail wear**; abrasive wear on the railhead, particularly the gage face of the high rail. Rail wear is outside the scope of the fastener system, although it is slightly affected by fastener stiffness.

B. **Rail translation**; rigid body movement of the rail, without any rotation, i.e., lateral movement of the base of the rail.

C. **Rail rotation**; rotation of the rail about its longitudinal axis, i.e., overturning (Figure 1).

From the point of view of track strength, modes B and C are of concern.

Figure 1: Rail Rotation Under Lateral and Vertical Loading

Tie Report #6: *Performance Requirements for Wood Crosstie Fasteners (continued)*

Fastener strength is generally defined in terms of deflection under loading, under defined lateral and vertical wheel/rail loading, in which case the combined deflection (B + C) is considered [3].

Table 1 presents several parameters that relate directly to the lateral gage strength of the fastener/tie system. Note that these are a function of the wood type as well as the fastener, since they represent the strength characteristics of the combined wood tie/fastener system. These include:

- Lateral rail restraint, defined by AREMA [4] to be a measure of the load necessary to move (B) or rotate (C) the rail section perpendicular to the running axis of the rail.
- Fatigue L/V test, defined by AREMA [4] to be a repeated load test conducted on the fastening system to determine its resistance to rail movement under repeated load. This test looks at the long-term performance and degradation of the tie/fastener system.

Tests comparing the gage widening strength (deflection under load) have shown that the lateral gage strength of new hardwood ties with elastic fasteners are comparable to (and in some cases greater than) the strength of concrete ties with the same elastic fasteners [5].

Table 1: *Properties of Rail Fastener Systems for Wood Ties*

	Oak	Northern Mixed Hardwoods	Southern Mixed Hardwoods	Southern Yellow Pine	Softwood	Douglas Fir
Longitudinal Rail Restraint (kips)	2.5+	2.5+	2.5+	2.5+	2.5+	2.5+
Lateral Rail Restraint (kips)	18-30	18-30	18.3+	18.3+	18.3+	18.3+
Fatigue L/V Tests	0.5-4.0	0.5-4.1	0.5-4.2	1.2	1.2	1.2
Spike/Screw Pullout Test (lbs)	5,000-6,600+	5,000-6,600+	5,000-6,600+	3,000-5,000	3,000-5,000	3,000-5,000
Impacts on Fastening System (lbs/in^2)	1,000-4,000	1,000-4,000	1,000-4,000	1,000-4,000	1,000-4,000	1,000-4,000

C. Vertical Strength

Vertical strength refers to the ability of the tie/fastener system to respond to loading in the vertical plane. [It includes the ability of the fastening system to withstand and attenuate high levels of dynamic loading and for wood tie track, to resist pull-out of the fasteners during uplift of the track (as a railroad wheel passes by).

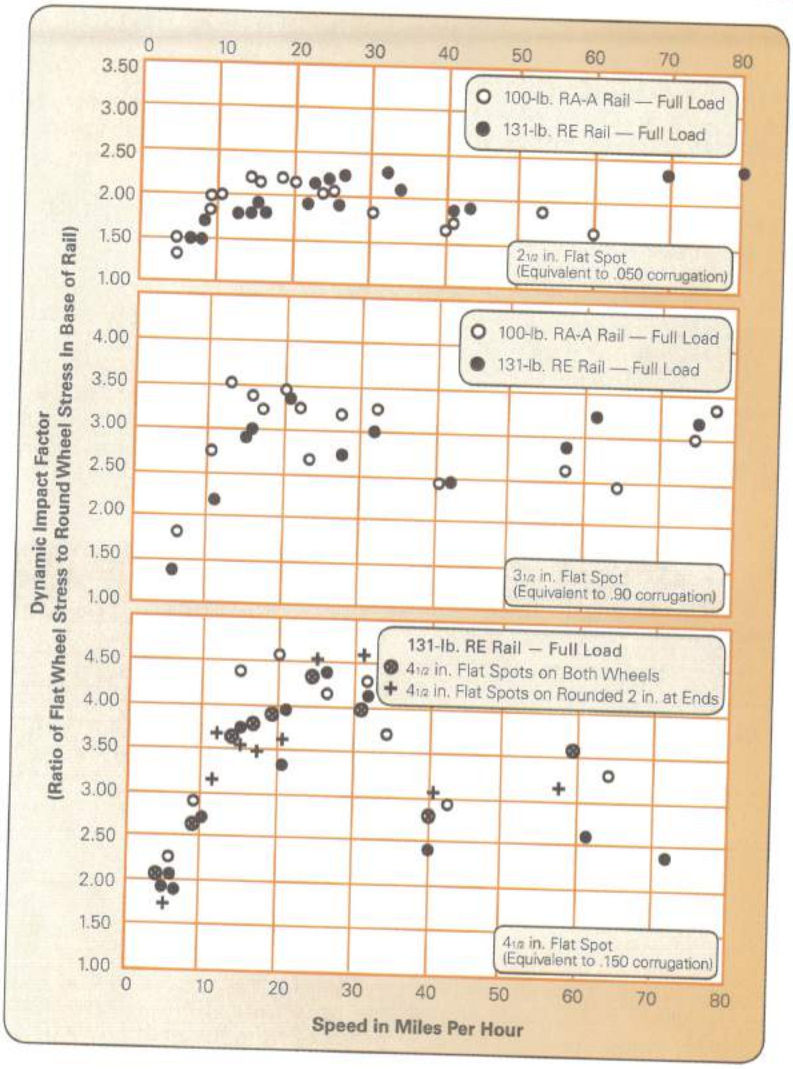
Traditional analyses of vertical dynamic effects (i.e., speed effects) calculate speed factors of the order of 1.6 times the static wheel loads at speeds of 60 mph (based on the AREMA speed effect formula [4]). Defects on the rail surface (corrugations, engine burns, battered welds), rail joints, or imperfections in the wheel tread, i.e., flats or out-of-round wheels, can magnify the vertical loads by factors of 2 to 4 [6], though recent measurements using wheel impact detectors have found factors of 5 and higher (Figure 2 [6]).

Table 1 presents several parameters that relate directly to the vertical strength of the fastener/tie system. Note, as in the case of the lateral strength, these parameters are a function of the wood type as well as the fastener, since they represent the strength characteristics of the combined wood tie/fastener system. These include:

- Spike/Screw Pullout Test defined by AREMA [4] to be the force required to remove the fastener (screw or spike) from the tie. A measure of the vertical strength of the fastening system.
- Impact on Fastening System. Defined by AREMA [4] to be the ability of the rail seat pad (or wood tie) to attenuate the effect of wheel and rail impact loads on ties.

Tie Report #6: Performance Requirements for Wood Crosstie Fasteners (continued)

Figure 2: Dynamic Impact Factor Associated Wheel Flats [6]



**Note: Many of the key properties of the fasteners will vary with wood type. In order to allow for the potential use of a broad range of wood types, the wood tie properties have been divided into six (6) categories of wood as presented in Table 1[4]. The fastener properties presented in Table 1 are consistent with those presented in the Manual for Railway Engineering of the American Railway Engineering and Maintenance of way Association (AREMA) [4].*

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RTA TieReport #7

Migration of polycyclic aromatic hydrocarbons from railway ties into wetlands

Dr. Kenneth M. Brooks

BACKGROUND

In 1996, Commonwealth Edison Company replaced unserviceable creosote-treated railway ties supporting a 45-year-old spur line serving a coal-fired power plant in Will County, Illinois. The line runs through the Des Plaines River wetland, which is home to the Hine's emerald dragonfly, an endangered species. The U.S. Fish and Wildlife Service expressed concern that polycyclic aromatic hydrocarbons (PAH) would migrate from the railway ties into the wetland in amounts sufficient to adversely affect the dragonfly.

What PAH concentrations would be of concern?

Creosote is a distillate of coal tar containing about 85% PAH. This family of compounds is created by the incomplete combustion of organic matter. They are ubiquitous in all environments. Common sources include electrical power generation, asphalt paving, vehicle exhaust, forest fires, home heating using wood,etc. They can enter the environment via direct input such as dripping automotive crankcases and oil spills. Bradley et al. (1994) reported mean PAH concentrations of 21.9 ppm alongside roadways in the U.S. cities of Boston, Providence and Springfield. The source of these PAH is most likely automobile exhaust, crankcase oil, abraded tire particles, asphalt, etc. Urban areas away from pavement had concentrations of 8.3 ppm. Similarly, Wild and Jones (1995) reported that urban soils in the United Kingdom contained 4.2 ppm PAH and forest soils 4.8 ppm. Atmospheric deposition of PAH-laden smoke particles and molecules of evaporated PAH are the sources of these widespread background concentrations.

Polycyclic aromatic hydrocarbons have been present on earth since there was life and plants and animals have evolved physiological adaptations that break them down and/or eliminate them. The breakdown products of high molecular weight PAH can be carcinogenic and at high concentrations PAH can be acutely toxic. Based on a literature review, Brooks (1996) concluded that dragonflies are not among the more sensitive animals to PAH.

All PAH are hydrophobic and they bind to other organic compounds and inorganic particulates reducing their bioavailability to living organisms. Sediment quality criteria for PAH are therefore tied to the organic carbon in sediments. Higher PAH concentrations are allowed with increasing sediment carbon. Sediments in the Des Plaines River wetland are organically rich with measured total organic carbon (TOC) concentrations of 11.91%. Numerical criteria have been proposed for the U.S. EPA for three of the 16 priority pollutant PAH and the sum of these three at 11.91% TOC is 110.8 parts per million (ppm) on a dry sediment basis. Criteria for the other 13 PAH have not been proposed by EPA. Washington State (WDOE, 2002) is in the process of developing freshwater sediment standards and has defined a Consensus-Based Standard described as a Probable Effects Concentration above which there is a demonstrated increase in toxicity associated with increasing concentrations of contaminants. For Total PAH (TPAH), this standard is 23 ppm dry sediment (not normalized to TOC). The Consensus Sediment Quality Benchmark recommended by Swartz (1999) for the 13 included PAH has been chosen for evaluating biological responses in this study. At 11.9% TOC, this benchmark is 46.8 ppm PAH.

Tie Report #7: *Migration of polycyclic aromatic hydrocarbons from railway ties into wetlands (continued)*

What concentrations of PAH were observed in the wetland?

Brooks (1996) examined PAH concentrations in sections of the track supported by 45-year-old ties and sections where unserviceable ties had been replaced with new ties. Three transects were examined in each of these treatments at distances of 0.25, 0.50 and 1.0 meter from the track's ballast and compared with 8 samples collected at wetland reference locations. No PAH were observed at 15 of the 18 samples collected near the railway ballast. However, one of three transects adjacent to the old tie section showed moderate contamination of 13 to 14 ppm PAH at 0.25 and 0.50 meter (10 and 20 inches from the ballast). A single sample, collected 10 inches from the ballast adjacent to the new tie section, contained 5.1 ppm PAH.

Requirement for further studies.

Based on the unknown effects of PAH on Hine's emerald dragonfly, and the fact that 3 of the 18 samples had slightly elevated concentrations of PAH, the U.S. Fish and Wildlife Service requested that creosote-treated ties not be used where the spur crosses habitat used by the dragonfly. The U.S. Army Corps of Engineers (USACE) conditioned Commonwealth Edison's 404 permit to require the use of untreated railway ties and required a study, to be completed within five years, to examine PAH migration from used creosote-treated railway ties into adjacent wetlands.

THE RAILWAY TIE MESOCOSM STUDY

The study required by the USACE was undertaken in 1998 and completed in 2000 using protocols approved by the U.S. Fish and Wildlife Service including strict quality assurance requirements. The study created a mesocosm wetland in May of 1998 that mimicked the area where the railway passes through the Des Plaines wetland. This included lining of three excavations with impermeable surfaces; providing a subsurface source of water to mimic the wetland's hydrology; placement of wetland soils from the Des Plaines wetland; and placement of three sections of railway ties on ballast constructed in a manner identical to the actual line (Figure 1). The three treatments included a section of old ties, a second section of new ties and a third section with untreated oak ties. Each of the sections was isolated from the others and great care was taken to prevent contamination during construction and sampling. Wetland hydrology and soils created an environment in which a rich wetland plant community developed in areas outside the ballast (Figure 1).

Figure 1: *Railway tie study mesocosm as it appeared in November 1998. Three treatments included new and used creosote-treated railway ties plus untreated control ties. The vegetation community growing within the constructed wetland area adjacent to the ballast is dominated by wetland species.*

Tie Report #7: Migration of polycyclic aromatic hydrocarbons from railway ties into wetlands (continued)

Migration of creosote into the limestone ballast.

Samples of the limestone ballast were collected prior to placement of the ties (baseline); ten days following placement; and quarterly thereafter until November of 1999. Ballast was evaluated at distances of 5 cm (2 inches), 20 cm (8 inches) and 30 cm (12 inches) from the faces of each of the three ties in each mesocosm. Little PAH was observed in ballast ten days after placing the ties. However, in August of 1998, ballast PAH concentrations were 1,052 ± 773 ppm at distances < 8 inches from the new ties. As seen in Table 1, ballast PAH declined significantly during the fall and early winter. The downward trend continued through winter and all samples were <1.0 ppm at the end of May 1999 (371 days post-construction). Ballast PAH concentrations remained <1.0 ppm during the second summer of sampling and in the final samples collected on November 24, 1999 after 555 days of study. At the end of the study (Day 555), core samples were retrieved from the ballast at 10 cm intervals to a depth of 80 cm. Ballast PAH concentrations were <1.0 ppm at all depths with no indication of any downward PAH migration. These results show that creosote migrated from newly treated railway ties during the first summer of exposure, but that concentrations declined quickly in fall. A similar increase was not observed from the weathered ties – nor was it observed from the newly treated ties in their second summer.

Table 1: Concentrations of polycyclic aromatic hydrocarbons observed in railway right-of-way ballast at distances of five, 20 and 30 cm from new creosote-treated railway ties and untreated ties on November 18, 1998, 184 days following tie placement. All values are in micrograms total PAH/g dry sediment (ppm). The detection limit was used as a minimum value for each compound.

Date	Matrix	Mesocosm	Distance	Mean TPAH	STDEV	95% Confidence
11/18/98	Ballast	Untreated	5	0.661	1.145	1.295
11/18/98	Ballast	Untreated	20	0.000	0.000	0.000
11/18/98	Ballast	Untreated	30	0.000	0.000	0.000
11/18/98	Ballast	New	5	54.561	80.740	91.364
11/18/98	Ballast	New	20	32.928	50.529	57.178
11/18/98	Ballast	New	30	8.782	3.218	3.641
11/18/98	Ballast	Weathered	5	1.082	1.874	2.121
11/18/98	Ballast	Weathered	20	0.088	0.152	0.172
11/18/98	Ballast	Weathered	30	1.489	2.578	2.918

Migration of PAH from ballast into wetland sediments.

Limestone ballast does not provide habitat for plants or animals and the real concern is for PAH that might migrate from the ballast into adjacent wetland areas that support numerous species. Triplicate wetland sediment samples were collected at distances of 0, 25, 50 and 75 cm from the edge of the ballast in each treatment and analyzed for 16 parental PAH on each sampling day. Figure 2 summarizes the total concentration of PAH in wetland sediments. Highest mean concentrations of 4.2 ppm were observed in the untreated tie treatment on 5/24/1999. One sample from the new tie treatment contained 3.95 ppm on day 463 and a single sample from the weathered tie mesocosm contained 3.4 ppm on day 555. It should be noted that all of these values include the sum of the detection limits for the 16 compounds (0.64 ppm). The presence of the highest concentrations in the untreated tie mesocosm suggests a potential for accidental contamination despite the use of gloves and booties dedicated to each treatment on each sampling day. These results indicate that creosote-derived PAH can migrate from ballast to adjacent wetlands but that the resulting concentrations will rarely exceed 2 ppm and the resulting concentrations were not statistically significantly different as a function of distance, treatment or day of sample collection.

Tie Report #7: *Migration of polycyclic aromatic hydrocarbons from railway ties into wetlands (continued)*

Figure II: *Categorized Plot for Variable: MEANTPAH*

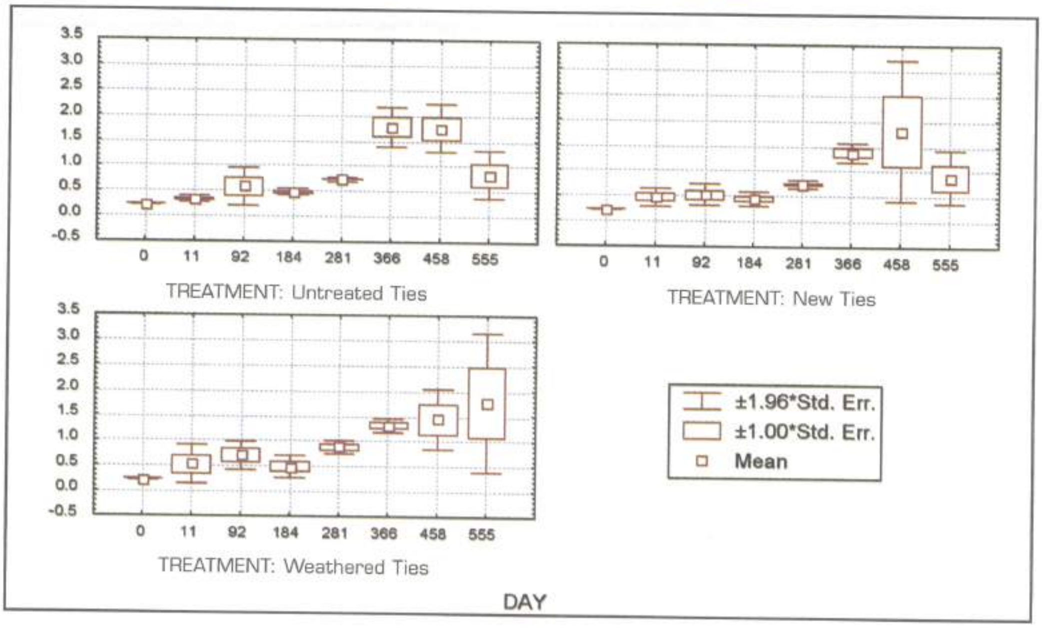

Figure II: *Box and whisker plots describing the significant (Anova, $p = 0.000$) differences in mean ΣPAH concentrations in sediments as a function of time following placement of untreated oak ties and newly treated or weathered oak ties preserved with creosote.*

PAH in stormwater.

Surface water was collected from each mesocosm on seven sampling dates. Polycyclic aromatic hydrocarbons were not detected in any of these samples on any date excepting the final sample when nanogram/L quantities of PAH were detected in all three mesocosms. The toxicity of these samples was assessed using the sum of toxic units method described by Swartz et al. (1995), who recommended a sum of toxic units (ΣTU) benchmark of 0.186 as protective of all aquatic resources exposed to waterborne PAH. The November 1999 results indicated a ΣTU = 0.059 for the untreated ties; 0.075 for the new ties; and 0.104 for the weathered ties – suggesting no potential toxicity.

Biological assessment.

The low concentrations of PAH observed in stormwater on the last day of the study did not approach the ΣTU benchmark proposed by Swartz et al. (1995) and no adverse effects can be anticipated in association with this route of exposure. Of the 234 sediment samples analyzed in this study, 142 had PAH concentrations <1.0 ppm and only two samples exceeded 4.0 ppm. None of the samples exceeded the Swartz (1999) benchmark of 46.8 ppm in 11.9% TOC sediments. The two samples higher than 4.0 ppm were chosen for an evaluation of the toxicity of individual compounds. One of the samples was from the weathered tie mesocosm (6.26 ppm) and the other from the newly treated tie mesocosm (9.83 ppm). The results of computing the sum of toxic units at the mean sediment TOC for each compound showed that no individual PAH or their sum exceeded the toxic unit threshold below which no effects can be anticipated in any species. The ΣTU for the 6.26 ppm weathered tie sample was 0.122 and it was 0.198 for the new tie sample. Both values are less than 20% of the benchmark ΣTU = 1.0. Also note that none of the samples approached any of the previously described regulatory benchmarks for PAH. These results indicate that the small amounts of PAH observed migrating from the railway ballast into the adjacent wetland posed no threat to any living organism.

SUMMARY AND CONCLUSIONS

Brooks (1996) assessed the potential impact of this railway right of way on Hine's emerald dragonfly (*Somatochlora hineana*) and concluded that, based on the limited data available at that time, "There was no indication that the past use of creosote ties, or their current replacement (new ties) had compromised the biological integrity of wetland plants or animals, including *Somatochlora hineana*. The completion of the River South PAH study (Brooks, 1997) and these results have added significantly to the database upon which the biological effects associated with creosote-treated railway ties can be evaluated. The following conclusions are substantiated by the results presented in these reports:

- Small amounts of creosote-derived PAH will likely migrate from newly treated railway crossties into supporting ballast during the summer of the first year. In this study, this pulse was not observed during the second summer. Site-specific behaviors will depend on the wood species, creosote retention, solar insolation and ambient air temperatures.

- Significant quantities of PAH did not migrate downward into the railway ballast.

- Based on PAH concentrations observed in the untreated tie treatment, it appears that atmospheric deposition of PAH contributes much of the observed background to Des Plaines River wetland sediments.

- Small amounts of PAH migrated from the ballast into adjacent wetlands during the summer of the second year of study. The PAH spectrum in these samples and a comparison of PAH concentrations in the untreated mesocosm with the creosote treatments suggests that ~0.3 ppm of this loading was associated with creosote. The observed increases were not statistically significant as a function of distance, treatment or day of the study.

- PAH were detected in one of 16 water samples.Those samples were collected on the final day of the study. The detected PAH concentrations were very low and an assessment using the sum of toxic units described by Swartz et al. (1995) indicated that none of the samples approached the benchmark recommended by those authors for the protection of aquatic life.

- The PAH concentrations observed in the highest sediment samples collected in the new and weathered tie mesocosms are not predicted to be toxic using the consensus sediment benchmark methodology of Swartz (1999) and no adverse biological effects can reasonably be predicted in association with the use of new or weathered railway ties in this environment.

There are many sources of PAH associated with railway transportation systems. These include diesel exhaust, lubricating oils, cargo (coal and oil) and herbicides. A mesocosm study was designed to minimize these confounding sources of PAH and to focus on those PAH associated with creosote-treated railway ties. These results suggest that seasonally variable atmospheric deposition of PAH contributes a significant portion of the background observed throughout the Des Plaines River wetland. It also appears that on average, the use of creosote-treated railway ties may add an additional 0.3 ppm PAH within half a meter of the toe of railway ballast.

Tie Report #7: Migration of polycyclic aromatic hydrocarbons from railway ties into wetlands (continued)

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RTA TieReport #8A

Tie Usage Index for Matching Wood Performance and Operating Conditions

The matching of wood species to specific railroad operating and environmental conditions allows for better use of different wood species and expanded availability of timber sources for use as wood crossties. Currently, several North American railroads use a very limited form of species segregation, to match wood performance and operating and environmental conditions. In order to build on this limited and subjective application, the Railway Tie Association sponsored a program to develop an objective Tie Usage Index that can be used to assist railroads in defining usage environments and matching the usage environment (both environmental and mechanical) with wood type and performance (e.g., species). This in turn provided a basis for defining species as a function of service environment and geographical location.

The Tie Usage Index is based on a set of specific numerical criteria ("indices") that can be used to define where different timber species can be installed. The Tie Usage Index includes the following specific behaviors and effects:

- Susceptibility to environmental decay, such as defined by a decay hazard index
- Susceptibility to mechanical damage such as defined by curvature and annual traffic density (annual MGT) and grade.

The resulting Tie Usage Index is a combination of these parameters and allows for the development of performance thresholds and the linking of these thresholds to specific wood species, preliminary values of which were presented in earlier RTA reports [1,2].

Development of Tie Usage Index

In order to address the two broad categories of crosstie degradation noted above, environmental decay and mechanical damage, the Tie Usage Index (TUI) was divided into two parts, with one part corresponding to the environmentally related degradation (the Environmental Decay Index) and the second part corresponding to the mechanically related degradation (Mechanical Damage Index). These two indices then combined to provide a single Tie Usage Index.

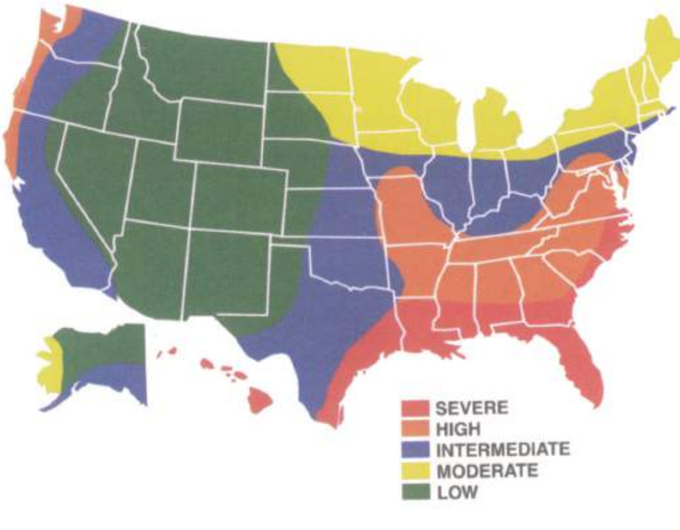


Figure 1: Deterioration Zones of U.S.

Tie Report #8A: Tie Usage Index for Matching Wood Performance and Operating Conditions (continued)

Environmental Decay Index
The environmental decay index was developed based on several studies, including a decay risk analysis for timber crossties by geographic region based on the U.S. Department of Agriculture [3] and the wood decay map developed by the Rural Electrification Administration for utility poles and incorporated into the American Wood Preservers' Association (AWPA) standards for Preservative Treatment of Poles (C-4) [4]. This latter map, which is presented in Figure 1, has five zones. Based on the referenced studies, a five-level wood tie Environmental Decay Index was developed as presented in Figure 2.

Mechanical Damage Index
For the case of mechanical damage or deterioration, significant research has been performed over the years on the relationship between wood tie life and key traffic and operating parameters. References 1 through 2 cite several studies that define key parameters that affect mechanical degradation of timber crossties. Recent research sponsored by the Railway Tie Association [5,6] has led to the development of engineering models for the analysis of tie life as a function of several of these key parameters. Among these key operating parameters that strongly influence the mechanical degradation of wood ties are:

- Annual traffic density (annual tonnage or MGT)
- Curvature
- Grade

Building upon the tie life damage effects used as a basis for the RTA equations, a series of mechanical damage indices was developed for each of the three parameters noted above and then combined to give an overall Mechanical Damage Index.

The specific equations used are presented in References 1 and 2. The corresponding Index values are presented in Figures 3, 4, and 5 for these three mechanical damage parameters.

To obtain the combined Mechanical Damage Index (MDI) the three individual mechanical indices are combined as follows: **MDI = CI * DI * GI/2867**

Where:
CI = Curvature Index
DI = Density Index
GI = Grade Index

Thus for the following case:

Curvature	= 1 degree;	CI	= 58 (see Figure 3)
Density	= 25 MGT;	DI	= 36 (see Figure 4)
Grade	= 1%;	GI	= 65 (see Figure 5)

The resulting Mechanical Damage Index (MDI) = 58*36*65/2867 = 47

Figure 6 presents a graph of the Mechanical Damage Index (MDI) as a function of curvature and traffic density (with grade = 0%).

Tie Usage Index
The Tie Usage Index (TUI) is then obtained by averaging the Environmental Decay Index (EDI) and the Mechanical Damage Index (MDI). Thus, applying this to the above example: for Zone 2; EDI = 48, MDI = 47 and the Tie Usage Index (TUI) = 47.

Tie Report #8A: Tie Usage Index for Matching Wood Performance and Operating Conditions (continued)

Figure 2: Decay Index

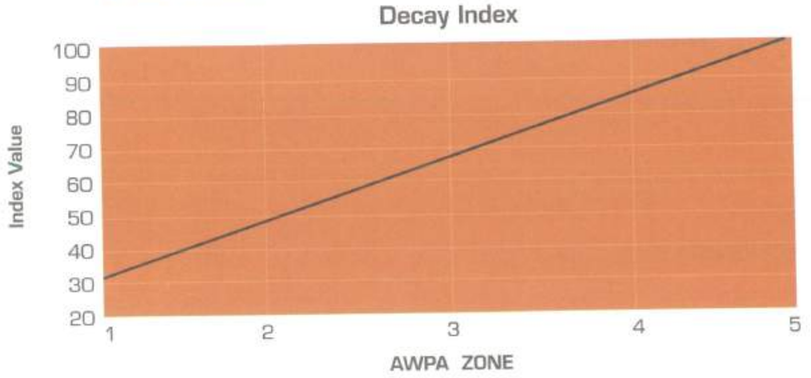


Figure 3: Curvature Index

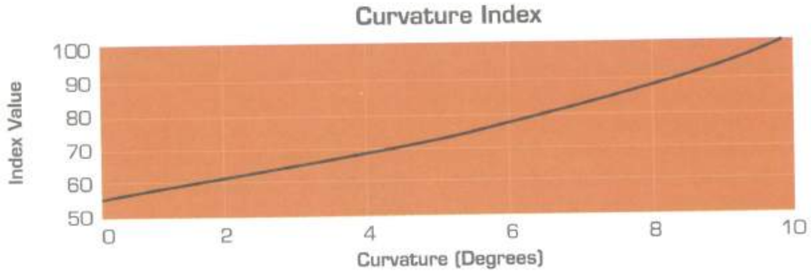


Figure 4: Density Index

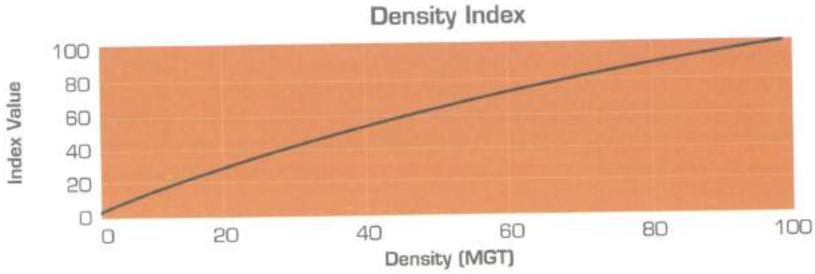
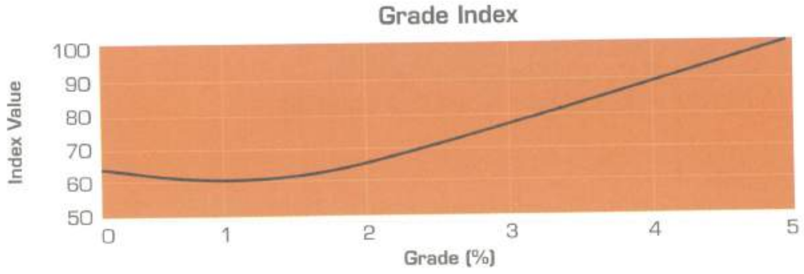
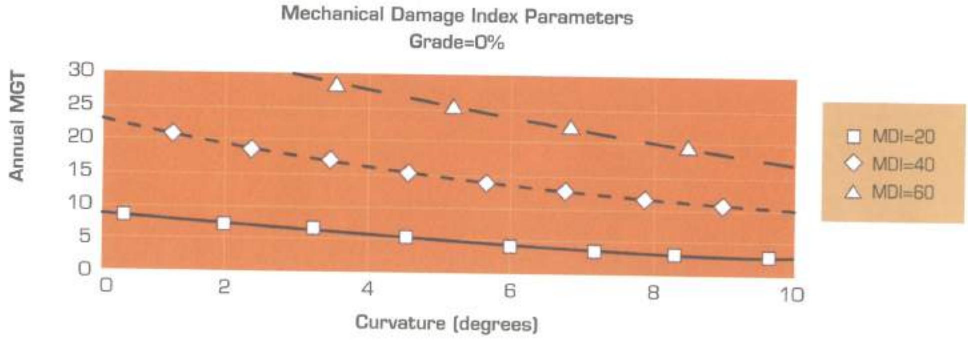


Figure 5: Grade Index



Tie Report #8A: Tie Usage Index for Matching Wood Performance and Operating Conditions (continued)

Figure 6: *Mechanical Damage Index as Function of Grade and Curvature*



APPLICATION OF TIE USAGE INDEX TO WOOD SPECIES

The Tie Usage Index is used to develop a relationship between those factors that influence tie performance, and thus life, and the different species of wood available for use as crossties. Starting with a comprehensive listing of all of the wood species that are available for use as crossties [7], the over 100 available species were grouped into "equivalent" categories based on ability to perform under both mechanical and environmental conditions. A total of 22 such equivalent categories were defined and are presented in Appendix A together with a list of all of the species corresponding to these 22 categories. (It should be noted that of these 22 categories, 6 are "E" or "Environmental" categories, which include those timber species where treatment or environmental/geographic use (e.g., locale) is a consideration.)

The full set of 22 timber categories were then rated, based on their expected level of mechanical performance, with the E categories rated mechanically but designated as a category with environmental considerations. Table A presents these timber category ratings, with the "best" performing timber categories at the top. Thus, wood species performance is expected to increase as the user moves vertically up the listing (with "best' on top).

Using the ratings presented in Table A, it is then possible to relate timber species to level of service, as defined by the Tie Usage Indices. A preliminary relationship is presented in Table B, which can be considered a preliminary Wood Species Usage Guide. This table relates wood species to railway use as a function of the two main deterioration categories defined above: environmental decay (as defined by the Environmental Decay Index) and mechanical damage (as defined by the Mechanical Damage Index). In this table, the railroad usage environment is divided into three levels of mechanical damage and three levels of environmental decay hazard as follows:

Mechanical Damage as based on the Mechanical Damage Index (MDI):

• Light	MDI < 20
• Moderate	20< MDI < 40
• Severe	MDI > 40

Note: The MDI values represent a combination of curvature, annual traffic density (tonnage) and grade. This combination is illustrated in Figure 7 for MDI values of 20, 40 and 60.

Environmental Decay Hazard as based on the Environmental Decay Index (EDI):

• Light	EDI < 50 (Zones 1 and 2 in Figure 2)
• Moderate	50< EDI < 80 (Zone 3 in Figure 2)
• Severe	MDI > 80 (Zones 4 and 5 in Figure 2)

Tie Report #8A: Tie Usage Index for Matching Wood Performance and Operating Conditions (continued)

For each of these nine usage areas, a listing of suitable timber species is defined. This is done by defining the lowest ranking timber category that is acceptable for use in that area. Thus, all of the timber categories located above the named category in Table B (to include the named category itself) is considered to be suitable for use in that category. Any timber category that is located below the named category is considered to be not suitable for use in that category. Furthermore, in the case of the Severe Environmental decay areas, any "E" category is likewise considered to be less than optimum, even if located above the named category.

Thus, for the case of the severe mechanical-light environmental usage area (upper right box in Table B), the following timber categories are considered suitable for use: Red Oak, White Oak, Northern Mixed Hardwoods (NMI) – I, Southern Mixed Hardwoods (SMI) – I and Northern Mixed Hardwoods (NMI) – H (see Appendix A in Tie Report #8B, which follows, for the specific wood species that make up this category).

However, for the case of the severe mechanical-severe environmental usage area (lower right box in Table B), White Oak would be excluded based on potential treatment concerns about this timber species. Similarly, for a light mechanical-light environmental usage area, all species in category WS III(E) and higher (from the category rating chart) are considered suitable for use. Thus Table B indicates the potential suitability of species for various applications ranging from light to severe mechanical wear and light to severe sensitivity to decay/environmental factors.

Table A: Category Rating

E = Treatment issues or where environment-of-use (locale as it applies to climate) is a consideration

Best

Red Oak
White Oak (E)
NMH-H
NMH – I
SMH-H
SMH – I
NMH – II
NMH – II (E)
Douglas Fir – Coastal
Douglas Fir – Intermountain (E)
SMH – II
SMH – II (E)
SYP – Dense
NMH – III
SMH – III
NMH – III (E)
ES – I
WS I
ES II
WS II
SYP – Standard
WS III (E)

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[1] *There exists a difference of opinion regarding the suitability of White Oak in severe environmental decay areas. As such, it has been excluded from the table for that application. However, some railroads continue to report satisfactory performance of White Oak even in the more environmentally rigorous areas of the country.*

Tie Report #8A: Tie Usage Index for Matching Wood Performance and Operating Conditions (continued)

Table B: Species Usage Guide

Environment (EDI)	Mechanical (MDI)		
	Light	20 Moderate	40 Severe
Light	WS III (E) ↑	SMH III ↑	SMH-H ↑
50 Moderate	WS I ↑	SMH III ↑	SMH-H ↑
80 Severe	SMH III* ↑	NMH III* ↑	SMH-H* ↑

* Excluding all "E" classes

This chart indicates suitability of species for various applications ranging from light to severe mechanical wear and light to severe sensitivity to decay/environmental factors. For example, if you have a light operating (mechanical) index of use and a light environment for decay (dry/arid) or "environment" index then all species in category WS III (E) and higher (from the category rating chart) are suitable for use. Conversely, if you have a severe application for both mechanical and environ indexes of use then it is suggested that only species NMH-H (excluding E classes) and higher are suitable.

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RTA TieReport #8B

Categorizing Wood Species for Railway Use

The matching of wood species to specific railroad operating and environmental conditions resulted in the development of a set of Tie Usage Indices to identify wood species that can perform in different levels of railway crosstie applications [1]. As part of this activity, the timber species categories (and thus the individual species) were related to level of service, as defined by the Tie Usage Indices. The result is a preliminary Wood Species Usage Guide which relates wood species categories, as defined in Table A, to railway use [2,3] as a function of the two main deterioration categories: environmental decay and mechanical damage.

However, there are over 100 species and subspecies of wood that have potential application as crossties under the full range of railway conditions, from high-density heavy axle load operations in high-decay climatic areas to low-density, light axle load operations in low-decay climatic areas. Using available data on North American wood species [4], these 100+ species were consolidated into the 22 categories as presented in Table B.

This expanded list of tie suitable wood species allows for better use of different wood species and expanded availability of timber sources for use as wood crossties.

Table A:
General Tie Categories

E = Treatment issues or where environment-of-use (locale as it applies to climate) is a consideration

Red Oak
White Oak (E)
NMH-H
NMH – I
SMH-H
SMH – I
NMH – II
NMH – II (E)
Douglas Fir – Coastal
Douglas Fir – Intermountain (E)
SMH – II
SMH – II (E)
SYP – Dense
NMH – III
SMH – III
NMH – III (E)
ES – I
WS I
ES II
WS II
SYP – Standard
WS III (E)

Best

Table B: Index of Wood Species - Expanded Categories

Species not included in the following are considered unsuitable for use as crossties.

RED OAKS

Black Oak
Blackjack Oak
California Black Oak
Northern Pin Oak
Northern Red Oak
Pin Oak
Scarlet Oak
Shingle Oak
Shumard Oak
Southern Red Oak
Willow Oak

WHITE OAKS

Burr Oak
Chestnut Oak
Chinquapin Oak
Live Oak*
Oregon Oak
Overcup Oak
White Oak
Post Oak

SOUTHERN MIXED HARDWOODS

SMH-H
Shagbark
Pignut
Mockernut
Bitternut
Pecan
Nutmeg

SMH – I
Osage Orange
Black Cherry
Black Walnut
Butternut
Black Gum

SMH – II
Coffeetree

SMH – II (E)
Red or Sweet Gum

SMH – III
Persimmon
River Birch
Red Maple
Silver Maple
Boxelder

NORTHERN MIXED HARDWOODS

NMH-H (Best)
Shagbark
Shellbark
Pignut
Mockernut
Bitternut
Pecan

NMH-I
Black Cherry
Black Walnut
Butternut
Black Gum
Black Maple
Sugar Maple
Honey Locust

NMH – II
White Elm
Slippery Elm
White Ash
Sassafras
Persimmon
Sycamore

NMH – II (E)
Red or Sweet Gum
Beech
Black Locust

NMH – III
Hackberry
Basswood
Yellow Birches
Sweet Birch
River Birch
Red Maple
Silver Maple
Cottonwood
Boxelder

NMH – III (E) (Env)
Red Mulberry
Hardy Catalpa
Yellow Poplar

Table B: *Index of Wood Species - Expanded Categories (continued)*

SOUTHERN YELLOW PINES

Shortleaf Pine
Loblolly Pine
Longleaf Pine
Slash Pine
Virginia Pine
SYP – Dense (as defined by SPIB standards. Timber and heavy decking, section 400)

EASTERN SOFTWOODS

ES – I
Eastern Spruces
Balsam Fir
Northern White Cedar
Atlantic White Cedar

ES – II
Tamarack
Eastern Hemlock

WESTERN SOFTWOODS

DOUGLAS FIR
Douglas Fir Coastal
Douglas Fir Intermountain (E)

WS – I
Western Larch
White Fir (Hem-fir family)
Grand Fir (Hem-fir family)
Balsam Fir (Hem-fir family)
Redwood*
Western Hemlock

WS – II
Ponderosa Pine
Lodgepole Pine
Port Orford Cedar*
Western Redcedar

WS – III (E)
Western White Pine*
Limber Pine*
Jeffrey Pine*
Engelmann Spruce

*Not commercially available

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RTA TieReport #9

Extending the Service Life of Wooden Crossties by using pre- and supplemental preservative treatments

Terry L. Amburgey[1]
Jimmy L. Watt
Michael G. Sanders

15-YEAR EXPOSURE REPORT

In 1987, a research proposal was submitted to a Railway Tie Association (RTA) and Association of American Railroads (AAR) joint committee to sponsor research to improve the service life of wooden crossties. It was hypothesized that treating unseasoned ties with diffusible preservatives (e.g., borates) would 1) protect ties from insects and decay fungi during air-seasoning, and 2) protect the interior of ties from decay in-track by being mobilized to checks or cracks as rainwater enters them in service. A subsequent treatment with an oil or oil-borne preservative (e.g., creosote, copper naphthenate, etc.) would prevent leaching of the borates and protect the ties from the soft-rot fungi that cannot be controlled with borates. Likely, lower retentions of creosote than usual could be used if ties were protected with borates. It was further hypothesized that pretreatment with borates (known corrosion inhibitors) would retard iron degradation of wood and the subsequent loosening of spikes (spike kill). An additional hypothesis was that borates would increase the service life of ties in-track by applying them, using a variety of delivery systems, as supplemental treatments.

These studies are documented in a progress report authored by T.L. Amburgey and S.C. Snyder dated January 12, 1989 that was submitted to AAR/RTA and in an undated AAR progress report authored by D.D. Davis and K.J. Laine. Five-year results were reported in *Technology Digest* (Feb 1994) and *Crossties* (July/August 1994) in manuscripts authored by Davis and Laine. Results of the 2002 inspection were summarized in a presentation by Amburgey at the RTA Annual Convention in St. Louis, Missouri and in a recent article in *Crossties* (Jan./Feb. 2003) authored by Jim Gauntt.

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[1] *The authors are, respectively, Professor, Department of Forest Products, Mississippi State University; President, The Crosstie Connection; Research Associate, Department of Forest Products, Mississippi State University.*

Tie Report #9: *Extending the Service Life of Wooden Crossties by using pre- and supplemental preservative treatments (continued)*

Treatment of Ties with Borates Prior to Air Seasoning

Unseasoned and some seasoned red oak, white oak, and gum (mixed hardwood) ties were treated at the Atchison, Topeka and Santa Fe (A, T & SF) facility at Somerville, Texas in late spring, 1987. Ties were dip-treated for three minutes in a heated (130° F) 30% boric acid equivalent (BAE) solution (wt/wt) of sodium borate (TimBor, U.S. Borax) and either bulk-stacked and covered with a tarp (to prevent surface drying and thereby increase borate diffusion) or air-stacked with or without a tarp cover. After six weeks, the bulk-stacked ties were air-stacked and covers were removed from some air-stacked ties. Most ties remained air-stacked until dry and then treated with creosote, but some were vapor-dried and treated with creosote at Somerville.

Results of the early phases of this study indicated that:

1. Borate up-take and diffusion was greater in unseasoned than in seasoned ties (Table 1).

Table 1: *Borate analyses of seasoned or unseasoned ties that had been bulk-stacked under cover for six weeks following dip treatment in a heated (130° F) 30% BAE TimBor solution.*

Species	Sample Location (inch)	Average % BAE	
		Seasoned Wood	Unseasoned Wood
White Oak	0-0.5	0.47	1.42
	0.5-1.0	0.09	0.49
Red Oak	0-0.5	0.55	1.26
	0.5-1.0	0.18	0.50

2. Borate up-take and diffusion was greater in ties bulk-stacked and covered for six weeks prior to being air-stacked than in those air-stacked following treatment (Tables 2 & 4).

Table 2: *Borate analyses of incised or non-incised unseasoned ties that were either bulk-stacked under cover or air-stacked for six weeks following dip-treatment in a heated (130° F) 30% BAE solution of TimBor.*

Species	Sample Location (inch)	Average % BAE	
		Bulk-Stack	Air-Dried
White Oak[a]	0-0.5	1.42	0.65
	0.5-1.0	0.49	0.14
Red Oak[a]	0-0.5	1.26	0.90
	0.5-1.0	0.50	0.24
White Oak[b]	0-0.5	1.05	0.14
	0.5-1.0	0.25	0.01
Red Oak[b]	0-0.5	1.09	0.13
	0.5-1.0	0.28	0.04

[a] *Incised – Test 1*
[b] *Non-incised – Test 2*

Tie Report #9: Extending the Service Life of Wooden Crossties by using pre- and supplemental preservative treatments (continued)

3. Borate up-take and diffusion was greater in incised than in non-incised ties (Table 2).
4. Large amounts of borate were lost from ties that were vapor-dried and treated with creosote shortly after six weeks of bulk-stacked, covered storage (Table 3).

Table 3: *Borate analyses of ties before and after creosote treatment. Unseasoned ties had been dipped in heated (130° F) 30% BAE TimBor and bulk-stacked under cover for 6 weeks.*[a]

Species	Sample Location (inch)	Average % BAE[b]	
		Before Creosote	After Creosote
White Oak	0-0.5	1.42	1.02
	0.5-1.0	0.49	0.22
Red Oak	0-0.5	1.26	1.13
	0.5-1.0	0.50	0.19
Gum	0-0.5	1.48	1.13
	0.5-1.0	0.27	0.13

[a] *Ties were vapor-dried and treated shortly after the six weeks of storage.*

[b] *Toxic limit for subterranean termites is approximately 0.058% BAE (100 ppm B) and the toxic limit for decay fungi is approximately 0.025% BAE (43 ppm B).*

5. Very little borate was lost from air-dried ties following creosote treatment (Table 4).
   All borate analyses during the initial phases of this study were performed by personnel at the A, T & SF chemistry laboratory.

Table 4: *Borate analyses before and after creosote treatment of unseasoned ties stored for six weeks in various configurations after being dipped in heated 30% BAE TimBor and then air-dried.*

Species	Sample Location (inch)	Stacking Configuration	Average % BAE	
			Before Creosote	After Creosote
White Oak	0-0.5	Air-stack	0.48	0.50
	0.5-1.0		0.17	0.22
	0-0.5	Bulk-stack[a]	0.85	0.86
	0.5-1.0		0.52	0.49
	0-0.5	Air-stack[a]	0.75	0.72
	0.5-1.0		0.48	0.43
Red Oak	0-0.5	Air-stack	0.39	0.43
	0.5-1.0		0.17	0.18
	0-0.5	Bulk-stack[a]	0.80	0.84
	0.5-1.0		0.42	0.41
	0-0.5	Air-stack[a]	0.50	0.61
	0.5-1.0		0.37	0.39

[a] *Covered with tarp.*

Tie Report #9: *Extending the Service Life of Wooden Crossties by using pre- and supplemental preservative treatments (continued)*

Following air-drying, the borate-treated ties were treated with creosote at either Somerville, Texas using the regular A, T & SF treatment (GBS) or Madison, Illinois (Kerr-McGee) using the regular Norfolk Southern (NS) creosote treatment (GBN) or a creosote dip treatment (GBC). The ties then were installed in-track at locations in several geographic regions.

The 15-Year inspection was at a site near Cordele, Georgia on a main-line, fully signaled track. Sample ties in each treatment group were removed from track and sectioned through the inner spike holes at both ends to check for decay, insect damage, and "spike kill." Samples were obtained for borate analysis between the inner spike holes from the upper surface to the center and from the lower surface to the center.

Average results of the borate analyses from ties dip-treated in creosote (GBC), pressure-treated with the regular A, T & SF creosote (GBS), or pressure-treated with the regular NS creosote (GBN) verified color tests that indicated that borate had diffused throughout the cross-section in the pre-treated ties and was present at retentions above the toxic threshold for decay fungi after 15 years in track (Figure 1). All borate analyses of ties at the 2002 inspection were done by U.S. Borax. Although creosote dip-treated ties and the upper half of both GBS and GBN ties were below the toxic threshold for termites (Figure 1), no termite damage was observed. Toxic thresholds for termites and decay fungi were assumed to be 0.058% BAE (100 ppm boron) or 0.025% BAE (43 ppm boron), respectively.

Results of this phase of the study can be summarized as follows:

1. Borates had diffused throughout the cross-sections and, after 15 years, were present at above toxic threshold levels for decay fungi (Figure 1).
2. No decay or termite damage was observed in either the creosote dip- or pressure-treated ties.
3. No "spike kill" was observed.
4. The borate-treated ties did not negatively impact electronic signaling in the test track.
5. Borate retentions were higher in the lower than in the upper half of the ties.
6. Evidence indicates that the creosote over-treatment reduces the rate of borate leaching from ties (e.g., Figure 1 – GBC vs GBS or GBN).
7. White oak ties pre-treated with borates are performing well on main-line track in the south.

Supplemental Borate Treatments To Ties In Service

Supplemental preservative treatments and delivery systems were tested either on sections of track not scheduled for maintenance or where rail and tie plates were being changed. Treatments included borate rods (Pandrol) placed either in unused spike holes or in holes drilled adjacent to tie plates, fluoride rods and pads (Osmose) applied under new tie plates as rail was replaced (pads) or in holes drilled adjacent to tie plates (rods), copper-borate paste (ISK) applied under new tie plates as rail was replaced, water-borne and oil-borne copper naphthenate spray (Mooney) applied to the area near one tie plate, and borate spray (U.S. Borax) applied to the area near one tie plate. The borate spray was a heated 30% BAE TimBor solution applied at the rate of one quart per tie plate area. This treatment was done to determine if the application of excess dip-treating solution could be used as an effective supplemental tie treatment. All supplemental treatments were applied to one end of each tie. The other end of each tie served as a control. Characteristics of these ties are documented in the Amburgey & Snyder report (1989).

The 14-year inspection of ties given supplemental treatments was done at the Cordele and Jessup, Georgia sites. Only the borate-containing treatments were examined. As with the borate-pretreated ties, ties were chosen at random from each treatment group and sectioned through the inner spike holes at each end. Comparisons of the cross-sections at the inner spikes at the treated and untreated end of each tie were used to evaluate the efficacies of the treatments. Borate color tests and analyses were taken from the area between the inner spike holes or approximately one-foot toward the tie midpoints from the inner spike holes.

Tie Report #9: Extending the Service Life of Wooden Crossties by using pre- and supplemental preservative treatments (continued)

Results indicate that in ties with internal decay prior to the application of supplemental treatments, decay continued to progress at the untreated end. In the treated ends, however, decay, in most instances, was less than in the untreated ends. It was hypothesized that the supplemental treatments diffused through the wood and arrested the growth of decay fungi that may be present. Results of borate color tests and analyses verified that borate was present throughout the cross-sections, in most instances at levels above the toxic threshold for decay fungi (Figure 2). A notable exception occurred when borate rods were placed in unused spike holes. Essentially no borate was found in ties treated in this manner. If borate rods are to be used, the holes in which they are placed cannot extend through the ties. As with the borate-pre-treated ties, analysis zones were from the upper and lower surfaces to the tie center.

Highest borate retentions were in ties where borate rods were placed in holes drilled on either side of tie plates (Figure 2). Essentially the same results occurred at both the Cordele and Jessup test sites (Figure 2 – BR (J) & BR (C)). Analyses indicated that borate released as rods solubilized also moved toward the centers of ties (Figure 2 – BR (C) INT). Borate spray treatments indicated that this is an effective procedure for disposing of excess dip-treatment chemical that contributes toward extending the service life of older ties (Figure 2 – BSP).

Placing treated materials under tie plates as they are replaced also proved to be an effective procedure for extending the service life of ties. Although the borate paste placed under tie plates was present at below decay threshold levels for boron after 14 years, no decay or "spike kill" occurred in these ties (Figure 2 – CBP). From other studies (Amburgey and West, Amburgey and Freeman)[a], it is apparent that the toxic threshold of the CBP formulation is lower than that of either copper or boron alone. Similar results were observed in ties where fluoride pads (another diffusible material) were placed under new tie plates (inspection by Jimmy Watt). Results indicate that both of these test materials will require formulation with higher levels with borate or fluoride if 14 or more years will occur between subsequent treatments.

DISCUSSION

Results of the tests reported above indicate that treatment of ties with borates prior to air seasoning is an effective procedure for increasing the service life of wooden crossties. Maximum borate uptake and diffusion occurred in unseasoned, incised ties that were bulk-stacked under cover for six weeks prior to air-drying. We chose to use a heated 30% BAE TimBor solution applied via a 3-minute dip. Anyone using a TimBor solution in excess of approximately 15% must use a heated solution that is not permitted to cool. It may be possible to use lower concentrations of borate if longer dip times are used, ties are dip-treated on each of two successive days, or increased borate retentions are achieved by pressure– rather than dip-treatment. Other borate formulations or other delivery systems may be used. For instance, perhaps borate rods (gels, pastes) could be inserted in holes drilled near the rail-bearing area and in the center of unseasoned ties. Our results indicate that the holes cannot be through-bored, and ties must be bulk-stacked for approximately six weeks prior to air-stacking. It is essential that tie surfaces do not dry too rapidly or borate diffusion will be limited. If borate rods (gels, pastes) are the delivery system of choice, the quantity of borate required for complete penetration at above toxic threshold levels must be determined (e.g., the diameter and length of rods, the concentration of diffusible preservative - borate or fluoride – in gels or pastes).

It may be possible to use reduced retentions of creosote (or other oil or oil-borne materials) if ties are properly treated with diffusible preservative and stored to maximize diffusion during the drying process. Results of these tests indicate that ties over-treated via a creosote dip retained fairly high levels of borate after 15 years in track. Perhaps a light pressure treatment with creosote would be more effective than a dip for preventing borate loss from ties. The type of over-treatment required likely would be different in ties exposed in alternative geographic regions.

Tie Report #9: Extending the Service Life of Wooden Crossties by using pre- and supplemental preservative treatments (continued)

Results of these tests also demonstrate the effectiveness of periodic supplemental treatments for protecting ties from decay and "spike kill." Once again, alternative delivery systems may achieve equally effective or better results than those obtained in this study. However, we must ask how long a supplemental treatment should remain effective (e.g., 5, 10, 15 years). A regular schedule for applying supplemental treatments may be required to assure long-term quality of ties. Should the rail-bearing area be retreated whenever rails are replaced? What is it worth to extend the service life of ties by 5, 10, 15 years?

COOPERATORS

Over the last 15 years, numerous people and organizations have cooperated in this study. These include:

- Railway Tie Association
- Association of American Railroads
- Atchison, Topeka & Santa Fe Railway Company
- Atchison, Topeka & Santa Fe Chemistry Laboratory personnel
- Norfolk-Southern Railroad
- U.S. Borax
- U.S. Borax Analytical Laboratory personnel
- Osmose Company
- Pandrol Incorporated
- ISK Biocides
- Mooney Chemicals

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[a] Amburgey, T. L., M. West. 1989. *Field tests with a groundline pole treatment.* International Conference on Wood Poles and Piles, Fort Collins, Colorado, USA, October 25-27, 1989. pp. E1-E11.

Amburgey, T.L., M.H. Freeman. 1993. *Groundline treatments with a water-borne copper naphthenate-boron paste.* In: Proc., 89th Annual Meeting of the American Wood-Preservers' Assoc., Newport Beach, CA. May2-5, 1993, 89:105.

Amburgey, T.L., M.H. Freeman. 1993. *Ten-year field test with a copper-borate ground line treatment for poles.* International Research Group on Wood Preservation, Document No. IRG/WP93-30017.

Tie Report #9: Extending the Service Life of Wooden Crossties by using pre- and supplemental preservative treatments (continued)

Figure 1

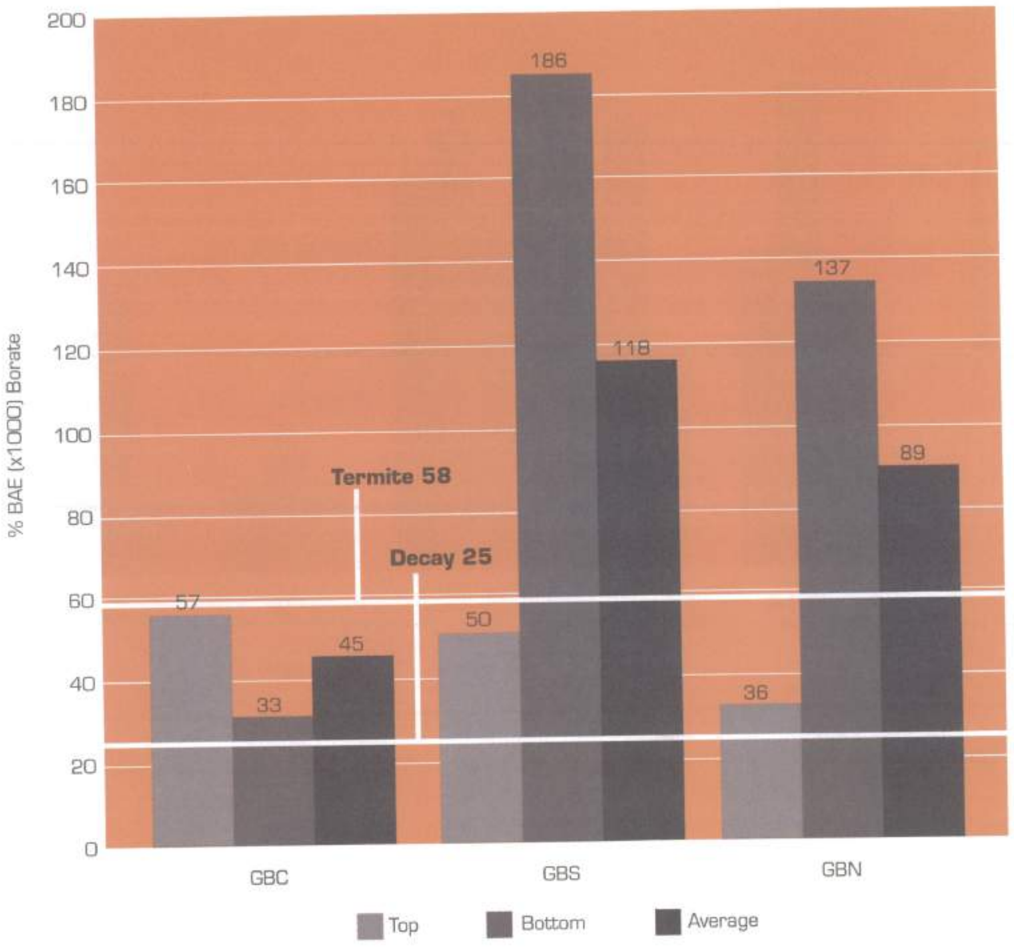

Figure 1: *Borate analyses of borate-treated mixed hardwood (red and white oak, hickory, and gum) ties over-treated with creosote by dip (GBC) or pressure GBS – Atchison, Topeka & Santa Fe treatment, GBN – Norfolk-Southern treatment after 15 years of field exposure. Analysis zones were from the upper or lower tie surface to the center.*

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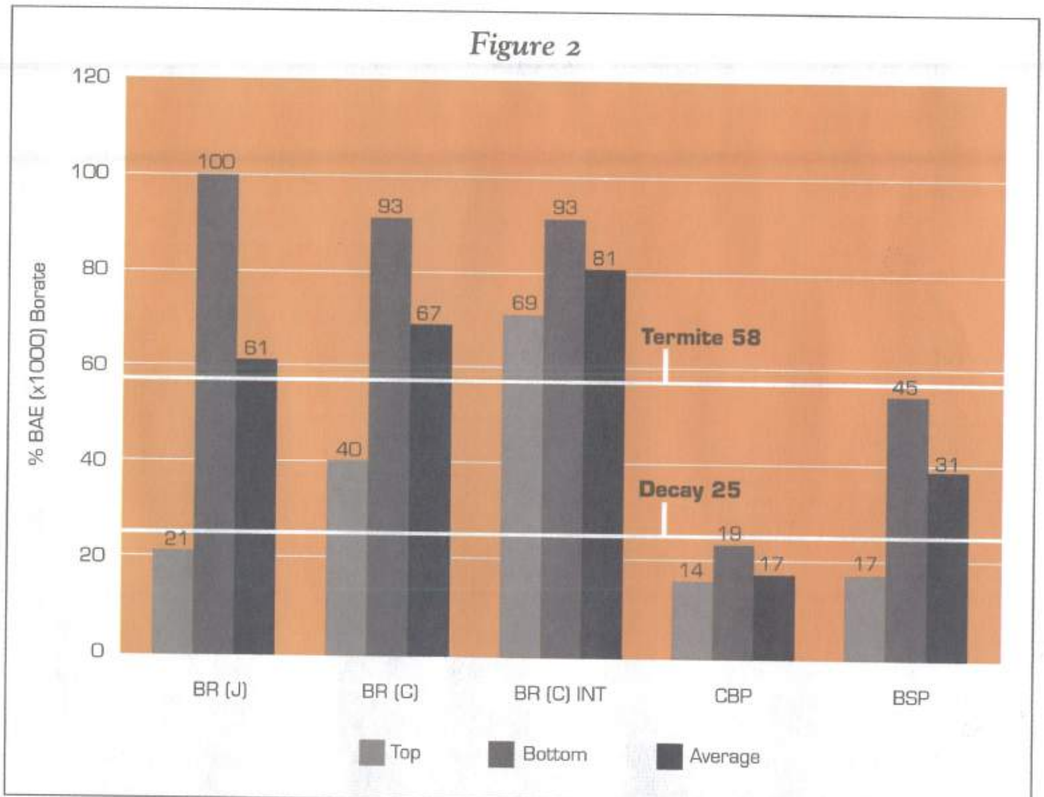

Figure 2: *Borate analyses of in-track (red and white oak, hickory, and gum) ties 14 years after they had received supplemental borate treatments using borate rods (BR-J Jessup, GA), (BR-C Cordele, GA); copper-borate paste (CBP -Cordele, GA); or borate spray (BSP-Cordele, GA). Analyses were taken at the inner spike holes (BP, CBP, BSP) or one foot toward the midpoint from the inner spike holes (BR-C-INT). Analysis zones were from the upper or lower tie surface to the center.*

Addendum July 2008

These findings were originally published in the May/June 2003 issue of *Crossties*. The results were further verified by a 20-year study of borate/creosote (B/C)-treated ties exposed at a test site in AWPA Hazard Zone 4 and reported on in 2007 (American Wood Protection Association Proceedings, 2007).

Also since 2003, studies have been conducted at two commercial treating facilities to determine procedures for making the borate diffusion/creosote treatment process commercially feasible. Separate tests conducted at these facilities have demonstrated the feasibility of this process in a commercial treatment plant setting. It is apparent from this research that optimum treatment/processing procedures will differ from plant to plant requiring careful scientific documentation to establish the proper quality control procedures that must be followed by any operation engaging in B/C dual-treatment technology. Orders from three class 1 railroads, Norfolk-Southern, Canadian National, and BNSF, and others for B/C ties are being processed in a timely manner. It is estimated at the time of this printing that well over 1 million B/C ties are now in service in these railroads.

The in-track supplemental treatment phase of the AAR/RTA/MSU has only been used commercially to date on the Panama Railroad, but tests are underway to increase the commercial feasibility of this procedure and to couple supplemental treatment borate delivery systems with new creosote-treated materials. Efforts are also underway to implement the use of in-track treatments to increase the service life of existing ties. Although at least one railroad has lowered their specifications for creosote retention when using B/C dual-treatment technology, specific studies to verify the performance of reduced creosote retention in B/C-treated ties have not been pursued on a commercial level.