On The Prediction of the Life of Wood Crossties

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The life of a wood crosstie will vary significantly based on track, roadway, and traffic conditions. Over the last several decades, significant research has been performed in evaluating the service life of wood crossties as a function of these parameters. This research has led to the development of analytical models for the prediction of the tie life and the effect of these parameters on this life. This paper will review the various studies that have examined the service life of wood cross-ties and the corresponding engineering relationships that have been developed. This paper will also examine the sensitivity of the tie life to such key parameters as track curvature, environmental conditions, track and roadway support conditions, traffic type (to include both speed and axle load), wood species, etc.

In order to develop suitable tie life relationships for use in this activity, this paper will concentrate on conventional wood cross-ties with cut-spike fasteners. This system represents the dominant tie and fastener system used on North American freight railroads and as such will be the primary system analyzed herein. The effect of non- conventional fastener types, such as elastic fasteners, will also be presented.

Tie Life Modeling

The life of conventional wood crossties has been the subject of extensive modeling attempts using various modeling techniques, including mechanistic models, empirical models, and statistical forecasting models. A component life model is a mathematical relationship or equation, used to calculate the time (or other appropriate measure) to "failure" of that component. In this context, "failure" is the point at which maintenance or component replacement (which is a form of maintenance) is required. Since the entire railroad system is not homogeneous, i.e. there is variation in both design details, operational characteristics, and maintenance history, the model must account for those variations that effect the "life" of the component. As in any sophisticated application, the level of complexity of the model is dependent on the actual application, the availability of the data, and the practicality of applying the model(s) in that given application. This is the case in this application as well. Therefore, the final models developed must represent a compromise between sophistication and ease of use.

There are two basic types of failure models that are traditionally developed; mechanistic models and empirical models [1].

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Mechanistic models are mathematical models that attempt to simulate the actual failure mechanism(s) in order to determine the time to failure of the component. This approach attempts to define the actual mechanical properties of the components and their complete loading environment, so that the interaction between the loads and the materials can be mathematically simulated to represent the mechanism(s) of failure. This approach generally is quite sophisticated, often requiring complex computer algorithms. However, this approach provides a clear understanding of the actual behavior of the track and its components. As such, these models are very effective for designing systems or developing improvements in these components. They also tend to require more detailed input data, some of which may not be readily available in broad application.

Empirical models are relatively simple models based on experimental or observational data, used to obtain relationships between key factors that affect the component lives. These models are generally derived from statistical approaches, by which a large volume of experimental or observational data is collected and correlated. Often a mechanistic model is used to help define the most critical variables with the statistical or empirical analyses providing for the relationships between these variables. Empirical models are often relatively simple in final form. They also tend to be very highly dependent on the data used to develop them, and as such can not be readily extended outside the range of behavior which is represented by that data.

While both of these approaches have been used in the development of mathematical models for the prediction of wood tie life, the empirical equations have been used somewhat more extensively, primarily because of their relative simplicity, ease of use, and less extensive data requirements.

Track component models in general, and tie life models in particular, allow for the calculation of an "average" component life, which is normally representative of the behavior (and associated life) of that component, e.g. wood crosstie. However, one major difference between tie failure models and the other track components models, such as rail models, is 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. Such statistical distribution curves have been developed by the USDA Forest Products Laboratory [2] and the Association of American Railroads [3].

This in turn suggests two possible tie modeling approaches, an "average" tie life modeling approach which determines an "average" tie life for a given set of conditions, and a statistical tie life approach, which predicts the actual number of ties failed each year. For the purposes of defining crosstie life, the average tie life model is most relevant, since it relates the tie life to the key track and traffic operating parameters.

One other traditional approach for determining average tie life should be noted here. This is the system average approach, where the total number of tie replacements

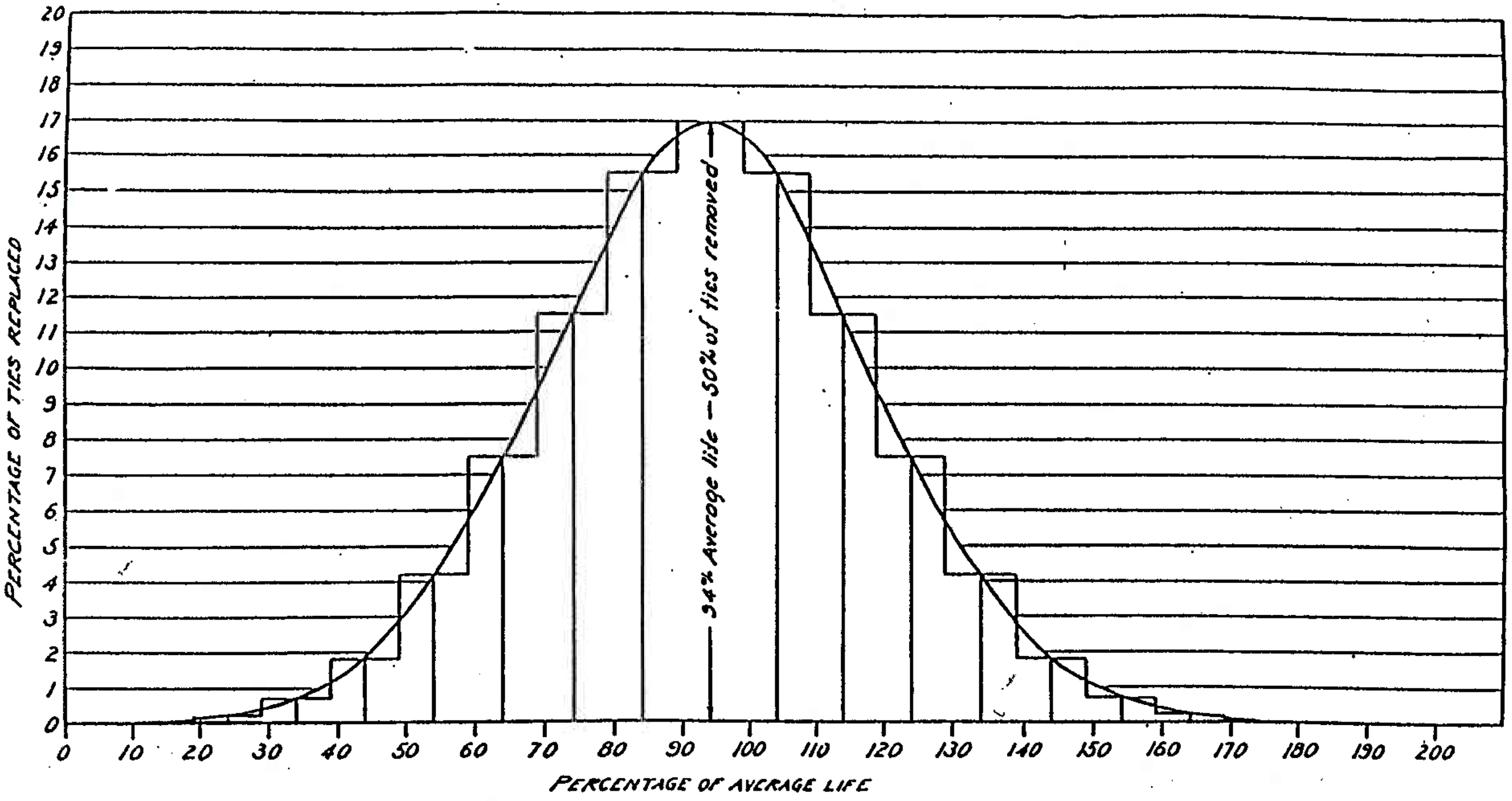


Figure 1 Frequency curve showing successive percentage tie replacements for 10 percent intervals of average life. Symmetrical form - Origin taken at 94 percent.

system wide (or nationwide) are added, together with the associated trackage and a single value for system tie life calculated. This approach, however, is potentially misleading, since it gives a system average that is not representative of specific conditions. In fact, by including the very low density lines, "high" average tie life are obtained (which while representative of the low density lines are significantly greater than those that are experienced on heavily trafficked lines where the majority of the maintenance expenditures are in fact made.

When this data is sorted by a parameter, for example density, some general tie life values can be obtained. This type of data is illustrated in Figure 2, where average tie life is obtained, from R-1 data [4], for four different density categories of track. (Note: Category A corresponds to mainline track.)

In order to develop an appropriate tie life equation, it is necessary to examine the modes of tie degradation. Figure 3 [5], presents the major modes, which include both mechanical types of degradation (spike killed, plate cut, broken, split, etc.) and decay/weathering related. While in general it has been noted that mechanical failure is the primary cause for failure or removal of hardwood cross-ties [6], which represent the majority of the mainline wood ties, there is a range of external factors that influence tie life in service. These factors, which are listed in Table 1, include weathering factors, biological factors, stress factors (which are mechanical in nature), incompatibility factors, and use factors. In fact, recent examination of the distribution of tie failure modes presented in Table 2 [7], which is based on field data, shows a noticeable shift in failure type from natural causes to mechanical causes, as the traffic density increases. This suggests, that for low and moderate density track, ties will decay rather than wear out. However, as the density increases there appears to be a shift in degradation mechanism, suggesting that for mainline type track, the failure mode distribution is strongly mechanical in nature (or has a very strong mechanical/load related component and effect).

This effect is further complicated by the fact that these failure modes are not exclusive, but rather combine with mechanical life hastening the onset of decay, and vice versa. Because of this, the use of mechanistic type tie models do not appear appropriate. Rather, the empirical approach appears to offer the best potential for developing a suitable tie life relationship. This approach has likewise been the one most commonly used by other tie life modeling efforts.

One such tie life model is the one developed by I. Reiner of the Chessie System [8]. This model is generally presented as:

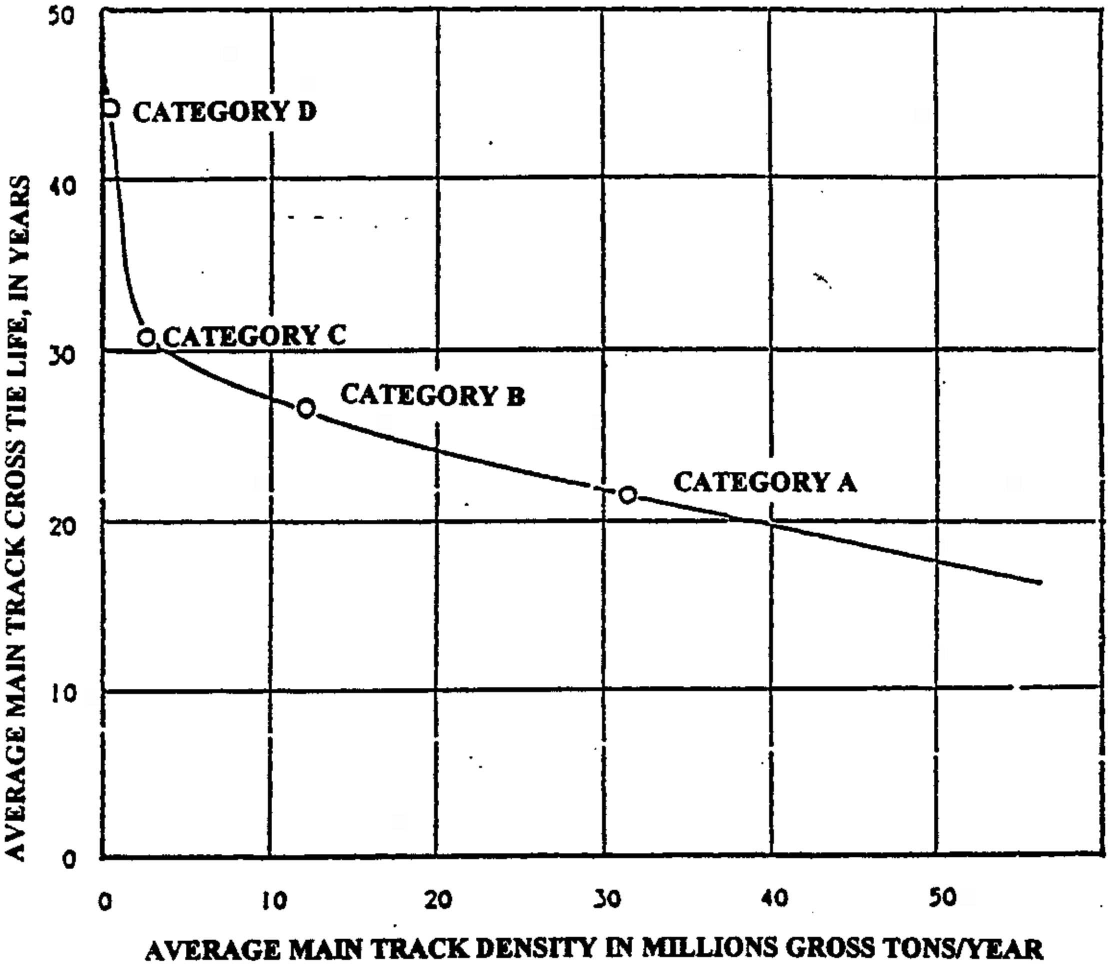


Figure 2 Tie Life vs Tonnage for Four Different Density Categories

Note: "acceptable" tie condition will vary as a function of the operational characteristics of the track. Thus, ties that would be acceptable for low density branch lines (Category D) would not be acceptable for high density lines (Category A).

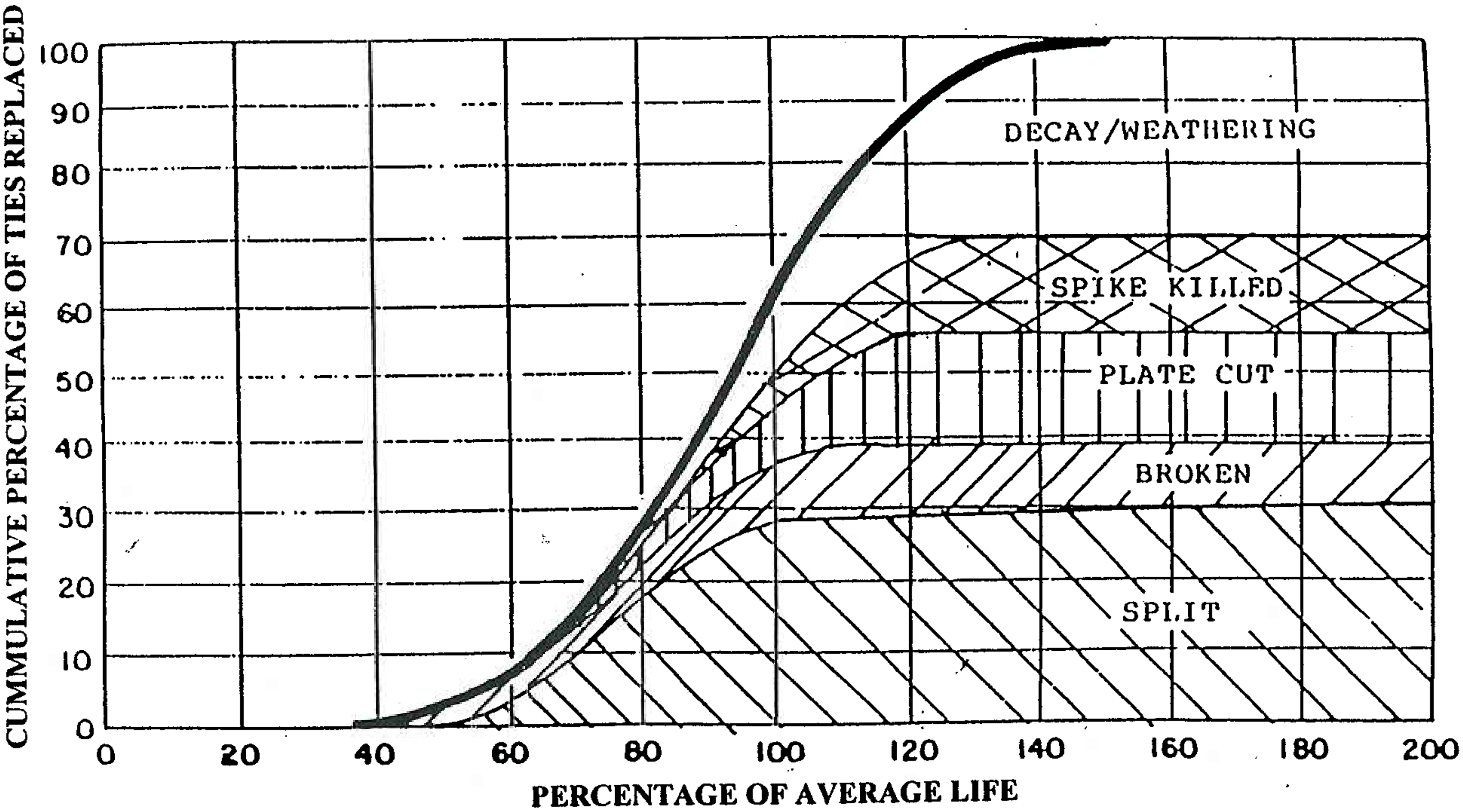


Figure 3 Tie Failure Distribution by Defect Mode. (Mainline Case)

I. Weathering Factors
   A. Temperature (elevated, cyclical and depressed)
   B. Water
   C. Temperature - Moisture Interactions (i.e. freeze-thaw)

II. Biological Factors (primarily fungi)

III. Stress Factors
   A. Abrasion and Compression due to ballast
   B. Impact Compression due to vertical rail loads
   C. Impact Bending due to vertical rail loads
   D. Spike loading due to lateral rail loads

IV. Incompatibility Factors
   A. Chemical degradation due to presence of rusting metal and high concentrations of acidic salts
   B. Physical degradation due to particulate matter under tie plate during loading

V. Use Factors
   A. Quality and Frequency of Maintenance (i.e. spike removal, adzing, type of ballast)
   B. Track geometry (i.e. curves, ties per mile)
   C. Accidents (derailment, dragging equipment, spills)

Table 1: Degradation Factors Affecting the Service Life of Crossties

Table 2

Comparison of Natural VS. Mechanical Wear in Different Service Environments.

Test Area	Environment	Annual Tonnage (MGT)	Curve/ Tangent	% of Tie Failures due to Natural	Mechanical
CP Thompson S/D	Cold/Dry	58	T	47	53
			C	50	50
CR Syracuse S/D	Cold/Wet	25	T	95-75	5-25
C&NW Des Plaines	Cold/Wet	20-30	T	97-78	3-22
CP Princeton S/D	Cold/Dry	0.5	T	100	0
			C	92	8
SRR Grouped Data	Warm/Moist	>23	T/C	43	57
		15-23	T/C	58	42
		10-15	T/C	70	30
		5-10	T/C	74	26
		1-5	T/C	86	14
		<1	T/C	97	3

$$Tie\ Life\ (L) = \frac{a}{1+b(1+cD)\left(1+dG^{2}\right)\left(T^{e}\right)(W/23)^{f}}$$

where:

a, b, c, d, e, and f are constants
D = degree of curvature
G = grade (%)
T = tonnage density (MGT/year)
W = wheel load (Kips)
and L = tie life (years)

A second commonly used and quoted tie life model is the TOPS model developed by the Southern Pacific Transportation Company [9]. This equation is generally given as:

$$Life\ (MGT) = Ke^{(a-bD)}T^{c}$$

where:

K = constant based on rail weight, rail type, grade, wheel load and track support
a, b and c are constants based on empirical data
D = Degree of Curvature
and T = Annual gross tonnage (MGT/year)

Another, empirically derived model was developed by the Canadian Institute of Guided Ground Transport [4]. This equation is:

$$Life = a-b^{*}\ \Sigma\left(P(t_i)d(t_i)(L/V/0.03)^{c}p(i)Ns^{d}\right)$$

where:

a, b, c and d are constants
L/V is the ratio of lateral to vertical forces
$P(t_i)$ = dynamic tie plate load for loading class i
$d(t_i)$ = maximum vertical track deflection for load class i
$p(i)$ = proportion of total loading cycles for load class i
Ns = millions of load cycles imposed by total traffic mix
and $Life$ = average tie life in years

Subsequent work under the sponsorship of the Association of American Railroads resulted in the development of several sets of damage based tie life models [10, 11] which have been used in the last several years as the basis for the determination of the effect of differing track and traffic parameters on tie life. These models, which are engineering damaged based, form the basis of the sensitivity analyses presented in this paper.

The general form of the first of these "current" tie equations [10] is:

$$\text{Tie Life (in years)} = a * f(P,S) * k(C) * R * G * J * h(D) * E / D$$

where:

a = constant
$f(P,S)$, $F(P,S)$ = function of axle load (P) and speed (S)
$k(C)$, $K(C)$ = function of curvature (C) R, R' = rail size factor
G, G' = function of grade
J, J' = function of joint condition, CWR vs Jointed.
E, E' = function of environment
and D, D', and $H(D)$ = function of annual traffic density in Million Gross Tons (MGT)

Figure 4 presents a summary of the tie life calculated using this relationship for a range of traffic densities and curvatures. It must be noted, that these values are not absolute but rather vary as a function of other key parameters (such as defined in Table 3). As can be seen from this Figure, wood crosstie life can vary from more than 50 years (for very low density tangent track under dry condition) to less than 15 years (for severe curvature, high density track). Table 4 presents a more detailed summary of this equation.

The second model [11], which is a mechanistically based engineering model is incorporated in a computer program. Figures 5 and 6 show calculated tie lives for hardwood and softwood crossties respectively. Again note the significant curvature effect. [This will be discussed in further detail later in this paper].

Analysis of industry wide data , such as presented in Figure 2, and more recently in Reference 12, shows service lives reaching the order of 50+ years in dry environments (Western U.S.). As already noted in Figure 4, this also corresponds with low density tangent track. Similar track, located in "hot', "wet" environments [Southeastern US] can have this lives reduced to the order of 30 years [12]. In severe curvature, severe density applications, this life is even further reduced, as illustrated in Figures 4 through 6. In all cases, the tie life is driven by and dependent upon the traffic and track parameters that influence this life. These sensitivities will be discussed in the next section.

Tie Life Sensitivities

Table 3 lists the key input variables that have been identified as influencing and affecting life of timber crosstie. In order to isolate these effects, a sensitivity analysis will be performed holding all the other factors "constant" , thus allowing for the identification of the direct influence of only the factor being discussed. In order to avoid confusion,

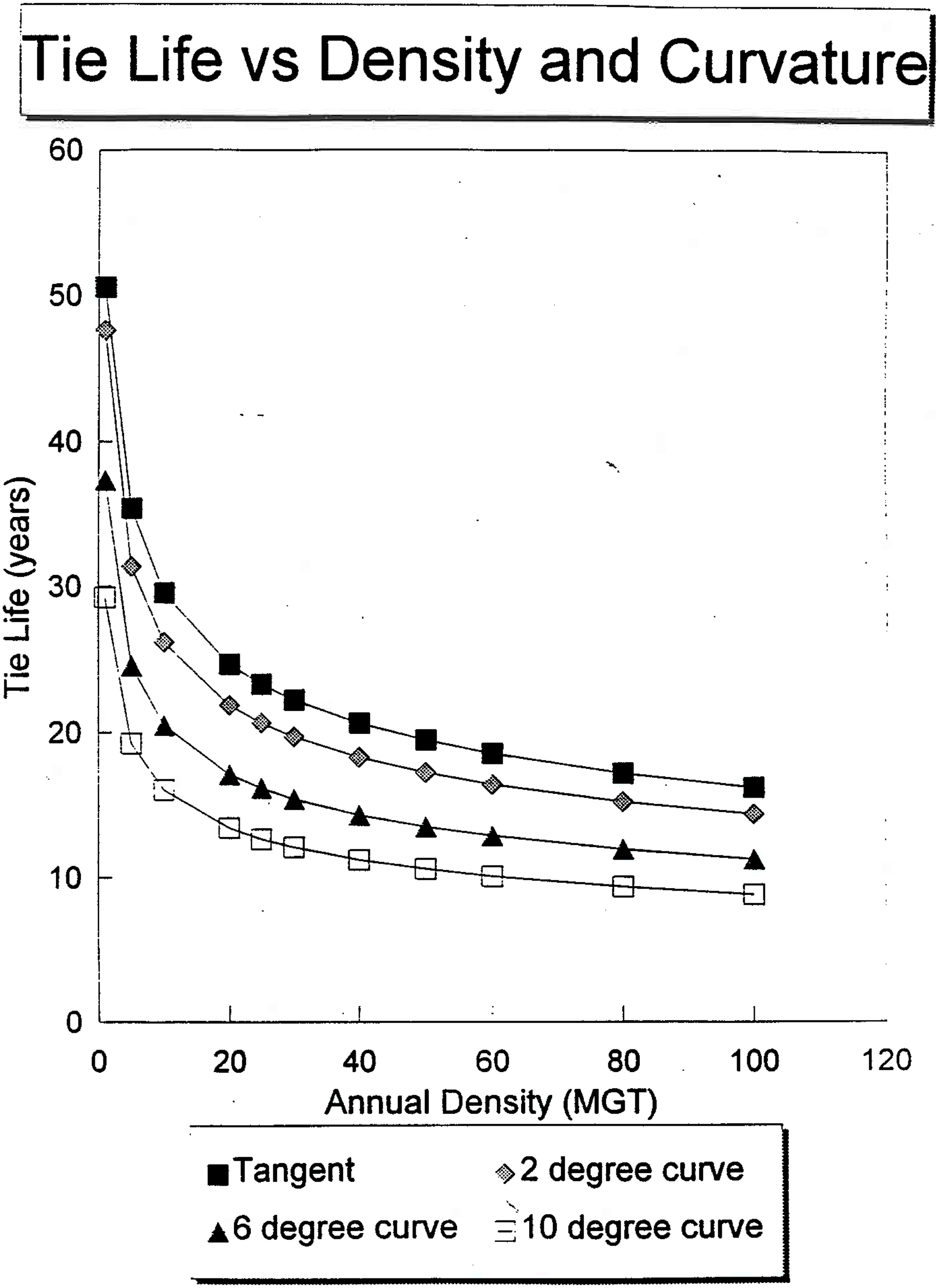
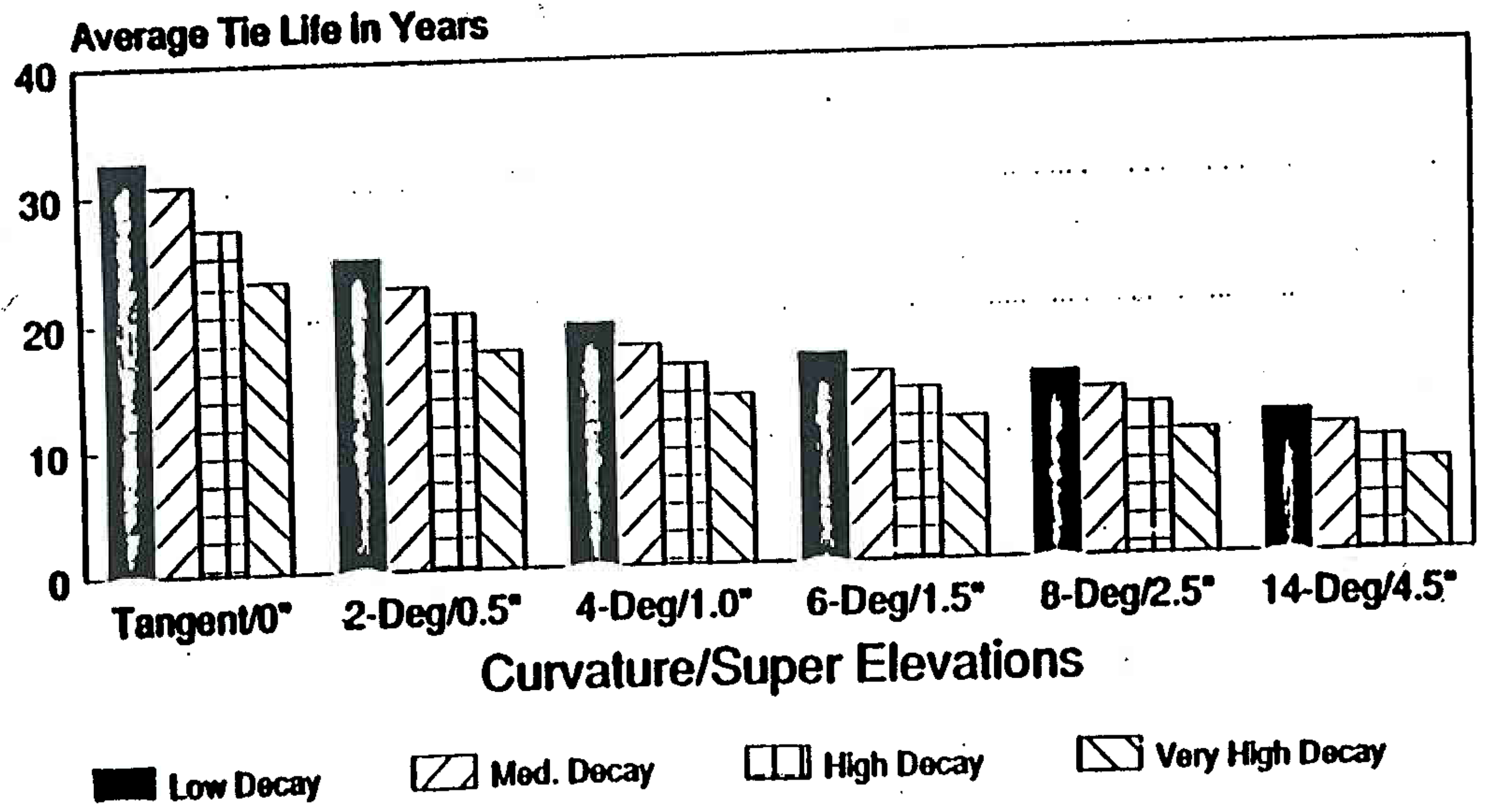

Tie Life vs Density and Curvature
60
50
40
30
20
10
0
Tie Life (years)
0
20
40
60
80
100
120
Annual Density (MGT)
■ Tangent
◆ 2 degree curve
▲ 6 degree curve
□ 10 degree curve

Figure 4

Average Tie Lives

30 mph Speed, 30 MGT Annual Traffic
33-Ton Axle Load Unit Trains



Hardwood Ties

Figure 5 Sensitivity of Average Tie Life Over Curvature for Hardwood Ties

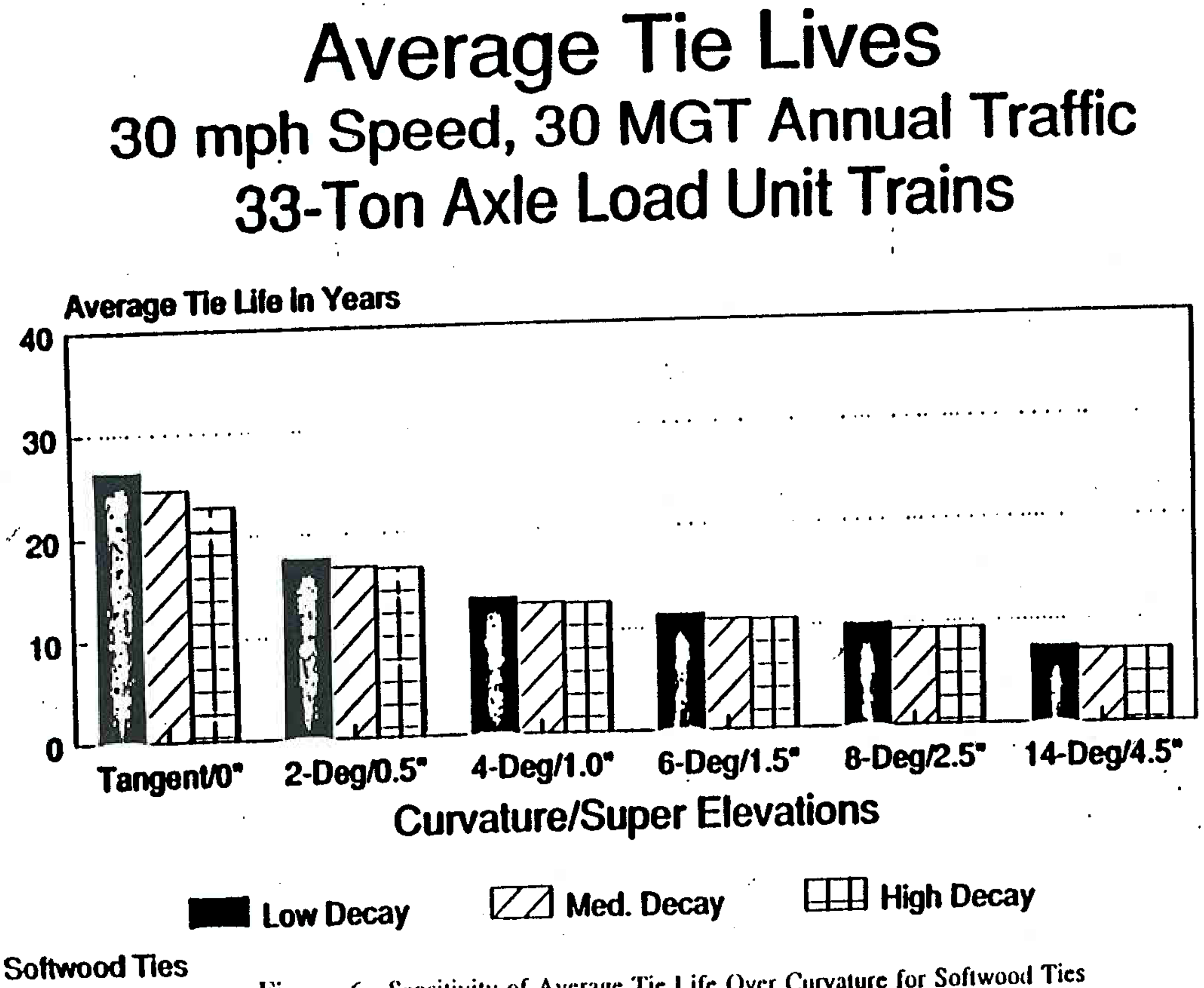


Figure 6 Sensitivity of Average Tie Life Over Curvature for Softwood Ties

TABLE 3
Parameters That Affect Tie Life

Traffic Characteristics
Traffic Density (annual)
Speed
Axle Loading
Traffic Type

Track Geometry
Curvature
Grade

Track Condition
Rail Section
CWR vs. JT
Ballast/Track Support
Fastener Type

External Factors
Environment (Temperature, Humidity, "Decay Hazard")
Wood Type (Hardwood vs. Softwood)

these sensitivities have been normalized, so that the relative effect can be readily observed. Unless otherwise noted, these sensitivities are based on the WSAC tie life relationships [10], which are presented in more detail in Table 4.

Traffic Characteristics

Traffic Density (annual)

Traffic density has a direct and non-linear effect on the life (in years) of the timber crosstie. Unlike other track components (e.g. rail), where there is a direct and linear relationships between life in years and life in cumulative tons (MGTs), in the case of tie life, traffic density (in MGT/year) has a direct and non-linear effect on tie life. This is clearly illustrated in Figure 7, which shows that while tie life (in cumulative MGT) increases with increasing annual density, it also increases at a less than linear rate [13]. Translating this into tie life, in years, results in the declining life with density behavior previously presented in Figure 2. This is due to the shift in failure mechanism to mechanical failure (which dominates under high traffic density) from natural (decay) failure mode, which dominates in low density situations (Table 2).

This effect is more clearly presented in Figure 8, which shows the relative sensitivity of tie life as a function of traffic density.

This effect takes the form of

$$Life \propto Density^m$$

where m varies between 0.6 and 0.74.

Note; values for the density exponent m include 0.74 (CIGGT [4], WSAC [10]), 0.61 (TOPs [9]) and $m = 0.66$ (Reiner [8]).

Speed

On both tangent and curved track, the vertical dynamic load is a major load factor applied to the track structure, which greatly influences the mechanical wear life of ties. Therefore, it is necessary to augment the static wheel or axle load with a dynamic speed effect. Numerous such speed effect relationships have been developed. Figure 9 compares the standard AREA speed effect formula with seven other equations[14]. As can be seen from this figure, in the speed range typical of North American freight operations, the AREA speed effect is a good representation of this dynamic effect. The result is a dynamic wheel force.

TABLE 4
WSAC Tie Equation [10]

Tie Life = a * Tie Relative Life

where a is a calibration constant

$$\text{Tie Relative Life} = \frac{G' * PD' * D'}{R' * J' * K(C) * E'}$$

where:

$G' = (1+.023^2 * g)$

$PD' = P * (1 + 33 * S/(100 * d))/36.9$

$K(C) = e^{-.061C}$

$E' = (63 - DH/7.25) / 55.41$

$D' = (D/25)^{0.74}$ for $D<25$ MGT

and $D' = 1$, for $D>25$ MGT

where:

R'= rail size factor

for Rail Size	R'
136 RE	1.02
132 RE	1.00
119 RE	0.95
115 RE	0.93
100 RE	0.86

$J' = 1$ for CWR
$= 0.95$ for Jointed Track

and:

P = the static axle load.
S = the speed in mph.
d = the wheel diameter in inches.
C = curvature, in degrees.
g = grade in percent.,
D = annual traffic density, in MGT/year.

DH = Decay Hazard value for the respective region.

Region	Decay Hazard
West	55
East	90
South	180

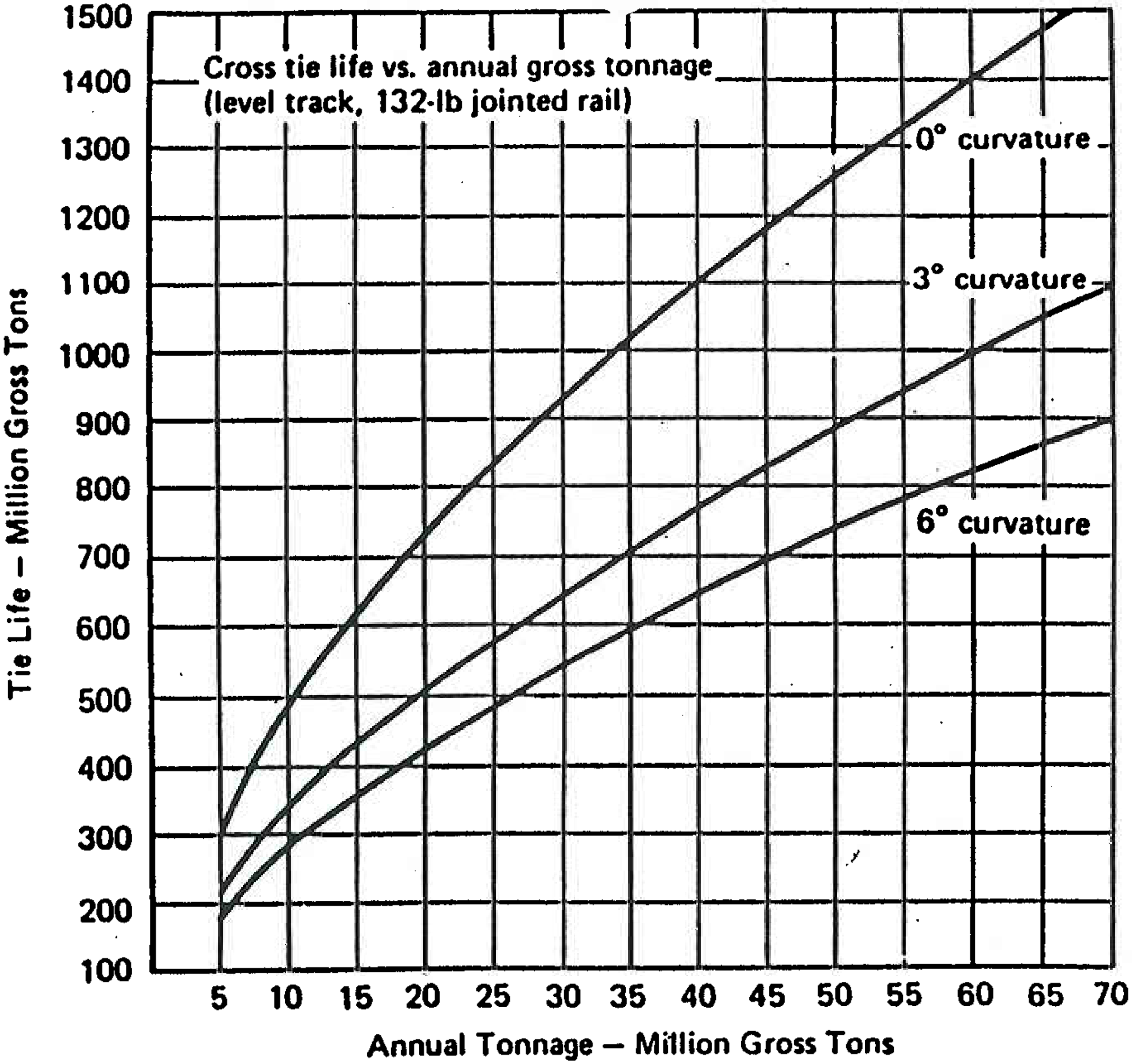


Figure 7 Cross tie life versus annual gross tonnage ("Procedures for Analyzing the Economic Costs of Railroad Roadway for Pricing Purposes," Report prepared by TOPS On-Line Services, J. H. Williams *et al.*, for U.S. Department of Transportation, FRA Report No. RPD-11-CM-R, DOT-FR-30028, January 1976, Figure 4, p. VII-62).

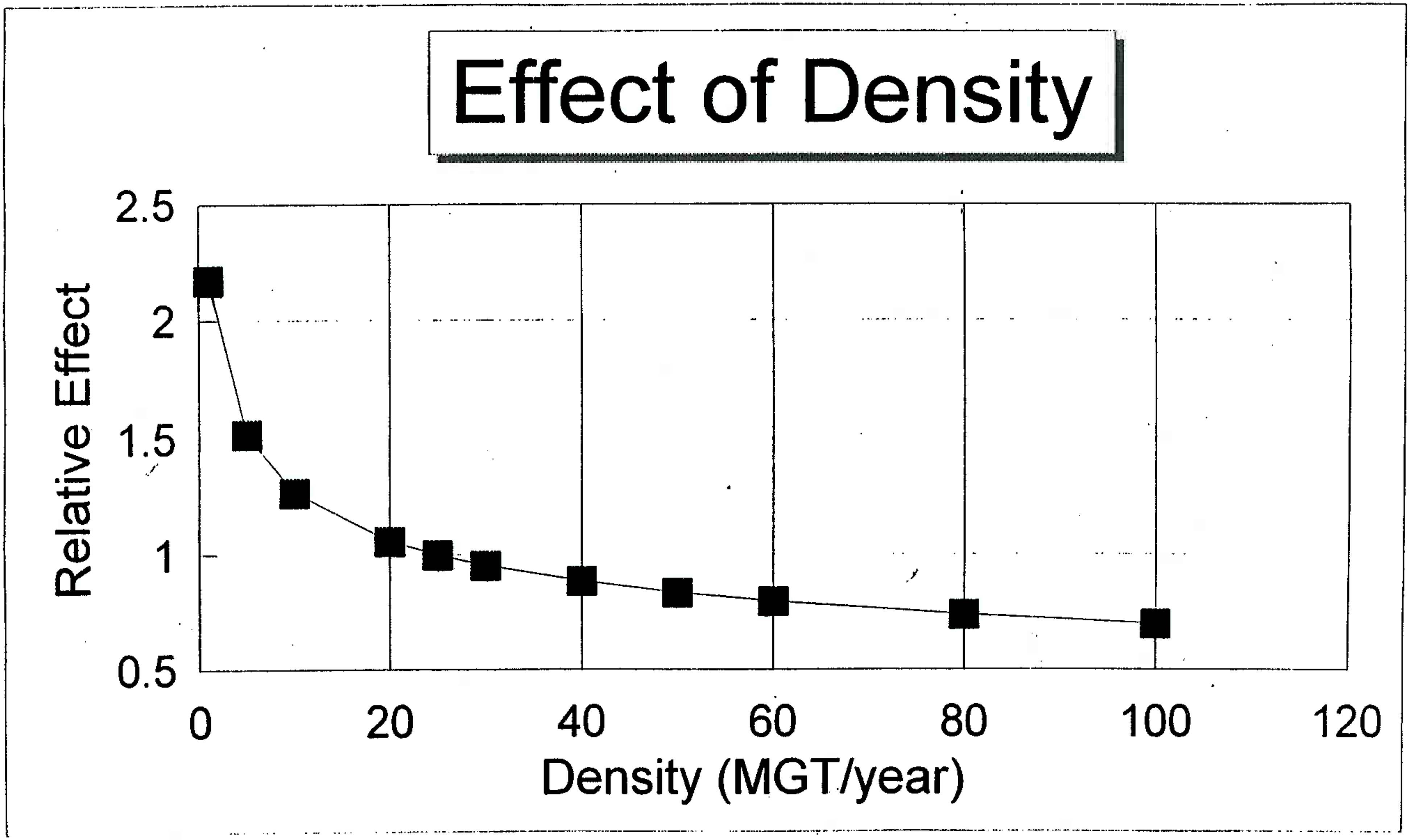
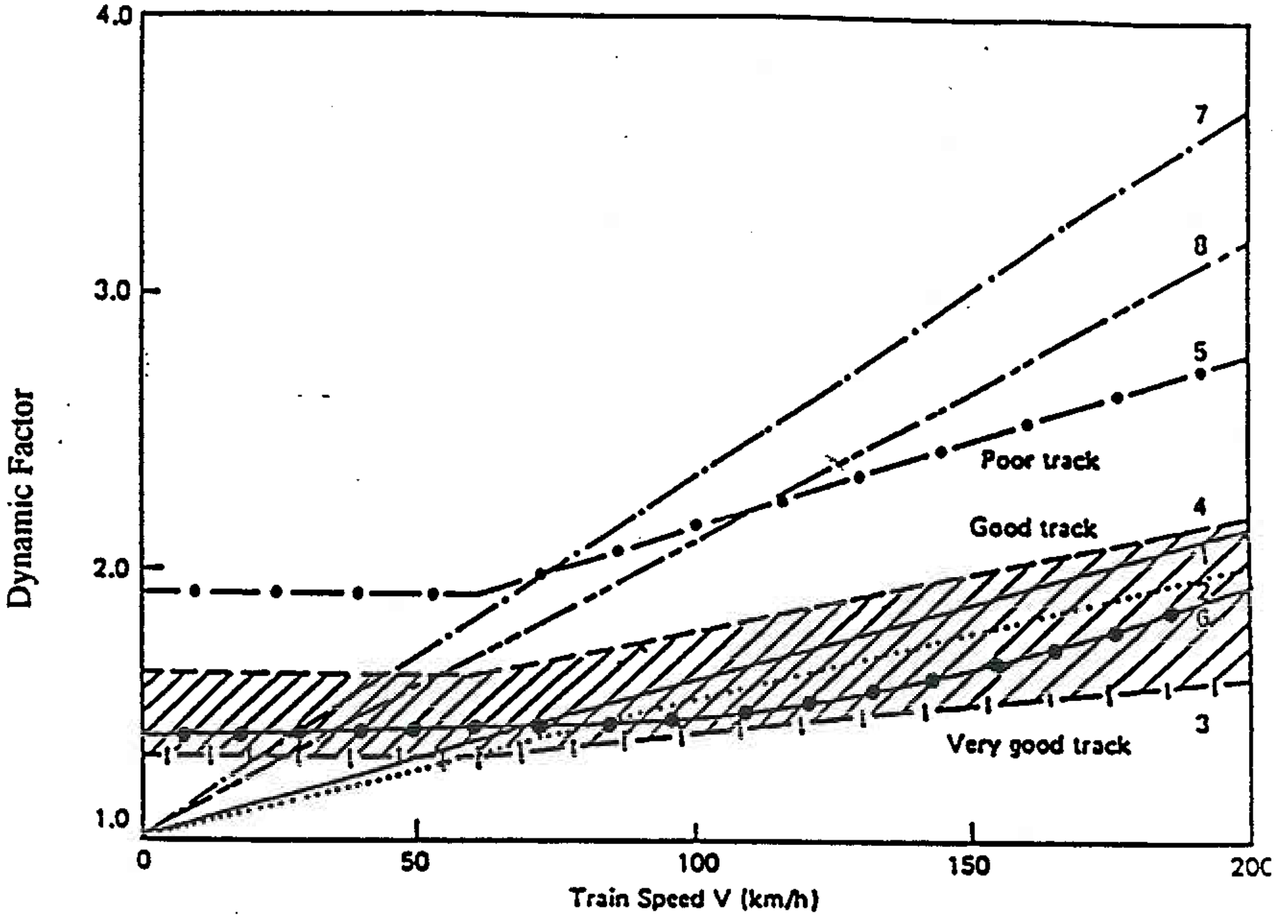

Effect of Density
Relative Effect
2.5
2
1.5
1
0.5
0
20
40
60
80
100
120
Density (MGT/year)

Figure 8



Legend:

No.	Formula	Remarks
1	Area	Wheel diameter = 900 mm
2	Area	Wheel diameter = 1000 mm
3	Eisenmann	Very good track UCL = 99.9%
4	Eisenmann	Good track UCL = 99.9%
5	Eisenmann	Poor track UCL = 99.9%
6	Ore	β assumed = 0.20 a_o = 1.5, b_o = 1.2
7	B.R.	Class 55 Deltic Diesel Elec. P_s = 86.2 kN P_u = 65 t
8	B.R.	Kestrel Diesel Elec. P_s = 112.7 kN P_u = 2.12 t

Figure 9 Comparison of Speed Effect Formulas

$$PD = P *(1 + 33*S/(100*d))$$

where:

P = the static axle load.
S = the speed in mph.
d = the wheel diameter in inches.

The effect of this speed relationship on tie life is illustrated in Figure 10.

It should be further noted that for curved track, the effect of speed is augmented by the actual balance speed and superelevation of the curve. The relationship presented in Figure 10 is based on balance speed (i.e. elevation set to match curvature and operating speed). The unbalance effect is included in the curvature effect presented later in this paper.

Axle Loading

Research studies have shown that the effect of axle load on track component life is given by the relationship:

$$\frac{\textit{Life under Load } P1}{\textit{Life under Load } P2} = \left(\frac{P2}{P1}\right)^n$$

where:

$P1$ and $P2$ are wheel (or axle) loads
and n is a constant

The development of suitable n values has likewise been the subject of extensive research. In the case of wood crossties, the following values have been defined:

$n = 1$ defined by TOPs [9], WSAC [10], Hay [3][13], Talbot[3] [15].
$n = 1.42$ defined by Reiner [8]
and $n = 2$ defined by CIGGT [4].

Figure 11 presents this axle load effect on tie life.

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[3] Based on linear beam-on-elastic foundation theory, where tie life is related to the stress level on the tie.

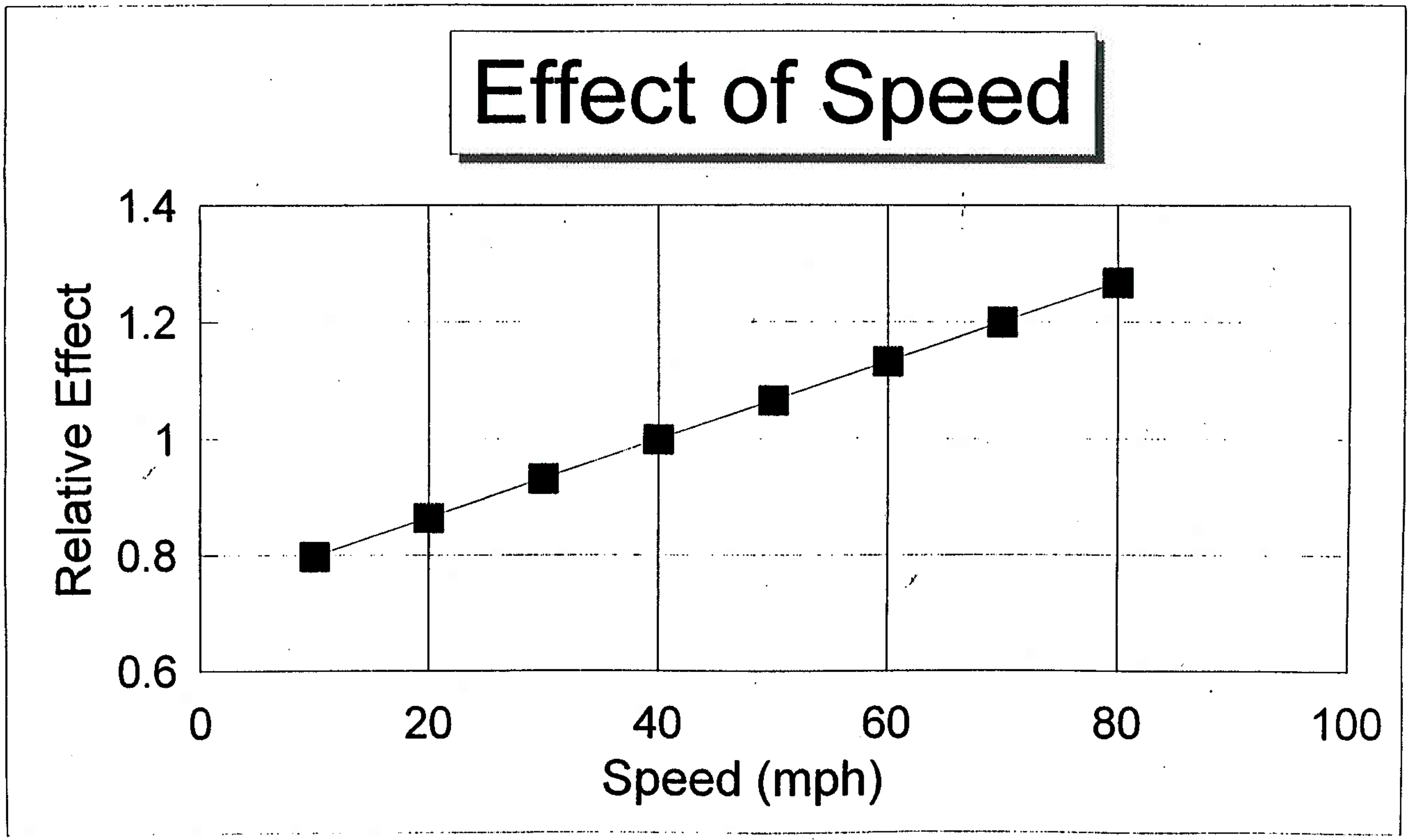
Effect of Speed
Relative Effect
1.4
1.2
1
0.8
0.6
0
20
40
60
80
100
Speed (mph)

Figure 10

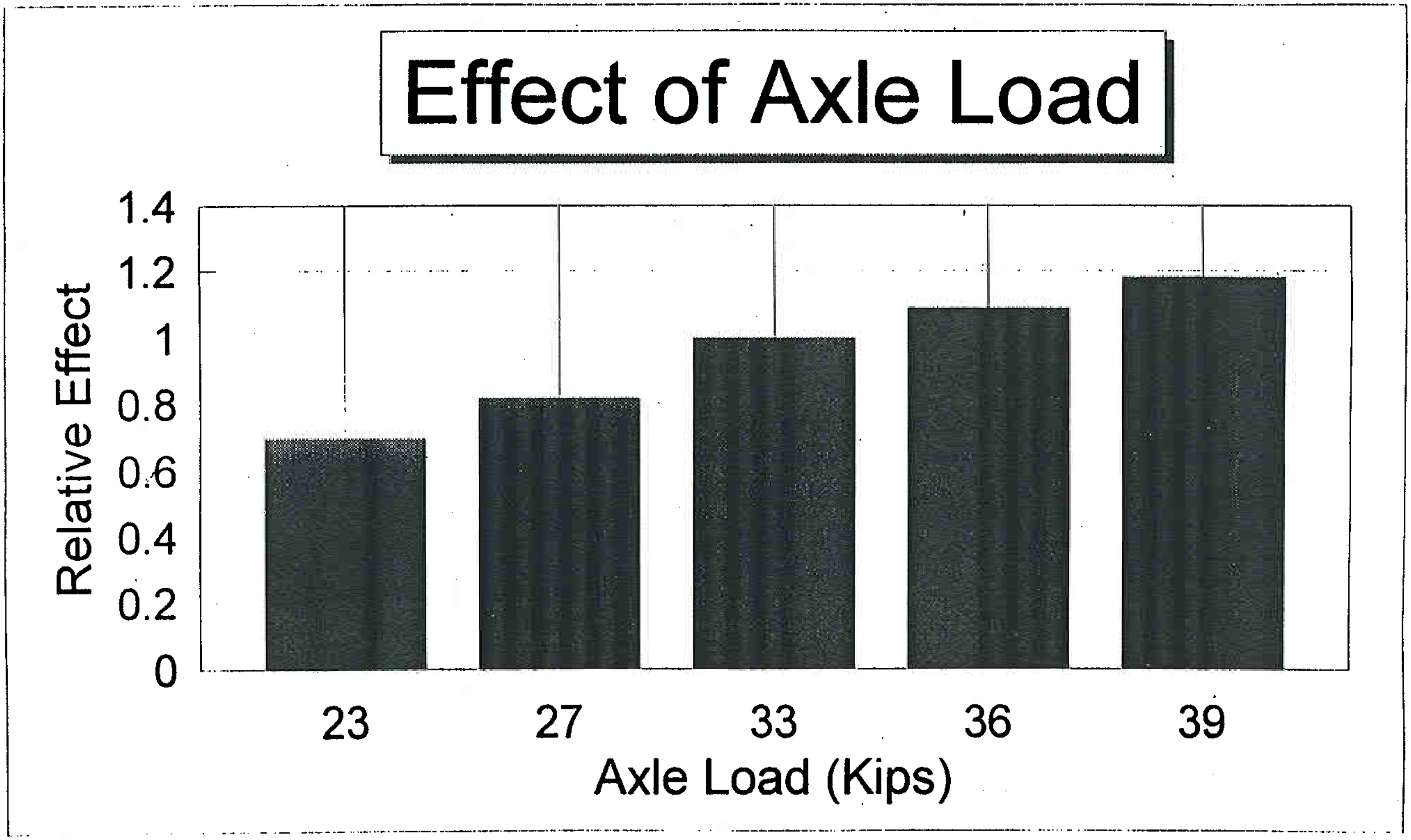
Effect of Axle Load
Relative Effect
1.4
1.2
1
0.8
0.6
0.4
0.2
0
23
27
33
36
39
Axle Load (Kips)

Figure 11

Traffic Type

Traffic type is often defined in terms of axle load and speed. These "effects" have already been discussed. Other traffic effects include unit train effects, i.e. where all axles uniformly and regularly impact the track, generating a "harmonic" loading environment. Likewise lateral curving behavior differs significantly as a function of traffic and equipment type. Thus, for example, cars equipped with self steering trucks (e.g. radial trucks) generate significantly less lateral forces, which in turn reduce the damage (and thus rate of degradation) on curves. As a result, the impact on tie life in curves would be reduced, with some data suggesting that this reduction would be of the order of 70 to 90% of the curving effect noted with conventional three piece trucks.

Track Geometry

Curvature

Curvature is a primary variable in tie life. This is due to the significant lateral forces that are generated by railway vehicles as they negotiate curved track. These lateral forces are transmitted to the ties, resulting in high levels of damage including plate cutting, gage widening, and spike damage. The results of this increased level of loading can be seen in the significant curvature effects previously shown in Figures 5 and 6 for hardwood and softwood ties respectively [11]. This is further compounded by the fact that as the curvature increases, the spiking patterns used by railroads change, with an increased number of spikes used in the higher curvature track. This is designed to negate the effect of increasing lateral load with curvature. However, one result of this is that there is an increased tendency towards spike killed ties in the higher curvatures because rail is changed out more frequently. With the increased number of spikes there are fewer available "fresh" spike holes (and holes can only be plugged a limited number of times). Therefore in higher curvature track, tie life may be a function of rail life (often 2 to 4 times rail life).

Noting this effect, a commonly postulated curve effect relationship is

$$Life \propto e^{-kC}$$

C = curvature in degrees.
And k is a constant.

This effect is illustrated in Figure 12 to reflect the sensitivity of tie life to curvature.

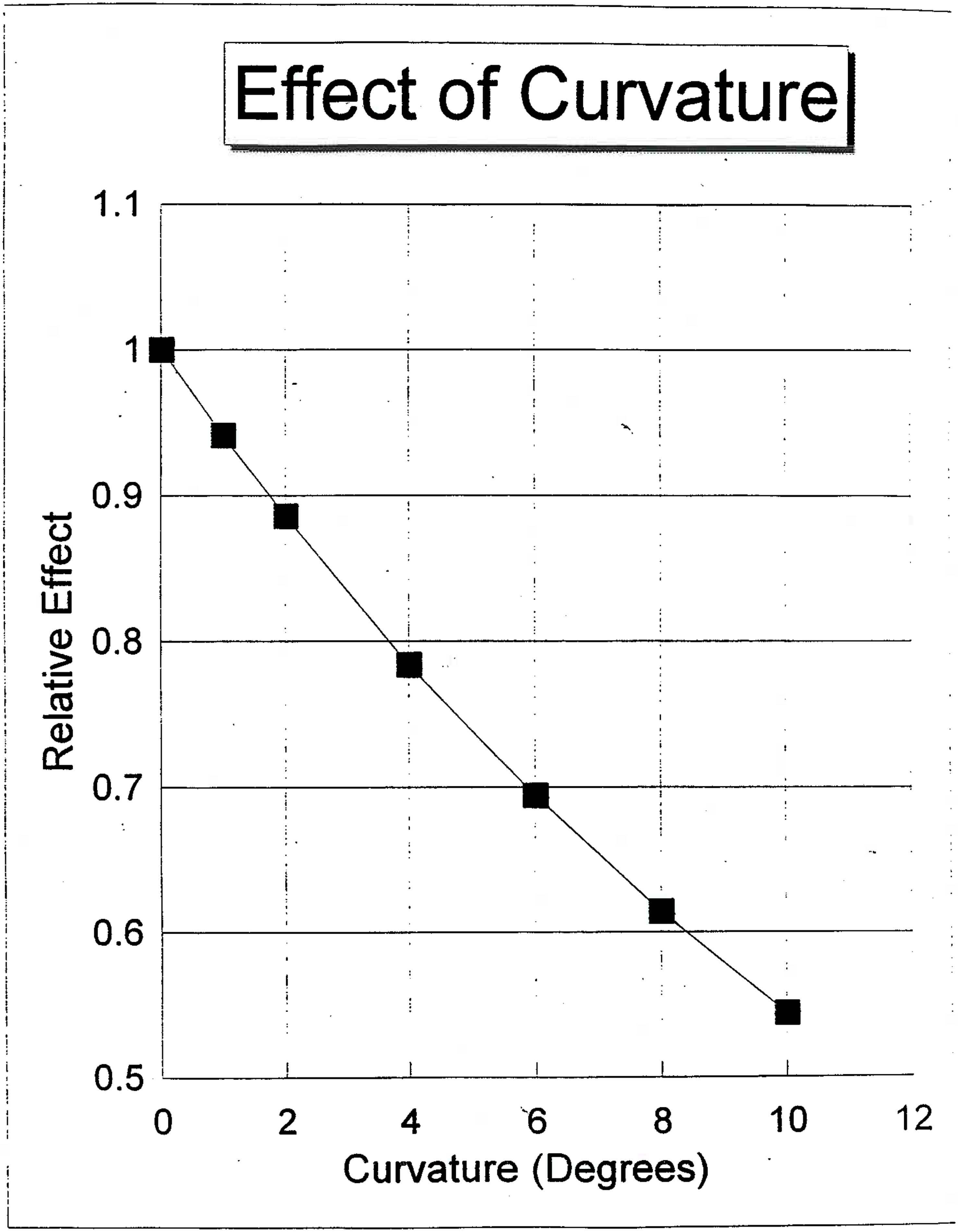
Effect of Curvature
Relative Effect
1.1
1
0.9
0.8
0.7
0.6
0.5
0
2
4
6
8
10
12
Curvature (Degrees)

Figure 12

Grade

The effect of grade on tie life has only very limited data available. The most effective analysis of this effect is that developed by Reiner [7] and subsequently used in the WSAC equation [11], in which the following relationship for tie life is developed:

$$Life \propto 1/(1+.023*g^2)$$

where

g = grade in percent.

This effect is presented in Figure 13.

Track Condition

Rail Section

In analyzing the relationship between tie life and rail size, it must be noted that the rail serves as a beam to distribute the applied wheel load across several cross-ties [13,15]. This distribution of load is related directly to the deflection of the track, which in turn is directly related to the moment of inertia of the rail to the 1/4 power.

Therefore, the relative effect of rail size (section) is directly related to the term:

$$(I/I\ reference)^{0.25}$$

where:

I = moment of inertia of the rail section

and $I\ reference$ = moment of inertia of the reference rail section.

Using the common 132 RE section as a reference (*I reference* = 88.2) , the relative effect of rail section is presented in Figure 14.

CWR vs Jointed Rail

While mainline track is predominantly Continuously Welded Rail (CWR), large stretches of jointed track remain. The effect of joints in track is that of generating increased dynamic wheel/rail forces. This effect is aggravated in the presence mismatched or battered joints which increase the dynamic wheel rail forces even further. Thus the rate of this degradation is related to the condition of the joints themselves, with joints in poor condition, having a significantly greater effect on tie life than well maintained joints.

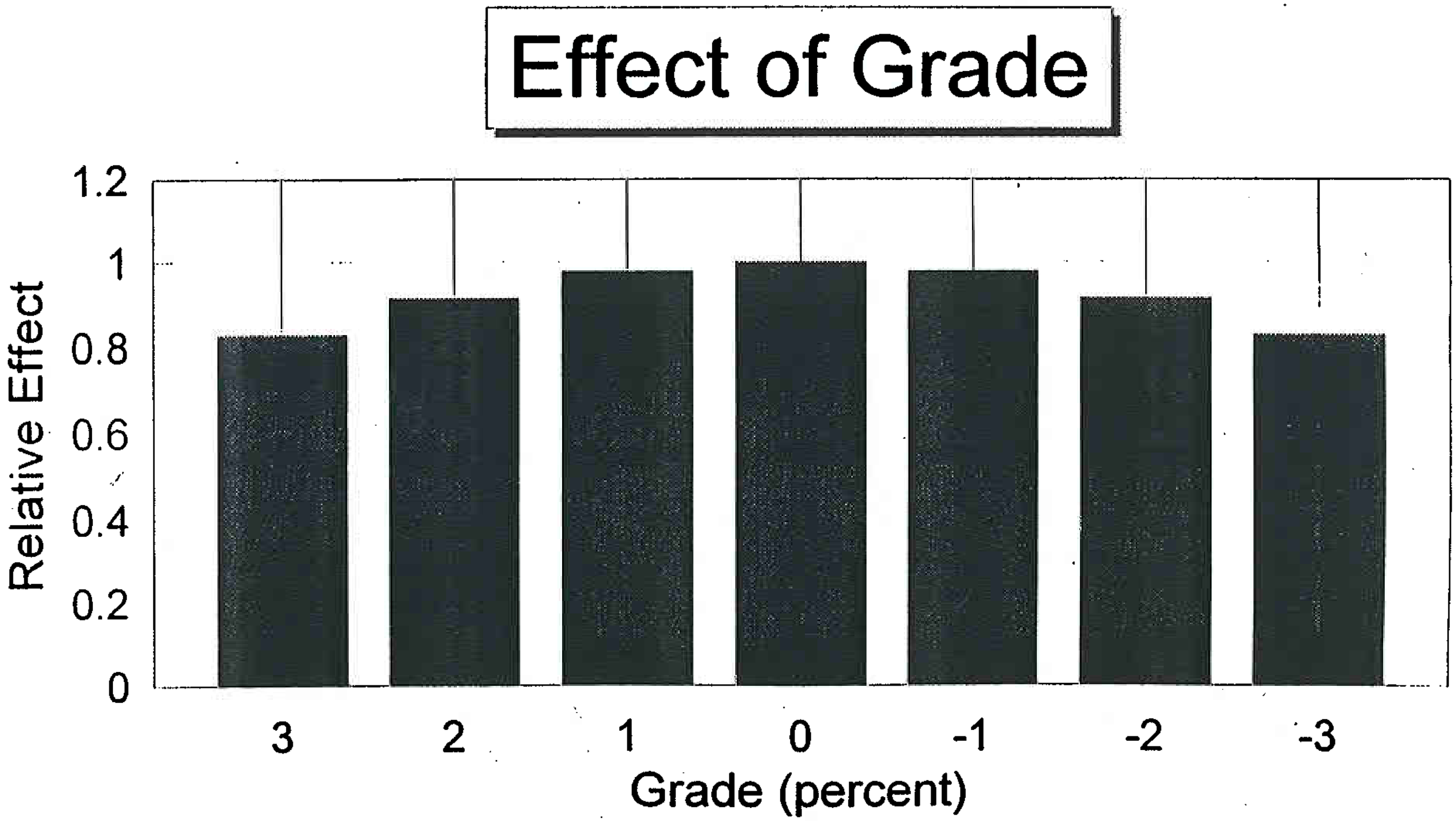
Effect of Grade
Relative Effect
1.2
1
0.8
0.6
0.4
0.2
0
3
2
1
0
-1
-2
-3
Grade (percent)

Figure 13

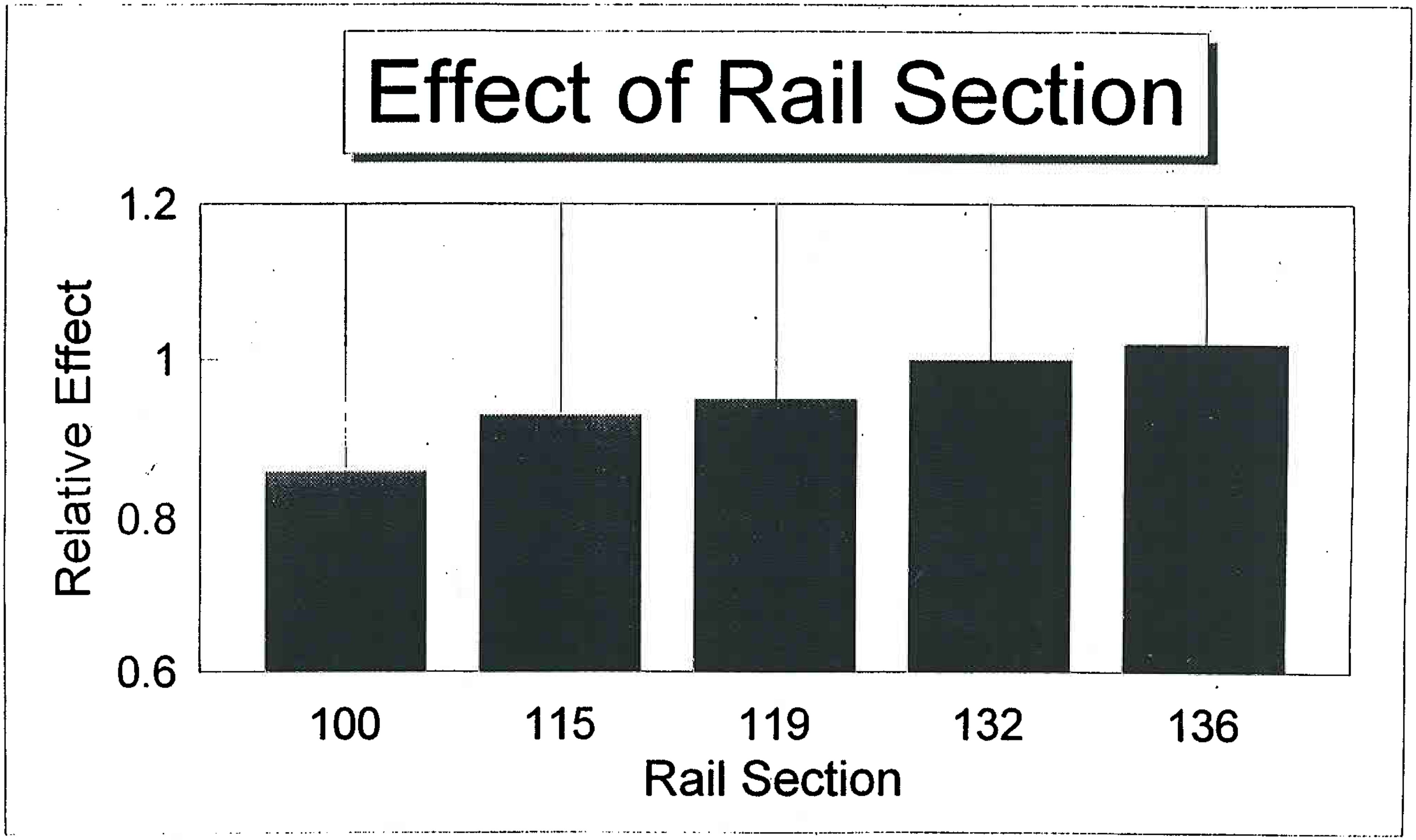
Effect of Rail Section
Relative Effect
1.2
1
0.8
0.6
100
115
119
132
136
Rail Section

Figure 14

The effect of joint condition on tie life, was analyzed by several studies to include TOPS study [9] and WSAC [10]. The resulting sensitivities of tie life to the presence of joints (to include joints in poor condition) is presented in Figure 15.

Ballast/Track Support

Tie life can be significantly effected by the condition of the ballast and the corresponding support of the crosstie. In the extreme case, center binding of the tie can result in dramatic premature tie failure, through center cracking. Non-uniform tie support can likewise increase the bending loading in the crosstie and effect its service life.

Ballast that is dirty or that does not allow free drainage can cause water to accumulate around the bottom of the crosstie. This in turn will result in an increased rate of deterioration, both due to decay, and due to combined decay and mechanical degradation (e.g. the bottom of the wet crosstie becomes more susceptible to abrasion of the wood).

While it is generally difficult to define the condition of the ballast and subgrade, it is possible to define the level of track support (such as by means of the track modulus [13]). Figure 16 presents the generalized sensitivity of tie life to three such levels of ballast condition/track support corresponding to good, moderate, and poor condition. Note that poor ballast and support condition can reduce tie life by more than 40%.

Fastener Type

The effect of increased numbers of cut spike fasteners, such as commonly used on sharper curves, has already been accounted for in the curvature effect. However, increasingly, railroads are introducing elastic fastener systems, such as the Pandrol fastening or other comparable system. These elastic fastener systems separate the rail hold down function (usually performed by the clip) from the plate hold down function (usually performed by screw or lock spikes). Therefore these systems avoid the problems of spike killed ties, associated with frequent rail change outs on sharp curves. They also provide for increased gauge holding strength, thus reducing the damage associated with dynamic gauge widening of the rail/fastener/tie system, as can commonly occur on sharper curves in heavy traffic territory.

The resulting effect on tie life will vary significantly as a function of curvature and traffic density, however, significant extension of wood tie life has been reported on moderate to sharp curves on high density main line tracks.

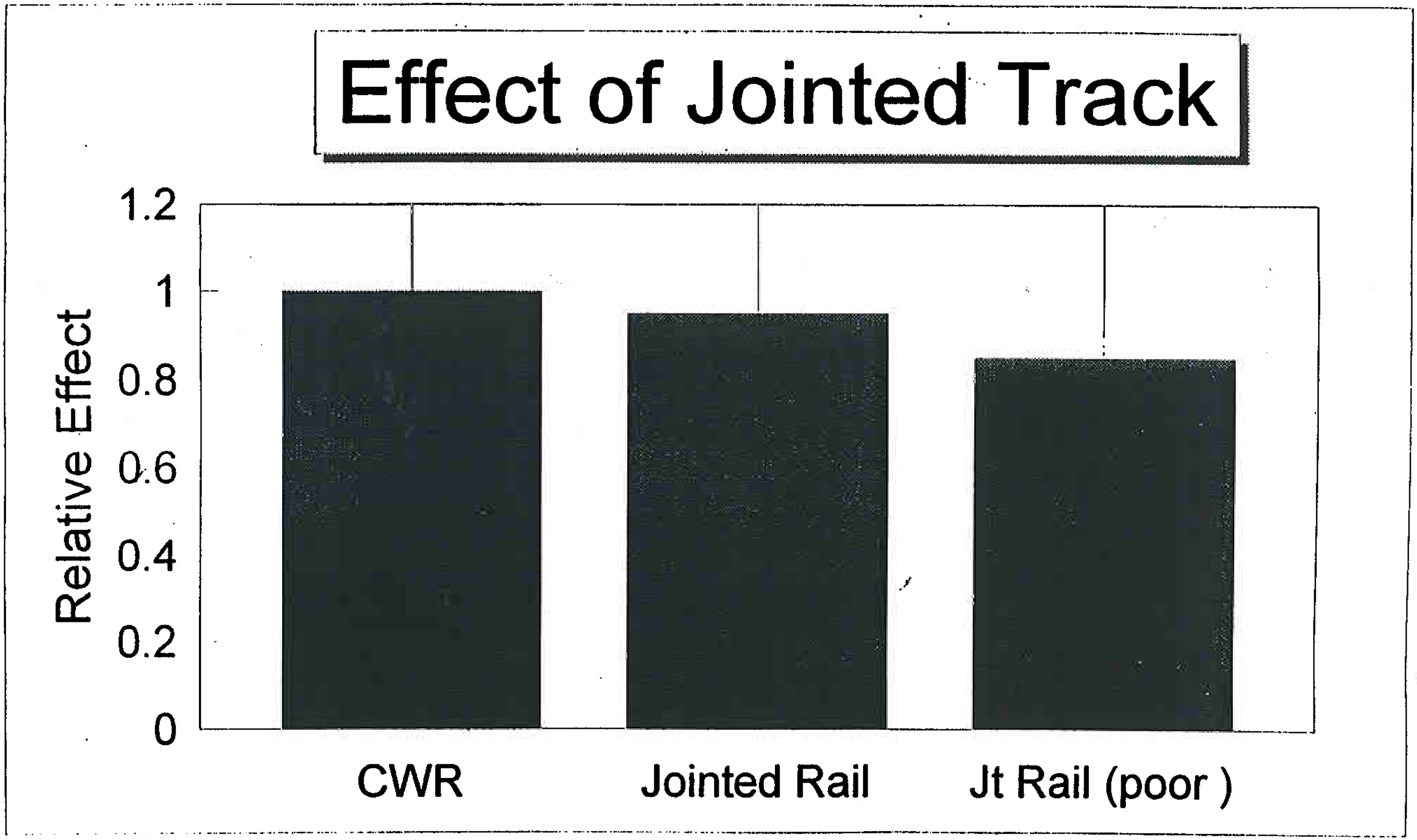
Effect of Jointed Track
Relative Effect
1.2
1
0.8
0.6
0.4
0.2
0
CWR
Jointed Rail
Jt Rail (poor)

Figure 15

Effect of Ballast/Track Support

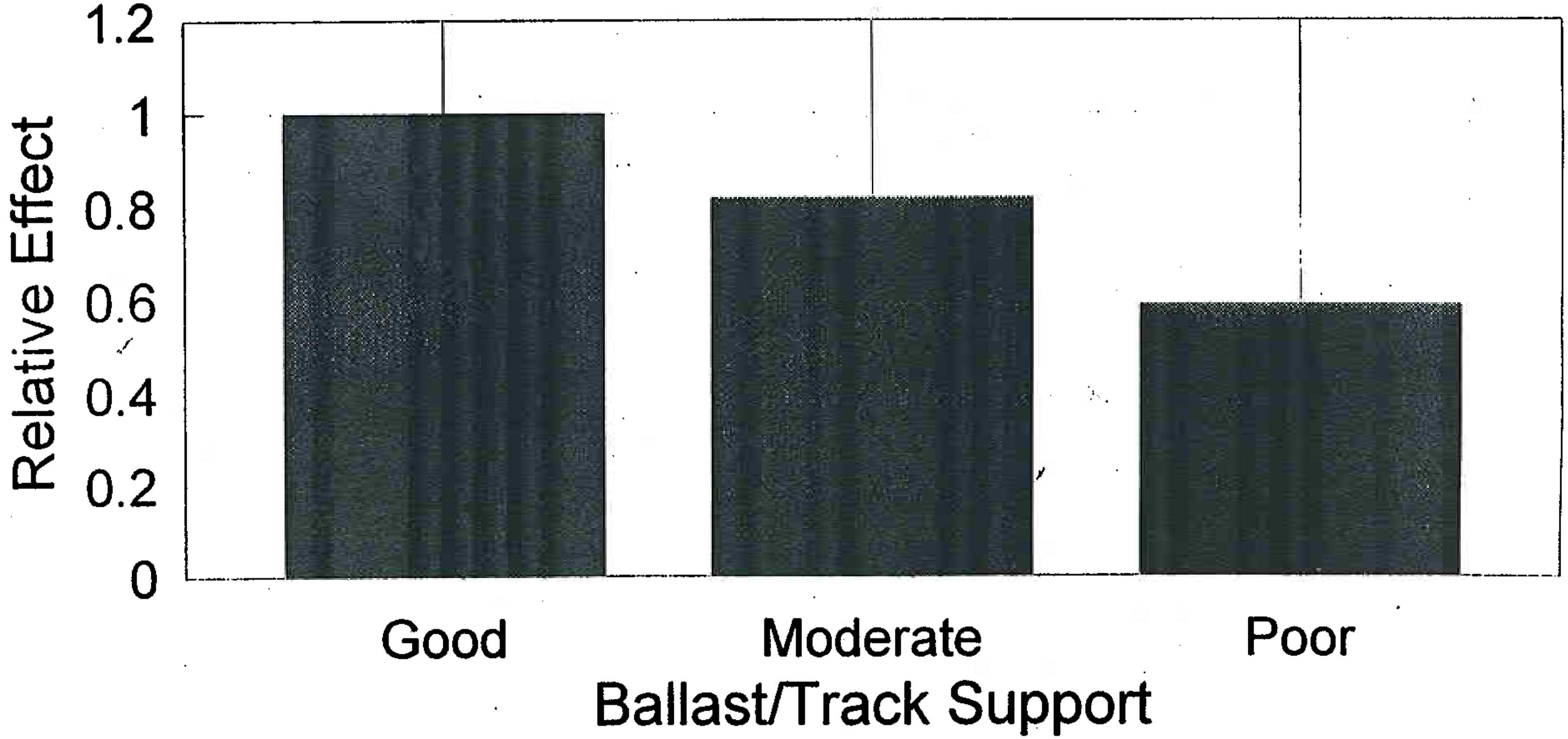

Figure 16

External Factors

Environment

As noted earlier, decay is an important failure mode for wood ties. This is illustrated in Table 2, where, for high density lines, natural failure modes (to include decay) represent approximately up to 50% of the ties that fail.

These environmental conditions can include rainfall, temperature range (variation), temperature extremes (hot and cold), freeze-thaw cycles, snow, water, as well as biological factors, such as fungi (Table 1).

One of the most effective techniques for relating these factors to tie decay, and thus tie life, is through the use of the U. S. Department of Agriculture's "decay hazard" values [12]. A map of these Decay Hazard values was developed by the Department of Agriculture, allowing for the determination of these values for geographic regions (Figure 17).

In analyzing this map, the United states can be divided into three zones [12], with decay hazards levels as follows:

Region	Decay Hazard
West	55
East	90
South	180

These, values, can , in turn, be related to relative tie life, as presented in Figure 18. Note that the "hot" and "wet" environment of the Southeastern US can result in a 30% reduction in tie life (from the nominal Eastern US value). In a similar manner the "hot" and "dry" environment of the Western US (particularly the Southwest) can result in an *increase* in tie life (with nominal tie life values exceeding 50 years).

Wood Type (Hardwood vs Softwood)

The final variable to be discussed is that of wood type. While tie life does in fact differ by species, in the general sense there is a large difference in tie life between hardwood and softwood ties, particularly on heavier density track and on curves. In the higher load environment, hardwood ties resist degradation longer, and as a result "hold up" better in main line service. As a result, most major freight railroads in the United States use hardwood ties exclusively. Furthermore, of these hardwood ties, the oaks, red and white, are most commonly preferred and used. Softwood ties are used on a much

DECAY HAZARD MAP of the UNITED STATES

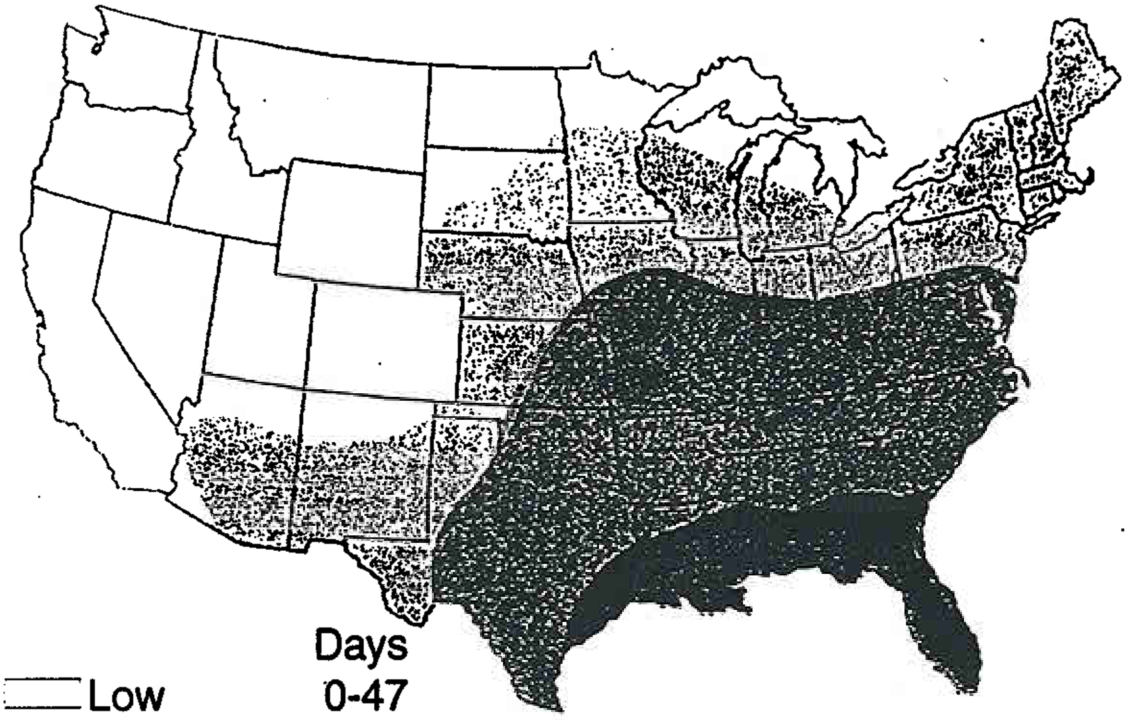

FIGURE 17
Decay Hazard Map

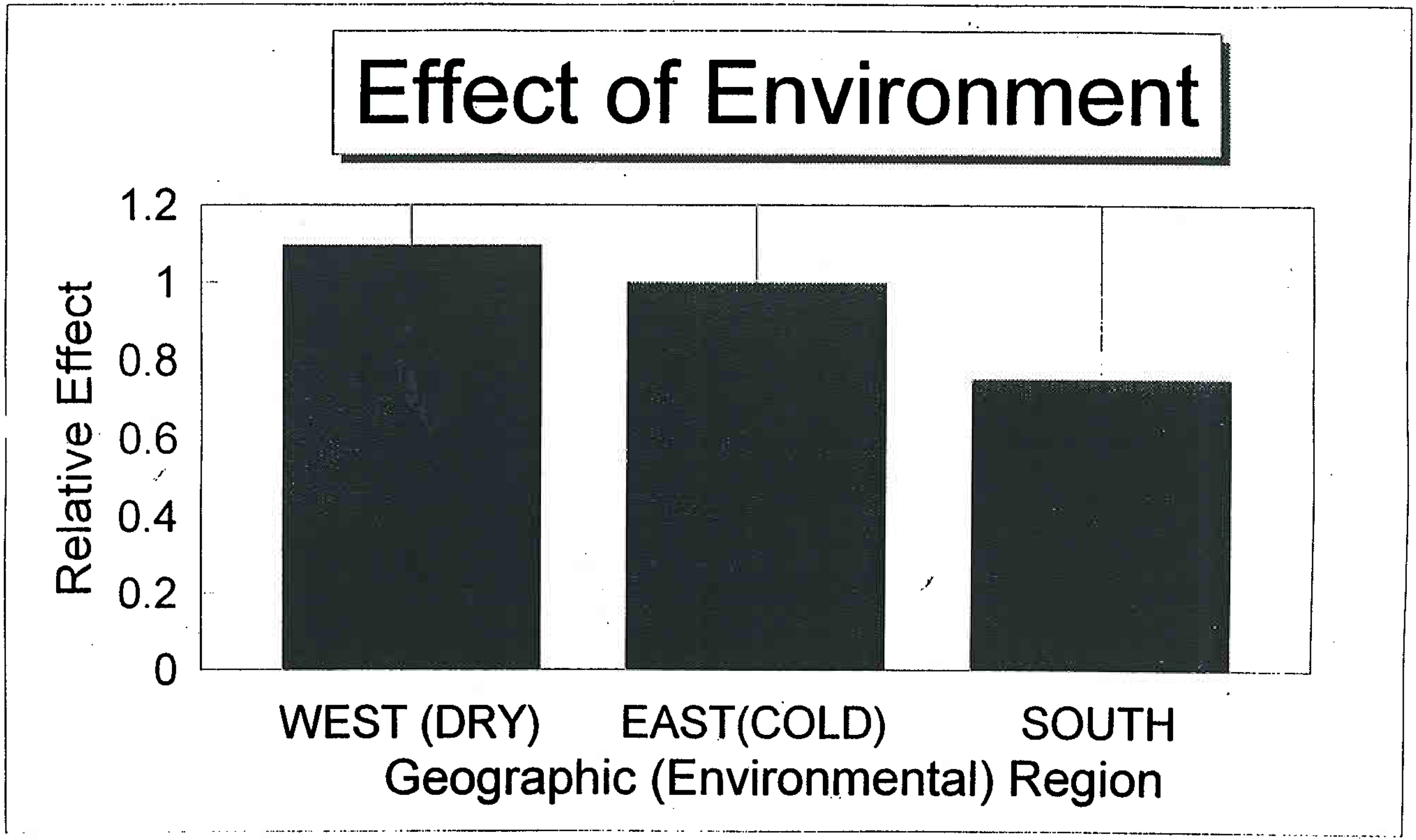
Effect of Environment
Relative Effect
1.2
1
0.8
0.6
0.4
0.2
0
WEST (DRY)
EAST(COLD)
SOUTH
Geographic (Environmental) Region

Figure 18

more limited basis in the US. (They are more common in Canada because of availability and cost issues.)

The effect of wood type was presented earlier in Figures 5 and 6 [11]. Figure 19 presents the relative sensitivity of tie life to wood type for light and severe curvature track. Again note (as in the case in Figures 5 and 6) the effect of the more severe curvature on the softwood ties.

Summary

Because of the variability in wood strength characteristics and the service requirements of differing railway environments, there is no single tie "life" value that can be generally applied. Tie life is a function of a range of factors that include tie type and treatment on one hand, and the track and traffic environment of the railway on the other hand.

As a result, tie life can range from as long as 50 years in secondary track in a dry climate to as short as 10 years (or less) on sharp mainline curves in the "hot" and "wet" Southeast.

The factors that effect tie life include traffic factors (tonnage, equipment type), track geometry factors (curvature), design factors (rail section, ballast support, fastener type), environmental factors and material factors (wood type). These factors can significantly effect the tie life, thus making it necessary to understand the impact and consequences of any changes in the tie's operating environment or condition.

However, by proper understanding of these factors, it is possible to match the best materials and properties with the most severe operating environment to provide the wood crosstie user with a cost effective and reliable product to meet his needs.

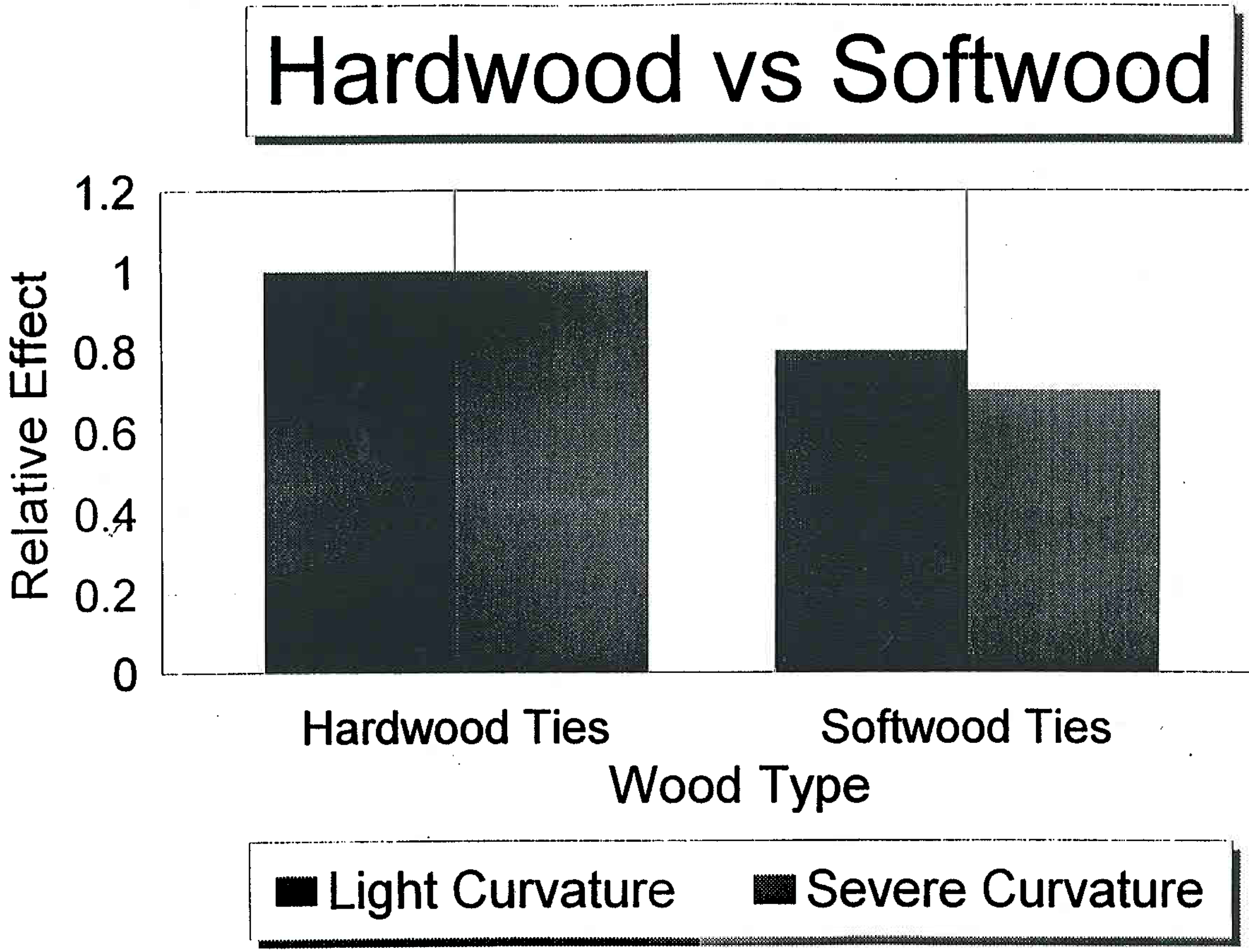
Hardwood vs Softwood
Relative Effect
1.2
1
0.8
0.6
0.4
0.2
0
Hardwood Ties
Softwood Ties
Wood Type
Light Curvature
Severe Curvature

Figure 10

REFERENCES

1. 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, BC June 1991.,
2. MacLean, J. D., "Percentage Renewals and Average Life of Railroad Ties", Forest Products Laboratory, USDA Forest Service Report No. 866, November 1957 (Reaffirmed 1965).
3. Wells, T. R., "Tie Failure Rate Analysis and Prediction Techniques", Association of American Railroads Report R-515, October 1982.
4. McIlveen, E. R., et al "The Road Maintenance Cost Model" , Canadian Institute of Guided Ground Transport (CIGGT) Report 80-16, March 1981.
5. Davis, D. D., and Shafarenko, V., "Tie Condition at Des Plaines: A Progress Report", Bulletin of the AREA, Bulletin 713, December 1987.
6. Chow, P., Lewis, S. L., Reinschmidt, A., and Barenberg, E. J., "Effects of Natural and Accelerated Aging on Oak Crossties", American Wood Preservers Association, 1987
7. Davis, D. D., "Tie Planning: A Progress Report of the Track Maintenance Research Committee", Association of American railroads Report WP-127, October 1987.
8. 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.
9. 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.
10. Zarembski, A. M. and Resor, R. , " Development of Alternate Maintenance of Way Cost Allocation Methodology", Final Report to the Association of American railroads Cost Analysis Organization, September 1988.
11. Acharya, D., "Tie Model: A Crosstie Replacement Planning and Life-Cycle Costing Model", Association of American Railroads, Report R-831, February 1994.

12. Russell, Allen, "Tie Decay-Underrated Factor", Railway Track & Structures, August, 1986.

13. Hay, W. W., Railroad Engineering, John Wiley & Sons, New York, 1982.

14. Doyle, N. F., Railway Track Design: A Review of Current Practice, Australian Government Publishing Service, Canberra, 1980.

15. Talbot, A. N. et al., "Stresses in Railroad Track-The Talbot Reports", American Railway Engineering Association, 1980.