# Development of a Tie Usage Index

# for Matching

# Wood Performance and Operating Conditions

Allan M. Zarembski, Ph.D., P.E., President ZETA-TECH Associates, Inc.

James C. Gauntt, Executive Director, Railway Tie Association

ABSTRACT

The matching of wood species to specific railroad operating and environmental conditions has long been recognized as a desirable goal in optimizing the use of wood cross-ties in track. In fact, several North American railroads currently use a limited form of species segregation in an attempt to match wood performance and operating and environmental conditions. However, to date, this species segregation has been subjective in nature, based on the identification of certain species for certain limited use applications.

This papers presents the results of a Railway Tie Association sponsored 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 leads to the application of this Tie Usage Index as a basis for defining species usage on a railroad as a function of service environment and geographical location.

The Tie Usage Index presented in this paper is based on a set of specific numerical criterion ("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 paper further presents a detailed listing of wood species that can be used for cross-ties, divides these species into 22 categories of similarly performing wood species and develops a preliminary ranking of these species based on performance. Finally, the paper relates these 22 categories to railroad usage environment (both mechanical and environmental) and presents preliminary recommendations for use of the different wood specie categories as a function of the Tie Usage Index.

## Introduction

It has long been recognized that the matching of wood species, specifically species used for railroad cross-ties, to specific railroad operating and environmental conditions is a desirable goal in optimizing the use of wood cross-ties in track. In fact, several North American railroads currently use a limited form of species segregation in an attempt to match wood performance and operating and environmental conditions. However, to date, this species segregation has been subjective in nature, based on the identification of certain species for certain limited use applications or restrictions in the use of certain species as a function of geographical (generally environmental) conditions. Thus, there exists no defined "index" or measure of performance that can assist the railroads in defining usage environments and matching the usage environment (both environmental and mechanical) with wood type and performance (e.g. species).

This papers presents the preliminary results of a Railway Tie Association sponsored program [1] to develop an objective Tie Usage Index (TUI) 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 leads to the application of this Tie Usage Index as a basis for defining species usage on a railroad as a function of service environment and geographical location.

The development and application of this Tie Usage Index (TUI) represents a next generation application of the current approach in timber species segregation and introduces several key environmental and usage parameters in the definition of a TUI. This includes the development of specific numerical criterion ("indices") that can be used to define where different timber species can be installed, the development of preliminary threshold limits, and an initial correlation of these thresholds to specific species.

The Tie Usage Index presented in this report 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 the above parameters and allows for the quantification of the potential for premature failure as a function of the above defined failure mechanisms. As such it sets the stage for the development of index thresholds and the linking of these thresholds to specific wood species, preliminary values of which are presented in this report. Specifically, the paper presents a detailed listing of wood species that can be used for cross-ties and divides these species into 22 categories of similarly performing wood species. These categories are then ranked based on performance and correlated to railroad usage environment (both mechanical and environmental). The result is a set of preliminary recommendations for use of the different wood specie categories as a function of railroad usage, as defined by the Tie Usage Index.

## Development of Tie Usage Index

Analysis of the key modes of wood cross-tie failure indicates that there are two broad categories of cross-tie degradation: [2,3]

- Environmental related degradation such as decay, rot, insect damage, etc.
- Mechanically related degradation such as crushing, cutting, splitting, breakage, etc.

In order to develop a meaningful tie usage index, both of the above classes of degradation must be addressed. In order to do this, 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, were developed independently and subsequently combined to provide a single Tie Usage Index.

### Environmental Decay Index

As already noted, susceptibility to decay is a primary consideration in the development of an index for use in selecting timber species for use as wood cross-ties. To date, the most commonly used numerical parameter for identifying decay hazard is the Decay Hazard map development by the US Department of Agriculture (see Figure 1) which divides the US into four hazard zones ranging from Low to Severe Decay Hazard. This map was used in the mid-1980's to quantify decay risk for timber cross-ties by geographic region [4]. The resulting decay hazard values developed for railroad cross-ties were as follows:

| Region | Decay Hazard Value |
|---|---|
| Western US | 55 |
| Eastern US | 90 |
| Southern US | 180 |

A better defined wood decay map was developed by the Rural Electrification Administration for utility poles [5] and incorporated into the American Wood Preservers' Association (AWPA) standards for Preservative Treatment of Poles (C-4) [6]. This map, which is presented in Figure 2 has five zones as follows:

| Zone | Deterioration Hazard |
|---|---|
| 1 | Low |
| 2 | Moderate |
| 3 | Intermediate |
| 4 | High |
| 5 | Severe |

By equating the wood tie decay hazard values of Figure 1 with the Deterioration Zones presented in Figure 2, a five level wood tie Environmental Decay Index was developed [1]. Normalizing this index to a scale of 100 (with 100 representing the most severe decay condition), the following Environmental Decay Index was developed:

| Zone | Environmental Decay Index | Deterioration Zone (Figure 2) |
|---|---|---|
| 1 | 31 | Low |
| 2 | 48 | Moderate |
| 3 | 65 | Intermediate |
| 4 | 83 | High |
| 5 | 100 | Severe |

Figure 3 presents the resulting Environmental Decay Index (EDI) as a function of the 5 zones defined in Figure 2. This term represents the environmental component of the Tie Usage Index.

**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 7 through 11 define several of the key parameters that effect mechanical degradation of timber cross-ties. Recent research sponsored by the Railway Tie Association [12, 13] 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.

These individual parameter indices were developed based on the damage effects defined above and then normalized to a common scale. The resulting parameter mechanical damage indices were defined as follows:

*Curvature Index*

The curvature index is based on the curvature damage effect relationship

$$CurveDamage = e^{-k*C}$$

Where $C$ is curvature in degrees and k is a constant.

Applying this equation generates the curve damage term shown below. Normalizing this term and setting it on an increasing damage scale (i.e. the larger the number, the more severe the service environment and the greater the damage) gives the Curvature Index relationship CI shown below, where

$$CI = 54.31/(CurveDamage)$$

| **Curvature** | **Curve Damage** | **CI** |
|---|---|---|
| 0 | 1.00 | 54 |
| 0.5 | 0.97 | 56 |
| 1 | 0.94 | 58 |
| 2 | 0.89 | 61 |
| 3 | 0.83 | 65 |
| 4 | 0.78 | 69 |
| 5 | 0.74 | 74 |
| 6 | 0.69 | 78 |
| 7 | 0.65 | 83 |
| 8 | 0.61 | 89 |
| 9 | 0.58 | 94 |
| 10 | 0.543 | 100 |

This Curvature Index is presented graphically in Figure 4 as a function of degree of curvature.

*Density Index*

The density or tonnage index is based on the tonnage damage effect relationship

$$TonnageDamage = A*(D)^{0.74}$$

where $D$ is annual traffic density in MGT and A is a constant

Normalizing this term and setting it on an increasing damage scale (i.e. the larger the number the more severe the service environment and the greater the damage) gives the Density Index relationship (*DI*) shown below, where

$$DI = 35.86*TonnageDamage$$

| Density (Annual Tonnage) | Tonnage Damage | DI |
|---|---|---|
| 0 | 0.00 | 0 |
| 5 | 0.30 | 11 |
| 10 | 0.51 | 18 |
| 15 | 0.69 | 25 |
| 20 | 0.85 | 30 |
| 25 | 1.00 | 36 |
| 30 | 1.14 | 41 |
| 35 | 1.28 | 46 |
| 40 | 1.42 | 51 |
| 45 | 1.54 | 55 |
| 50 | 1.67 | 60 |
| 60 | 1.91 | 69 |
| 70 | 2.14 | 77 |
| 80 | 2.36 | 85 |
| 90 | 2.58 | 92 |
| 100 | 2.789 | 100 |

This Density Index is presented graphically in Figure 5 as a function of annual MGT.

*Grade Index*

The grade index is based on the grade damage effect relationship

$$GradeDamage = 1 + 0.023 * G^2$$

Where $G$ is grade in percent

Applying this equation generates the grade damage term shown below. Normalizing this term and setting it on an increasing damage scale (i.e. the larger the number the more severe the service environment and the greater the damage) gives the Grade Index relationship G1 shown below, where

$$GI = 63.29 * GradeDamage$$

| Grade | Grade Damage | GI |
|---|---|---|
| 0 | 1.00 | 63 |
| 0.5 | 1.01 | 64 |
| 1 | 1.02 | 65 |
| 1.5 | 1.05 | 67 |
| 2 | 1.09 | 69 |
| 2.5 | 1.14 | 73 |
| 3 | 1.21 | 77 |
| 3.5 | 1.28 | 81 |
| 4 | 1.37 | 87 |
| 4.5 | 1.47 | 93 |
| 5 | 1.58 | 100 |

This Grade Index is presented graphically in Figure 6 as a function of percent grade.

*Combined Mechanical Damage Index*

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 4) |
| Density | = 25 MGT; | DI | = 36 (see Figure 5) |
| Grade | = 1%; | GI | = 65 (see Figure 6) |

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

In applying the MDI, it is possible to define constant mechanical damage by fixing a MDI value and then looking at the combination of curvature, tonnage and grade necessary to achieve this constant MDI value. This is illustrated in Figure 7, which shows lines of constant MDI corresponding to MDI values of 20, 40 and 60.

In Figure 7, grade is set to 0% (level track) so that each line in the Figure corresponds to the curvature-tonnage combinations that will result in a constant MDI value. This, in turn, allows for the definition of equivalent damage, such as for the MDI = 40 curve, where a high curvature-low tonnage combination (e.g. 10 degree curve with 10 MGT annual tonnage) is defined as being equivalent, from a tie damage point of view, to a low curvature-high tonnage combination (0 degree curve with 23 MGT).

## Tie Usage Index

The Tie Usage Index (TUI) is then obtained by combining the Environmental Decay Index (EDI) and the Mechanical Damage Index (MDI) using the following equation:

$$TUI = [a * EDI + b * MDI]/(a + b)$$

Where *a* and *b* are weighting constants.

In this preliminary analysis, a and b are both set to 1.0, giving the equation

$$TUI = [EDI + MDI]/2$$

This applying this equation to the above example;

For Zone 2; *EDI = 48*

| | | |
|---|---|---|
| For | Curvature | = 1 degree |
| | Density | = 25 MGT |
| | Grade | = 1% |
| | MDI | = 47 |

Then the Tie Usage Index (TUI) = 47

## Application of Tie Usage Index to Wood Species

Since the objective of the Tie Usage Index approach is to develop a relationship between those factors that influence tie performance, and thus life, and the different species of wood available for use as cross-ties, it is necessary to first define the wood species that are available and to develop a rating of these species.

Reference 14 includes a comprehensive listing of all of the wood species that are available for use as cross-ties, which includes over 100 species of hard and soft woods. As part of this activity, these 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 (expanded from the original 7 in Reference 14) 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 remaining 16 categories were evaluated primarily based on their mechanical performance, since they were considered species that treated well and were not subject to undue potential environmental degradation.

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 nine (9) combinations of mechanical and environmental damage based on three levels of mechanical damage and three levels of environmental decay hazard. These three levels are 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)

For each of these nine usage areas, a listing of suitable timber species is defined. This is done by defining, in each of the nine usage areas, 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 it 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*

Northern Mixed Hardwoods (NMI) – H*

* See Appendix A 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.[1]

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.

[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.

## Summary

This paper presents the development of a preliminary Tie Usage Index that can be used as a basis for matching wood cross-tie species to specific railroad operating and environmental conditions.

The Tie Usage Index includes the following specific behaviors and effects:

- Environmental Decay Index to address susceptibility to environmental decay.
- Mechanical Damage Index to address susceptibility to mechanical damage defined by:
    - Curvature
    - Traffic density (annual MGT)
    - Grade.

The specific index values are determined and presented together with combined indices to include an Environmental Decay Index (EDI), which is related to geographical zones in the US and a combined Mechanical Damage Index (MDI), which is related to the above three mechanical damage parameters. A combined Tie Usage Index (TUI) can then be calculated from the above individual indices.

This Tie Usage Index, together with the two major sub-indices (EDI and MDI) can then be used to define the potential for premature tie failure, development of index thresholds, and linking of these thresholds to specific wood species. In order to accomplish this, the currently available wood species suitable for use as cross-ties (over 100 such species) were evaluated and grouped into 22 "equivalent" timber categories based on ability to perform under both

mechanical and environmental conditions. These 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.

Using these ratings, 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 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). The resulting table, which is presented in this paper, indicates the potential suitability of wood species for various cross-tie 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 that 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 | Best |
| 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) | |

**Mechanical (MDI)**

| Environ(EDI) | Light (0–20) | Moderate (20–40) | Severe (40+) |
|---|---|---|---|
| Light (–50) | WS III (E) ↑ | SMH III ↑ | SMH-H ↑ |
| Moderate (50–80) | WS I ↑ | SMH III ↑ | SMH-H ↑ |
| Severe (80+) | SMH III ↑ | NMH III * ↑ | SMH-H * ↑ |

**TABLE B: SPECIES USAGE GUIDE**

* 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 "environ" 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 the only species suitable.

## Acknowledgement

The authors would like to acknowledge the contribution of Mr. Jeffery Broadfoot and Mr. Gene Dodson of Kerr-McGee Chemical company for their assistance in developing the timber category ratings and the species usage matrix. The authors would also like to acknowledge the following members of the RTA Tie Usage Index task force for their assistance in the development of this overall approach and the application presented inn this paper:

| | |
|---|---|
| Alan Miller | Burke Parsons Bowlby Corp |
| Fritz Horn | CSX Transportation |
| Gary Zaversnik | Union Pacific Railroad |
| Paul Merrick | Trus – Joist |
| Dave Webb | Dave Webb Inc. |

## REFERENCES


1. Zarembski, A. M., "Development of a Preliminary Tie Usage Index", Report Submitted to the Railway Tie Association, July 2001.
2. Hay, W. W., Railroad Engineering, John Wiley & Sons, New York, 1982.
3. Talbot, A. N. et al., "Stresses in Railroad Track-The Talbot Reports", American Railway Engineering Association, 1980.
4. Russell, Allen, "Tie Decay-Underrated Factor", Railway Track and Structures, August 1986.
5. Zabel, R. A. and Morrell, J. J., "Wood Microbiology; Decay and Prevention", Chapter 15, 1992.
6. American Wood Preservers Association, Standards 2000, C-4 – Poles-Preservative Treatment by Pressure Processes.
7. Zarembski, A. M., "Development of Track Damage Equations", Report to the Association of American Railroads, 1988.
8. McIlveen, E. R., et al "The Road Maintenance Cost Model", Canadian Institute of Guided Ground Transport (CIGGT) Report 80-16, March 1981.
9. Davis, D. D., "Tie Planning: A Progress Report of the Track Maintenance, Research Committee", Association of American railroads Report WP-127, October 1987.
10. Lewis, W. F., Association of American Railroads Cost Analysis Organization Subcommittee on the Economics of the 80 vs100 Ton Cars, Final Report of the Engineering Panel, July 1981.

11. Danzig, J. C., et al.," Procedures for Analyzing the Economic Cost of Railroad Roadway for Pricing Purposes, Volume I-Procedures", Federal Railroad Administration Report RPD-11-CM-R (DOT-FR-30028), January 1976

12. ZETA-TECH Associates, Inc., "SelecTie II- Economic Benefit Analysis of Alternate Cross-Tie/ Fastener Configurations", Report to the Railway Tie Association, 1997.

13. ZETA-TECH Associates, Inc., "TieLife- Determination of Wood Tie Life and Future Cross-Tie Requirements", Report to the Railway Tie Association, June 1998.

14. Webb, G. V. and Webb, D. A., "Tie Guide: Handbook for Commercial Timbers Used by the Cross-Tie Industry", Railway Tie Association, Fayetteville, GA.

## APPENDIX A: INDEX OF WOOD SPECIES - EXPANDED CATEGORIES

The following is a complete listing of species from the RTA TieGuide by "expanded" category. The TieGuide has 7 broad categories, which are delineated for the purpose of providing mechanical properties for wood species. The "expanded" categories take into consideration railroad engineering experience and market based considerations to arrive at more finely tuned categories of use for the purpose of employing Tie Usage Indices to their fullest potential. 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

* Not commercially available

## 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

# 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

**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

15.

## Figures

**Figure 1**

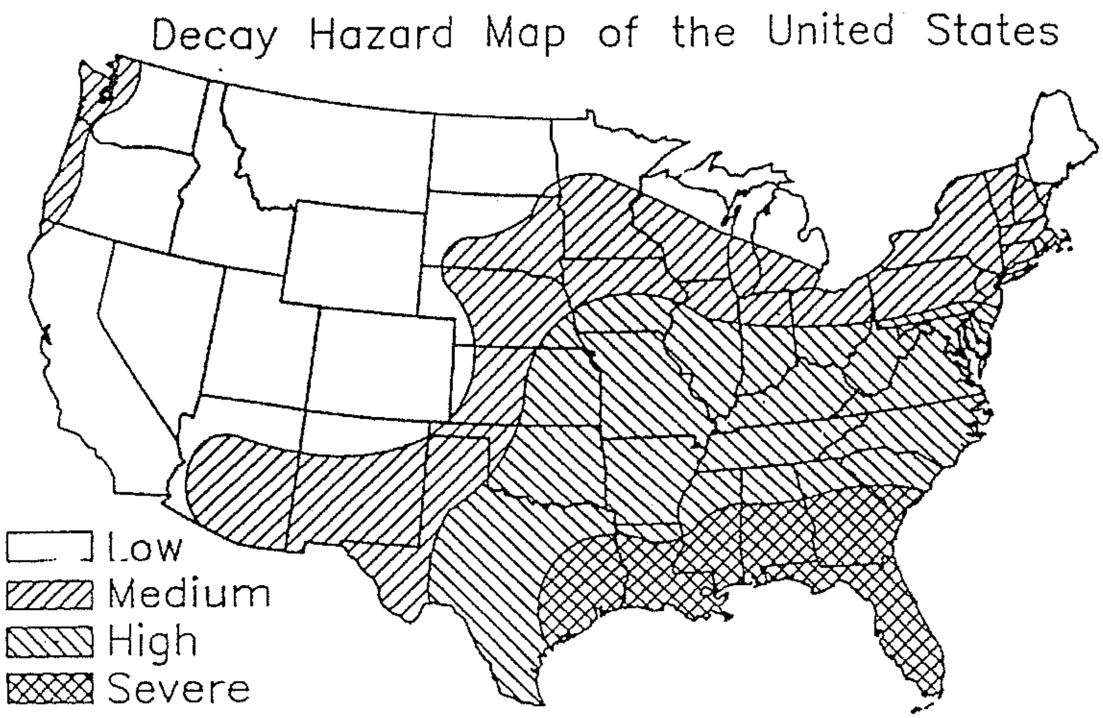
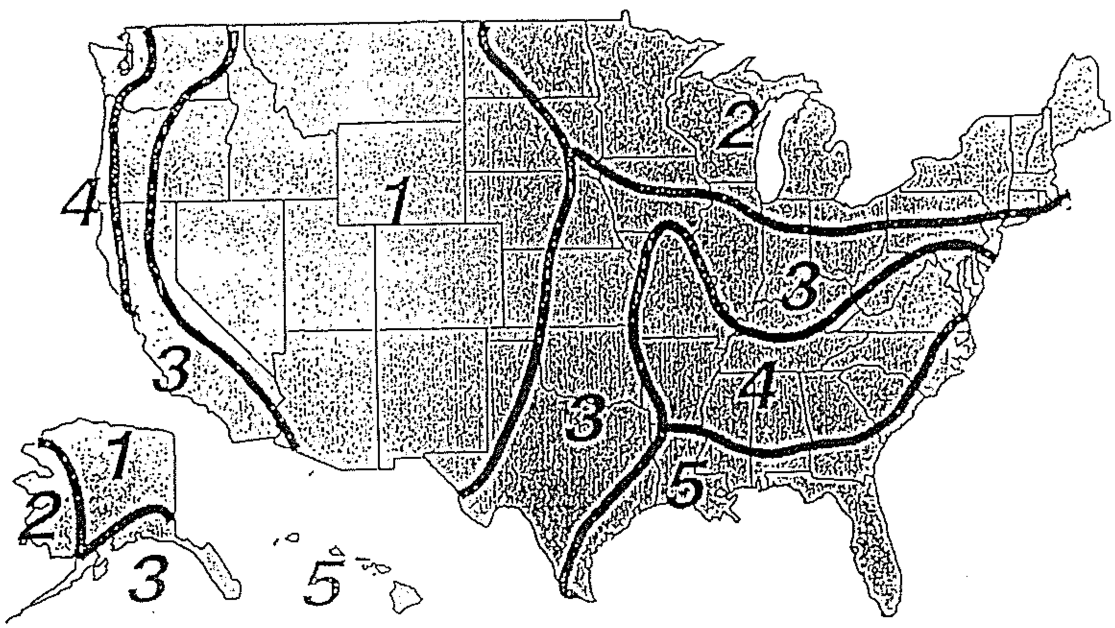

Decay Hazard Map of the United States
Low
Medium
High
Severe

**Figure 2**

## Deterioration Zones




1=Low 2=Moderate 3=Intermediate
4=High 5=Severe

Figure 3

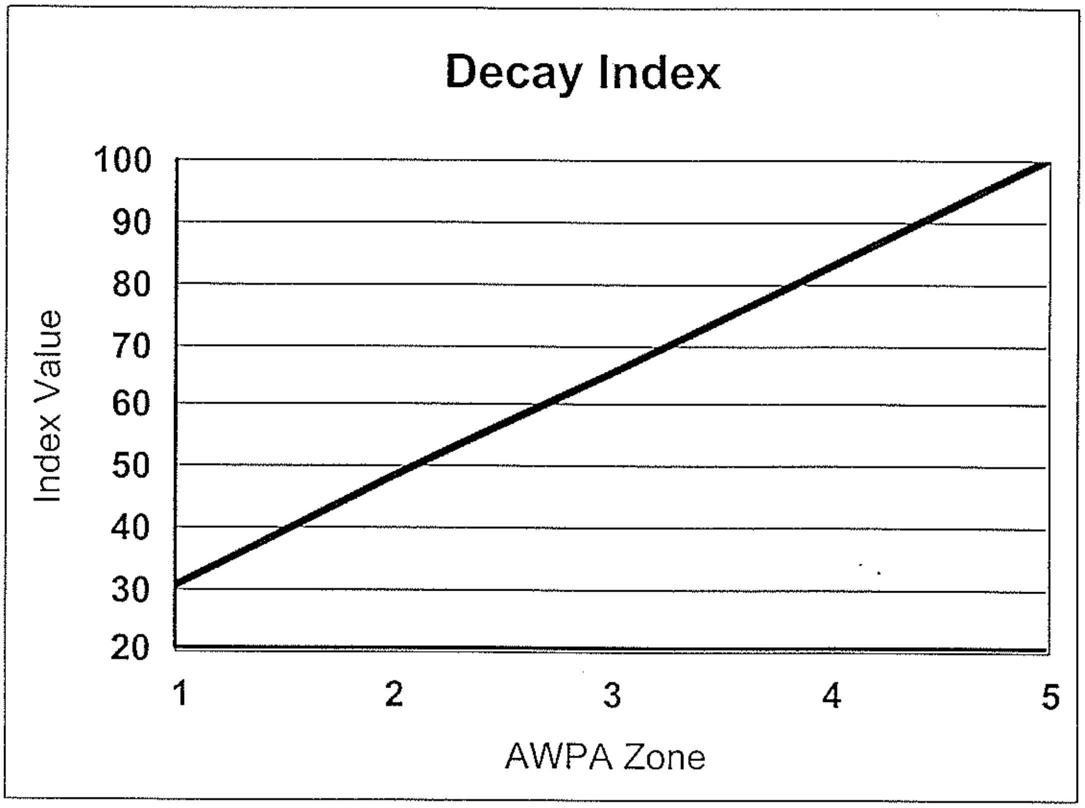

Decay Index
100
90
80
70
60
50
40
30
20
Index Value
1
2
3
4
5
AWPA Zone

Figure 4

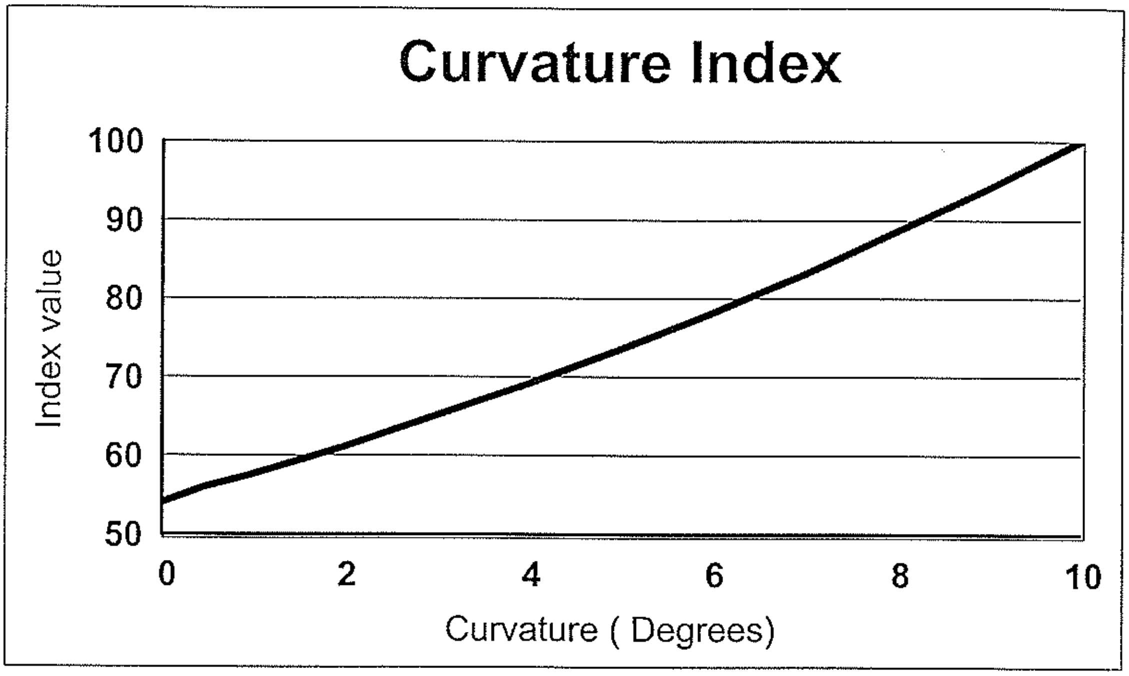

Curvature Index
100
90
80
70
60
50
Index value
0
2
4
6
8
10
Curvature ( Degrees)

**Figure 5**

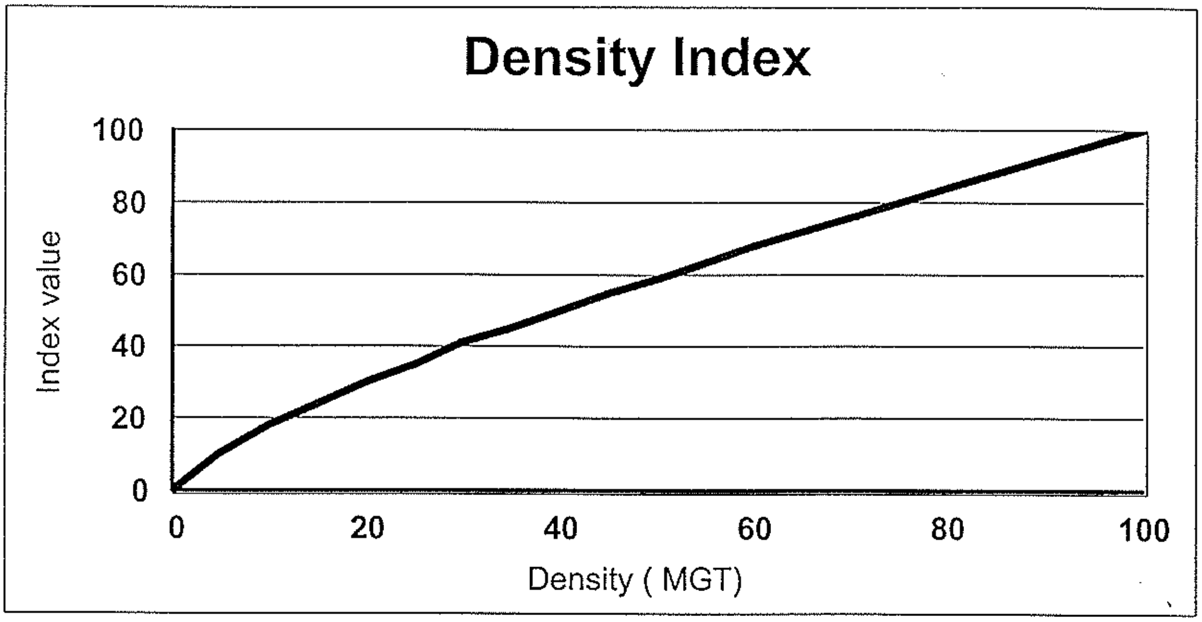

Density Index
100
80
60
40
20
0
Index value
0
20
40
60
80
100
Density ( MGT)

Figure 6

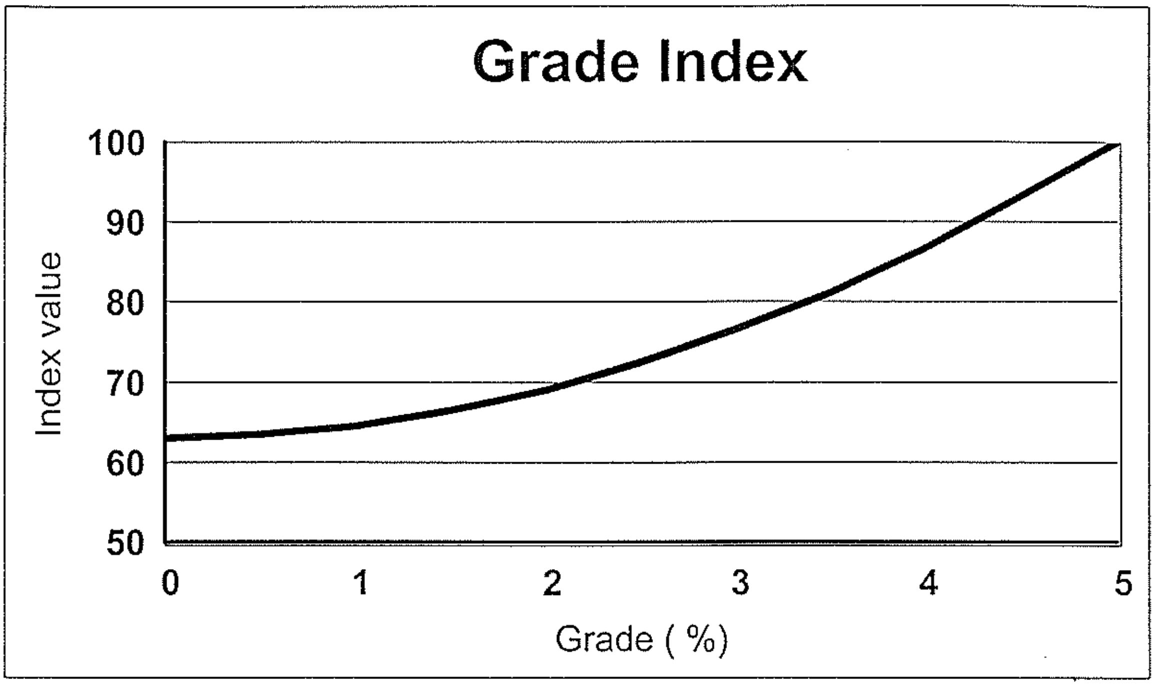


**Figure 7: Mechanical Damage Index as Function of Grade and Curvature**