AN ECONOMIC ANALYSIS OF ALTERNATIVE METHODS OF DRYING AND TREATING RAILROAD CROSSTIES

Letter Report

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EXECUTIVE SUMMARY

The Association of American Railroads has undertaken a series of accelerated aging tests on air, Boultonized, and vapor dried ties. Test results indicate that the actual difference in performance depends upon the characteristics required of the tie. In general, it is reasonable to conclude that air dried ties will perform better than ties dried by the other types of seasoning (a process which removes moisture). However, the financial impact of the differences in tie lives is negligible unless ties last less than 25 years.

An economic analysis of the initial treatment cost discussed in this report shows that air drying is very sensitive to the cost of the capital assigned to the green tie inventory. Air drying of ties takes 3 to 12 months, expending not only the cost of the green tie, but also the cost of transportation, purchasing, and initial processing. These costs, for a Grade 5, 8-foot 6-inch tie, are between $13.81 and $26.91, and average $18.24.

NOT CONRAIL or CN

Generally, Class 1 railroads own the ties that are in the air drying process, but whether the ties are owned by the railroad or the treater, there exists an assignable cost to the tied capital. One of the more difficult questions this report attempts to answer is: What interest rate should be assigned to this capital? Typically, economic analysis of methods will use 8 or 10 percent. In 1994, the Interstate Commerce Commission (ICC) determined that the revenue adequacy rate or the cost of capital should be 11.4 percent. If the railroad were investing in a new capital project, the minimum required rate of return would be 15 to 20 percent, and if they were in serious financial difficulty it would be a possible 50 percent or higher before committing to an investment.

Using a series of national averages for the cost of a tie, drying time, and alternative treatment costs, and the ICC's 11.4 percent interest rate, there is very little difference in the treatment cost between air drying and Boultonizing. While vapor drying is about 20 percent more expensive than Boultonizing, it only increases the cost of the average tie by 2 percent. If, however, the interest rate is lowered to 8 percent or raised to 15 percent, the difference in cost is about $0.66 a tie, in favor of air drying or Boultonizing. For a Class 1 railroad, this could translate to either a substantial savings or an extra cost. The exact savings or additional costs are contingent upon some 10 to 15 factors, many of which are specific to the location and treatment plant.

The only way to determine which is the optimum combination of treatment methods is by detailed analysis. Since the optimum will vary based on the green tie price, it will be constantly changing. It is therefore recommended that computer programs be developed to optimize purchases by location and treatment method, and that railroads train and assign personnel for this purpose. If the range of drying or seasoning times and green prices are considered, then there can be as much as a $1.10 per tie difference in cost between air drying and Boultonizing. Therefore, a Class 1 railroad may experience savings in excess of $0.5 million.

An analysis has also been made of the possible financial implications of using a combination borate and creosote tie treatment. At best, this type of treatment will raise the cost of a tie 5 percent to 8 percent (about $2.00 per tie). Even if it extends the tie life by 20 percent, in most cases, the financial result would still be negative. To offset the extra cost of borate treatment, the amount of creosote would have to be reduced by about 50 percent. The resultant creosote content would be below the minimum recommended for creosote treatment alone, however, the combination may be effective. Research must be undertaken to determine if this is feasible.

One of the purposes of using creosote with borate is to prevent the borate from being washed out of the tie. An alternative would be to coat or jacket the tie with some other material, such as a latex or an epoxy. If further research into borate is undertaken, then alternative jacketing materials should be researched.

TABLE OF CONTENTS

1.0 INTRODUCTION

The Association of American Railroads is researching the performance of crossties subjected to three methods of drying prior to treatment. The methods are: air, Boulton, and vapor drying.

Artificial drying, which can be completed in approximately a day, has the advantage of eliminating the need to inventory the green ties for air drying (for even up to a year). Each of these methods has an effect on the long-term structural strength and integrity of the ties, and therefore the life in track. The purpose of this analysis is to develop a general understanding of the likely economic impact of the differences in treatment cost in comparison to the life of the tie. The results of these three drying methods have been described in the AAR report number R-843 (7).

Several organizations, including the AAR, have experimented with borate as a supplemental or an alternative treatment for ties. Borate is a chemical compound of boron, a commonly found mineral. If used in appropriate concentrations, borate is also a fungicide and a herbicide. It has the advantage of being water diffusible, and, if given time, will penetrate the complete cross section of a tie. Unfortunately, because it is also water soluble, it will wash out into the track. Treatment first with borate and then pressure treatment with creosote, is thought to be the best treatment method. Although the AAR has undertaken some preliminary testing(6), there is insufficient data available to develop an understanding of the likely economics of such a process.

2.0 TIE TREATMENT METHODS

There are three methods of commercially seasoning a tie prior to treatment: air drying, Boultonizing, and vapor drying. The basic components of these processes are shown in Figure 1. (A discussion of the costs listed in Figure 1 appears in Section 5.0.) The possible approach to borate treating ties is also shown in this figure.

Before the appropriate treatment process is applied, all ties are unloaded, sorted, trimmed and possibly incised and end-plated. Then the process changes, depending upon the treatment method used.

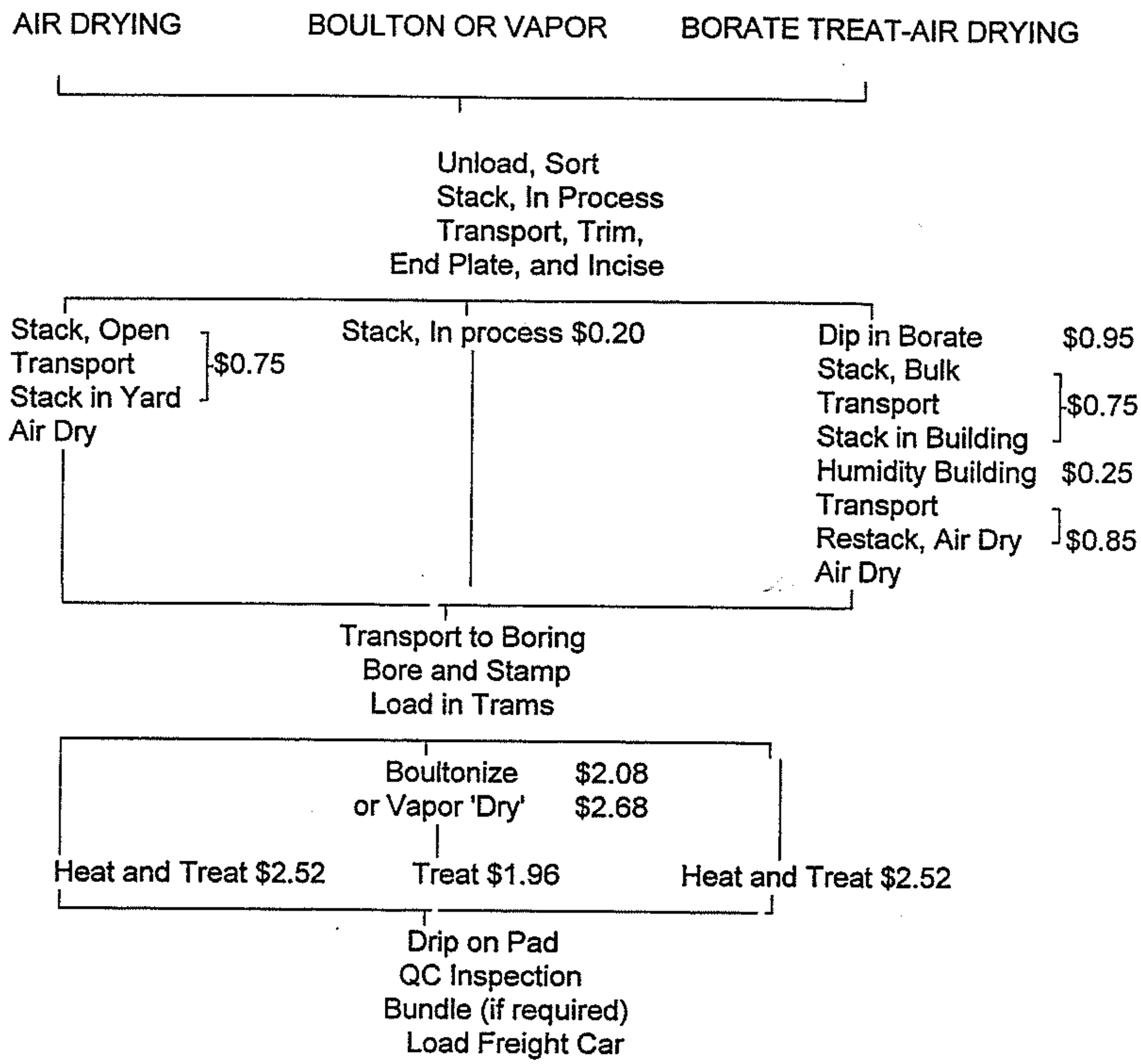

Figure 1. Basic Components of the Tie Treatment Process
(cost for 'average' tie shown after component (1))

2.1 AIR DRYING

Ties are mechanically stacked to allow for good air circulation. These stacks are then transported to the yard and stacked as high as the fork lift can reach. The ties are then periodically tested for moisture content, and at an appropriate time, they are transported to the boring and stamping facility, and, after processing, are loaded into the trams for treatment. The preservative pressure treatment usually requires 8 to 10 hours.

2.2 BOULTONIZING

After end plating, the ties are transported to the boring and stamping facility and loaded onto the trams for treatment.

Boultonizing removes moisture from a green tie by boiling it in creosote in the treatment cylinder, while in a vacuum. This process, which must be used only on unseasoned ties, has the advantage of being able to treat ties without months of delay for air treatment.

The drying process in the cylinders takes between 10 and 18 hours and averages 16.6 hours. The tie is then treated in 6 to 7 hours, by applying creosote under pressure. Treatment is quicker using this process, rather than the air drying method, since the ties have already been heated. The actual national average drying time is probably closer to 18 hours, since few softwoods, and only a small percentage of the hardwoods are Boultonized.

With this process, control is critical to the final tie quality. For example: if partially seasoned timber is Boultonized, a lower quality tie will result. From the time the tree is felled until it is dried in the cylinder should take not more than 30 days.

2.3 VAPOR DRYING

This method is similar to Boultonizing, except the green ties are placed in the treatment cylinder and subjected to organic vapors to remove moisture. The vapors condense on the tie surface, which boils the water off the ties. After vapor drying, the cylinder must be drained before the creosote is pumped in. As a result, this process, while similar to Boultonizing, requires a slightly longer treatment cylinder time. It also requires effective process control.

2.4 BORATE DIP - AIR DRYING

Borate tie treatment has never yet been undertaken on a large scale. Based on discussion with tie treaters, the likely procedure would be to index the ties by the trim and end plating facility conveyor through a hot soak tank and then bulk stack them. The stacks would then be transferred to a humidity controlled building for borate diffusion. After 6 weeks, the stacks would be disassembled and transported to the air drying yard and restacked to allow for good air circulation. The ties are periodically tested for moisture content. At an appropriate time, the stack would be transported to the boring and stamping facility to be processed. After processing, the ties are loaded into the trams for treatment, which would be similar to the process used to air dry ties.

2.5 BORATE DIP - BOULTON OR VAPOR DRYING

This process is similar to Borate Dip - Air Drying. Instead of restacking the ties for air drying, however, they are transported to the boring and stamping facility. The ties are then loaded into the trams for transfer to the treatment cylinders using a procedure similar to the Boulton or vapor process. Because the drying process appears to remove the borate, it is probably not effective.

3.0 EVALUATING THE PHYSICAL EFFECT OF VARIOUS NEW TIE TREATMENTS

Under the Association of American Railroad's sponsorship, the University of Illinois developed a process to accelerate the aging of tie samples. This process, as described in AAR Report No. 843, has been correlated to actual conditions, and is considered valid.

3.1 EVALUATION OF AIR, BOULTON, AND VAPOR DRIED TIES

Tie samples were subject to 6 cycles of accelerated aging. Prior to the first cycle, and after each cycle, the samples were physically tested for bending, compression, face hardness, spike retention, lateral spike retention, and cracking. Based on these tests, life under a range of traffic conditions can be determined.

Bending - Ties only bend if the track is poorly maintained, causing the ties to become center bound. It therefore is probable that bending has little impact on tie life, except in light tonnage track. Then the primary degradation is decay. Tests show that air dried ties are about 60 percent and 30 percent stronger in bending than Boulton and vapor dried ties, respectively. In the field, this probably makes little difference.

Compression - Higher compressibility probably reduces the possibility of fatigue cracks. This characteristic may have an impact on mechanical failure and on decay. There appear to be few differences between air and Boulton, but nearly a 10 percent reduction with vapor dried ties. It could therefore, be argued that there might be a slightly lower life with vapor ties on high tonnage lines.

Face Hardness - Face hardness has an impact on plate cutting on high tonnage lines. Low tonnage plate cutting is largely the result of decay. Since there are few differences between the drying methods, the differences can be ignored.

Spike Retention - In newly treated ties, there is about a 7 percent reduction in withdrawal loads between air and Boulton, and between Boulton and vapor dried ties. This probably makes little difference. However, as the ties age, this difference increases to about 25 percent. Spike holding power has an impact primarily on higher tonnage and medium tonnage curves. From this, an assumption can be made that there will be a slight increase in mechanical failure with Boulton, and an even greater increase with vapor dried ties.

Lateral Spike Resistance - In newly treated ties, there is about a 14 percent reduction in lateral resistance between air, and Boulton, and between Boulton and vapor dried ties. This percentage holds true with aged ties. It is therefore reasonable to assume that the life of ties removed for loose spikes, particularly in curves, will be lower by approximately the above percentages.

Cracking - Cracking is measured by percent surface loss. In newly treated ties there is about 10 percent greater checking between air, and Boulton, and about 25 percent between air and vapor dried ties. As the ties age, the difference is about the same for air and Boulton, but increases to nearly 45 percent for air and vapor. Since cracking is the means by which fungi spores enter the untreated portion of the tie, it is reasonable to assume that the decay rates will vary in proportion to the propensity to check.

freeze/thaw?

Based on the above data, depending on the installation location, it appears that Boulton ties may last about 90 percent as long, and vapor will last about 80 percent as long as air dried ties.

3.2 THEORETICAL EVALUATION OF BORATE DIPPED TIES

There has been some testing of borate treated ties (6), but unfortunately, the tests have not progressed far enough to determine how they will perform in track. Borates have been used for some time to treat poles. From this experience and an understanding of the theoretical performance, a conclusion can be drawn as to the possible impact of borate use.

Creosote treated ties are generally resistant to decay until the creosote content has been reduced so that surface absorbs moisture, and the moisture-drying cycle causes checks or cracks when the tie is about 12 to 15 years old. These cracks permit the fungus spores to enter the untreated center of the tie. This is the point at which a borate treatment would have a positive impact in preventing the start of decay.

There is an additional advantage to initially dip treating the ties. Those that are air dried in a humid environment will better resist any decay that may start before the creosote treatment.

The economics are such that an up front investment is being made which will not have physical impact for 12 to 15 years. (Only a small percentage of ties fail, through decay, before 25 years). Therefore, the additional cost of borate treatment must be offset by reducing the cost of conventional creosote treatment. Not likely!

4.0 RAILROAD COST OF CAPITAL

The air drying process requires that ties are stacked for seasoning for 3 to 12 months. Since this requires a substantial capital investment, it is important to understand the cost of the capital used for this investment.

The economic analysis of investments using discounted cash flow methods requires a determination of the cost of capital. The appropriate cost of capital varies according to numerous factors, reflecting the risk of the investment and the competition for capital funds. In this study, the AAR is looking for a relevant range of capital costs within which analyses can be performed.

In general, the cost of capital may be thought of as having three components: the required rate of return for a risk-free investment, a risk premium appropriate to the company and the specific capital project, and an inflation premium. For the purposes of this analysis, the inflation premium is not considered because it requires (for analytical consistency) the application of an inflation forecast to all future cash flows.

Analyses of many years of stock and bond market data indicate that the risk-free rate of return (e.g., from investment in U.S. government securities) is on the order of 2 to 3 percent per annum. These analyses also show that the average risk premium demanded by the capital markets is in the five to 6 percent per annum range. The resulting real (i.e., inflation-adjusted) cost of capital for the U.S. private sector, as a whole, is therefore approximately 8 percent per annum. This number serves as a useful floor for cost-of-capital estimates, unless the investment is known to have low-risk features (e.g., certainty of future cash flows or backing by salable collateral).

For individual firms, a current "weighted average cost of capital" (WACC) can be calculated based on the firm's capital structure and current prices and yields of its securities. While this number better reflects the risks and growth potential of a given company than the economy-wide average, it includes an inflation premium and is also subject to short-term distortions based on current capital market conditions.

Each year, the Interstate Commerce Commission determined which railroads were "revenue adequate" for rate regulation purposes. An industry-wide cost of capital similar to the WACC was calculated as part of this determination. The most recent calculation, for 1993, resulted in a railroad industry cost of capital of 11.4 percent per annum. After deducting an inflation premium of 2.5 to 3 percent (based on the inflation rate during 1993), this number was consistent with (though slightly higher than) the economy-wide number of 8 percent. The slightly higher number probably was the result of the capital markets' view of the railroads as a cyclical industry with greater-than-average earning volatility (i.e., risk) due to high fixed costs. (Whether this view is still correct is open to debate, given the industry's moves to increase variability in its cost structure.) The "revenue adequacy cost of capital," as calculated by the ICC, supports the use of 8 percent as a floor for the "real" cost of capital range.

As a practical matter, most firms do not invest in all capital projects with a rate of return in excess of the cost of securing additional investment capital (though this would theoretically be the right thing to do to maximize present investor value). There is no consensus among economists as to the reasons for this "capital rationing" behavior. It is, however, fairly well established that in financially healthy, mature companies, rates of return of 30 percent are required to get a capital project funded on the basis of return on investment alone. (Projects are also justified on the basis of safety, government regulation or company policy). In such a scenario, the firm acts as if its cost of capital were 30 percent. Since this is common behavior, we will use this number as a typical discount rate in our economic analyses.

With discount rates of 30 percent or more, the so-called "payback period" becomes a useful way of looking at management requirements for investment returns. For example, a 3-year payback period is consistent with a 31 percent required return (provided the investment has a useful life of 10 years or more). In organizations under financial stress (i.e., those with limited ability, for whatever reason, to raise funds by borrowing or issuing stock), requirements for a 2-year or even 1-year payback are common. Once again, assuming an investment life of 10 years or more, these payback periods indicate required rates of return in the 50 or 100 percent ranges, respectively. It is almost always true that a project with a single-year payback will be funded unless failure of the company is imminent. This would tend to place a ceiling on the required rate of return at 100 percent.

The relevant costs of capital therefore appear to range from a theoretical minimum of 8 percent on the low end, to 100 percent on the high end, with the most relevant numbers in the 30 percent range for financially healthy companies with access to investment capital.

5.0 TIE TREATMENT COST COMPONENTS

There are three components required to analyze the alternatives: the treatment cost, the lifetime cost, and the risk cost.

The costs quoted below were determined through discussion with various treatment companies, experts on the use of borates, and various railroads. It should be noted that treaters costs and prices vary by plant. The costs are also based on Grade 5, 7-inch x 9-inch x 8-foot 6-inch ties.

The Class 1 railroads use the following types of timber for Grade 5 ties in these estimated national proportions: mixed hardwoods, 25 percent; oaks, 70 percent; and softwood ties, 5 percent. The low, average, and high green tie cost FOB the saw mills are: $12.50, $15.80 and $20.00 (December 1994 prices).

A summary of all costs required to produce a tie and replace a tie are shown as Appendix 1. A full description of these costs are given as Appendix 2.

Costs specifically related to the economic analysis of the various methods are discussed below.

5.1 AIR DRYING

This process involves stacking ties in an open area from 3 to 12 months, depending on the type of wood and the humidity of the location. The range in months, by timber type follows:

Table 1. Months to Air-Dry Mixed Hardwood, Oak and Softwood

Months to Air-Dry Stacked Ties	Low	Average	High
Mixed Hardwood	4	5	6
Oak	9	10.5	12
Softwood	3	4	5

The weighted average is 8.8 months.

The range of green tie costs, FOB the saw mill, is $12.50 to $20.00. Once the ties are stacked for seasoning, the total cost, including transportation, purchasing, and processing is between $13.81 and $26.45. The average tie cost is $18.24, so the seasoning cost would be $1.52, at an 11.4 percent discount rate for 8.8 months. The 11.4 percent discount rate is the ICC revenue adequacy criteria.

Air drying is generally preferable for large quantities of ties that can be planned up to a year in advance. This is because it can be cheaper and requires about 40 percent of the cylinder time used with other methods, thus permitting higher production for a given capital investment.

5.2 BOULTONIZING

Removing moisture from the tie is achieved by heat and a vacuum, which requires a considerable amount of energy, as well as use of the treatment cylinder. The time required for Boultonizing varies considerably from about 10 to 18 hours, depending on the type of timber, the time of year (there is less moisture in the tree in the fall than in the spring), and the humidity, temperature, and time between harvesting and treatment. Therefore, the cost of this process also varies considerably from $1.50 to $2.70, an average of $2.49 (assuming all ties are Boultonized), for a Grade 5 tie. At the end of the moisture removal process, the tie is hot and ready for creosote impregnation.

5.3 VAPOR DRYING

Moisture removal is achieved by organic vapors condensing on the surface of the tie and, in effect, boiling the moisture out of the tie. While the heat requirements and processing time are similar to Boultonizing, this process requires a change over from the solvent to creosote, which involves approximately an extra hour of cylinder time. There are losses of solvent additional capital cost. The actual drying process, which has similar variations in drying time, is about 20 percent more expensive than Boultonizing.

Due to the extra cost and a slightly lower strength end product, there appears to be only one plant left in the country that uses this method.

5.4 TREATMENT

The cost of treatment has four components: equipment, labor, and heat, which vary according to the drying process used and the cost of the preservative. If an artificial drying process has been used, cylinder time can be reduced because the ties are already hot. For a Grade 5 tie, the cost of the actual treatment (cylinder time) can range from $1.96 to $2.80 per tie. However, the appropriate cost is that which is relevant to the drying method. Therefore, the cost is $2.52 for the average tie (the cost associated with the average air dried tie).

The preservative cost depends on the quantity specified (pounds/cubic foot) and the cost of the treatment chemicals. Most railroads use 7 pounds/cubic foot, however, the range is 6 to 8. The cost of preservative is subject to considerable fluctuation in price since it can also be used as a fuel. At the present time, the cost (depending on local demand and transportation) is $0.75 to $0.95 per gallon, with an average of $0.83. Depending on the quantity specified and the cost of the chemical, the price range is $1.82 to $3.07 per tie. The average preservative cost is $2.35.

5.5 BORATE TREATMENT

To date, borate treatment has only been tried on an experimental basis, and as such, there are no firm costs available for this form of treatment on a production basis.

A conveyorized dip treatment could conceivably cost about $0.95, including chemicals. The ties must be kept moist while the borate is diffusing. A tie plant producing one half million ties per year will require a million dollar building to store the ties for 6 weeks at about $0.25 per tie.

After 6 weeks, the ties would be removed from the building. Those intended for air drying would be fed on to a conveyor for open stacking and then stacked in the yard. This cost would be more than conventional stacking, and is estimated to be $0.85.

5.6 OTHER RELEVANT COSTS

The open and bulk stacking and yard stacking costs are based on what treaters would typically charge for an additional handling—$0.75 per tie. In this process, stacking cost is an estimate based on the other stacking costs—$0.20 per tie.

With borate dipping, the option exists for reducing the amount of creosote impregnation. Besides reducing the use of creosote, there would be a proportional reduction in the treatment (but not the drying) cylinder time. This has been estimated at $0.15 per pound of creosote per cubic foot.

6.0 ECONOMIC ANALYSIS OF TIE TREATMENTS

There are about 15 significant cost factors that effect the economics of various present and future tie treatments. For about 10 of these factors there are a range of costs. A spreadsheet model has been developed to compare the relevant costs of the five basic approaches to tie treatment, as shown in Table 2.

Table 2a. Relevant Costs of Alternative Tie Treatments

Parameters:	Assumptions: Interest Compounded Monthly
Cost of Green Tie at Treater	$18.24
Cost of Average Treated Tie	$26.91
Creosote Cost	$0.83/gallon (9.2 pounds)
Cylinder, Boultonizing Cost	$0.15/tie/hour
Cylinder, Vapor Cost	$0.18/tie/hour
Cylinder, Treatment Cost	$0.28/tie/hour
Creosote and Cylinder Cost/pound	$0.15
Vapor Drying Premium	20 percent
Cost of Capital	11.4 percent ICC Revenue adequacy
Tie Replacement Cost	$40.80
Average Air Dried Tie Life	35 years

Table 2b. Relevant Costs of Alternative Tie Treatments: Cost Analysis

Method	Air Dried			Boultonized	Borate Dip		
	Low	Average	High		Vapor	Air Dried	Boultonized
Process Time (Months)	3	8.8	12	0.5	0.5	10.3	2
Cylinder Hours, Dry				16.6	17.6		14
Cylinder Hours, Treat	8	9	10	7	7	9	7
Relevant Processing Costs:							
Stack, In Process				0.20	0.20		
Stack, Trans, Stack	0.75	0.75	0.75				
Dips and Chemicals						0.95	0.95
Stack, Transport, Stack						0.75	0.75
Humidity Building						0.25	0.25
Transport, Restack						0.85	
Inventory Cost	0.55	1.65	2.28	0.09	0.09	1.95	0.36
Cylinder, Drying				2.49	3.17		

Table 2b. Relevant Costs of Alternative Tie Treatments: Cost Analysis (con't.)

Method	Air Dried			Boultonized	Borate Dip		
	Low	Average	High		Vapor	Air Dried	Boultonized
Cylinder, Treatment	2.24	2.52	2.80	1.96	1.96	2.52	1.96
Relevant Total	3.54	4.92	5.83	4.74	5.41	7.27	6.37
Percent Difference in Total Cost	-5.5%		3.3%	-0.7%	1.8%	8.3%	5.2%
Tie Life Factor		1		0.9	0.8	1.2	1.1
Tie Life		35		31.5	28	42	38.5
PV Tie Replacement Cost		.93		1.36	1.99	0.44	0.64
Tie Replace. Rela. to Air Dried				0.43	1.05	-0.49	-0.29
Total Relevant Cost		5.85		6.10	7.40	7.75	7.02
Net Cost Impact				.25	1.55	1.90	1.17
Extra $ Borate Treatment						2.39	1.46
Creosote Reduction to Offset Additional First Cost (lbs/cu ft)						4.38	2.87
Percent Reduction						63%	41%
Creosote Reduction to Offset Long-Term Additional Cost (lbs/cu ft)						3.48	2.30
Percent Reduction						50%	33%

The air dried option has been divided into three sub-options to account for the large variation in drying time. There could also be ranges for each of the remaining treatment methods since the primary analysis is for the impact of the inventory cost on air drying compared to Boultonizing. However, for reasons of simplification, only the average is shown on the spread sheet. Also, for simplification, only those costs that vary by method have been compiled.

The chemical drying methods pose a small risk of damaging the tie, if done improperly. Unlike improperly air-seasoned ties, these cannot be detected visually. The likelihood of defectively seasoned ties is less than one percent. It will not affect the system average tie life, but may cause a local problem. The percent difference in total cost compares the difference in relevant cost to the average cost of an air dried tie.

The tie life factor considers an air dried tie as 1, and the other tie lives are a proportion of this tie life. By varying the air dried tie life and the tie life factors, it is possible to determine the economic impact of using one treatment method versus another.

The comparison of air dried to other treatment methods is very sensitive to the cost of capital (discount rate). The example shown in Table 1 uses the ICC revenue adequacy interest rate of 11.4 percent since this is the return that the ICC considers necessary to cover the cost of borrowed capital. This indicates Boultonizing is cheaper by $0.18, compared to the average air dried tie (drying for 8.8 months), resulting in a 0.6 percent difference for total cost, based on the average tie. If a 10 percent interest rate is used, then air drying is 5 percent less expensive. Even if the Boultonized tie life is 90 percent that of an air dried tie, given an average tie life of 35 years, the difference is only $0.28 per tie in favor of air drying. The accuracy of basic data is such that, given 11.4 percent cost of capital and 35 years average tie life, these two treatment methods are similar.

If low and high drying times are used for ties, then Boultonizing is either $1.09 less or $1.21 more expensive. For a railroad buying half a million white oak ties a year, this could make over $550,000 a year difference in cost.

Vapor dried ties have about a $0.59 first-cost disadvantage and a 10 percent lower life. It is assumed that the long term cost (present worth) disadvantage is about $1.60.

The borate dipped ties would be about $1.49 or $2.39 more expensive to treat, depending on the method of drying. Even if an assumption is made that the tie will last 20 percent longer, the long-term cost is still about a $1.50 more than a conventional air dried or Boultonized tie. It is possible that the increased cost can be offset by a reduction in creosote of about 50 percent. It is unlikely that this could be done without a reduction in tie life. However, if the discount rate is lowered to 8 percent and the assumption of a 20 percent increase in life is still used, then the long term cost of air dying and borate dipping are similar.

If the railroad's cost of capital is only 5 percent, then air dried ties would be about $0.75 or 3 percent cheaper. However, if a higher and more realistic opportunity cost of about 15 percent is used, then Boultonizing is about $0.66 cheaper.

For small unplanned quantities, and if the cost is high, Boultonizing is the generally preferred method.

7.0 RAILROAD TIE PURCHASING OPTIONS

Railroads have basically three options, or a combination of these options, with respect to purchasing ties:

- Railroads buy the green tie and ship it to the treater who then either air seasons, Boulton, or vapor treats the tie.
- The treater buys the green tie and the railroad buys the finished product.
- The railroads buy a basic demand quantity, which they then air season; should they require more, they will either purchase more for drying and use the more rapid process, or they will enter the spot market.

Air drying is comparable in cost and probably produces the best quality tie. Railroads should maximize the number of ties that are treated by this process. However, there is a risk that the railroad will find, when it comes to install the ties, that it does not have sufficient funds to pay for the installation, and may wish to cut back on installation. In this case, it may have to carry a portion of the inventory until next season. Depending on the type of timber and the plant location, it may be necessary to treat the ties to prevent decay while the ties are inventoried. In which case, the holding and restacking cost will more than negate the savings in all but the extreme situation.

8.0 RAILROAD PURCHASING POLICY

Given an 11.4 percent cost of capital, in the average case, there appears to be little first cost difference between air dried and Boultonized ties. There is indication that air dried ties will last up to 10 percent longer. Given that the average tie life is about 35 years, though, this makes little difference.

If the railroad has a capital investment policy that it only funds investments with at least a 15 percent rate of return, it should perhaps consider that the tie inventory cost should also be discounted at 15 percent. In which case, Boultonizing is clearly preferable, reducing the present total cost of an average tie ($26.91) by 2.5 percent, or $0.67 per tie. At the present time, this option exists because there is a surplus of treatment capacity. If this capacity is filled because a large number of railroads change to Boultonizing, and the treaters are forced to construct additional treatment capacity, then, they too will require a return on investment of at least 15 percent. This in turn will force an increase in the cost of Boultonizing, possibly negating the cost advantage.

For a softwood tie, in a low-humidity location, there can be a $1.20 (at a cost of capital of 11.4 percent) difference in favor of air drying. On the other hand, an oak tie in a high humidity location, requiring a 12-month seasoning, will cost $1.09 more. In addition, a long seasoning in a high humidity location will result in higher decay losses.

From this it is clear that a well-managed tie purchasing program can yield significant savings. This program, while relatively simple, would require considerable effort for a large railroad. Planning the overall tie requirements is far more complex and can carry substantial penalties for error. Air drying ties originally thought to be needed but no longer required, will cost about $2.00 each for treatment, restacking and inventorying until the next season. This penalty can be minimized by better tie replacement planning and understanding the cost of postponing tie installation.

There are railroads that purchase in excess of a million ties annually. It is clear from this analysis that savings or additional cost of $1.00 per tie are clearly possible. This can easily justify a dedicated staff to develop the plans and programs, and then run the tie purchasing program.

9.0 RECOMMENDATIONS

The combinations and permutations of tie treatment possibilities are so extensive that when coupled with the number and size of treatment plants, their respective prices and locations would make it virtually impossible to efficiently manage a tie purchasing program manually.

It is therefore recommended that a computer program be developed to indicate by plant, the number of ties that should be purchased and how they should be treated.

Borate, in principle, shows considerable promise as a tie treatment, but the tie must also be jacketed with a waterproof material. If creosote is used, the amount would have to be in the range of 4 pounds/cubic foot. This quantity, by itself, is considered to be marginal, as a fungicide, by the American Wood Preservers Association. Little is known about the characteristics of a combination of these two fungicides. It is possible that ties could be pressure treated with borates at a lower cost, and that certain timber, such as white oak might retain enough to be effective. These possibilities need to be examined.

Another possibility is jacketing the tie with a material entirely new to the tie industry, such as a latex or epoxy. A superior tie may be developed, but to be cost effective, it will have to cost no more than a creosote pressure treated tie.

Consideration must be given to who will fund further research in this field. The treaters' margins are small, and they have little desire to obsolete their capital equipment. The best potential appears to be in a chemical company that would benefit by jacketing the ties in their product.

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Appendix 1: Analysis of Tie and Tie Installation Costs

Assumptions:

- Grade 5, 7" x 9" x 8'6" ties
- Purchase quantity 500,000 or more
- Long-term purchase contract
- December 1994 prices

Cost Factors per Tie:	Typical	Low-cost	High-cost
Green tie	$15.80	$12.50	$20.00
Purchasing Overhead	$0.40	$0.31	$0.50
Transportation:			
Truck	$0.56	$0.11	$1.13
Rail - Home Road	$0.44	$0.22	$1.02
Rail - Foreign Road	$1.18	$0.59	$2.76
Composite Transp. Cost	$0.50	$0.11	$2.76
Unloading, etc.	$0.55	$0.50	$0.75
Inbound Inspection	$0.13	$0.10	$0.35
Incising:			
per Tie	$0.15	$0.10	$0.20
Percent Treated	70.00%	60.00%	80.00%
Adjusted Cost	$0.11	$0.06	$0.16 (or 100% above)
Pre-drilling:			
per Tie	$0.63	$0.50	$0.75
Percent Drilled	50.00%	0.00%	100.00%
Adjusted Cost	$0.31	$0.00	$0.75

Replacement in Track:				
Type of Gang	**Production**			
By Hand	8	10	6	ties per man per day
On/off Track Gang	120	150	100	
Single Tie Gang	600	700	500	
Double Tie Gang	1100	1300	800	
	Cost per Tie			
By Hand	$29.38	$23.50	$39.17	8.00%
On/off Track Gang	$13.70	$10.96	$16.44	17.00%
Single Tie Gang	$8.54	$7.32	$10.25	50.00%
Double Tie Gang	$8.98	$7.60	$12.35	25.00%
Weighted Average	$11.72	$9.30	$14.14	
Typical Cost	$8.54	$7.60	$39.17	Single, Double, By Hand
Per Diem Cost	$1.27	$1.11	$0.00	
Start Up and Relocation, Days	13	8	0	
Start Up and Relocation Cost	$0.59	$0.32	$0.00	
Scrap Tie Pick-up	$1.04	$0.78	$1.56	bundling, add $0.70/tie
Tie Disposal	$0.00	($3.90)	$3.00	
OTM pick-up	$0.21	$0.14	$0.28	
New Tie Losses	0.50%	0.10%	3.00%	
New Tie Loss Cost	$0.15	$0.02	$1.47	
Train Delays				
Sub-total Installation Cost	$13.89	$7.16	$50.92	
Treated Tie Cost	$26.91	$19.91	$39.66	
Total Tie Replacement Cost	$40.80	$27.07	$90.58	

APPENDIX 2: TIE REPLACEMENT COST ANALYSIS

There are almost an infinite number of factors that will effect the cost of replacing an individual cross tie. The purpose of this analysis is to define the more important elements and the likely ranges of cost associated with those elements.

This analysis deals with the cost of replacing a cross tie. It consists of two primary sections: developing the cost of a black tie (treated), and developing the cost to install it. Switch and bridge ties are considerably more costly to replace and are not considered in this analysis. For the purposes of this analysis, an "average" tie is a Grade 5, 7-inch x 9-inch x 8-foot 6-inch tie found in the typical main-line track and purchased in large quantities (500,000 plus on a long-term contract basis). Other cross ties and quantities are discussed briefly at the end of the analysis.

GREEN TIE COST

There are three basic grades of wood ties used in the United States: Grade 5, a main line tie, 70 percent of which are oak, 25 percent mixed hardwoods and 5 percent softwood; Grade 3, a branch line tie, which has a higher percentage of soft wood; Industrial grade ties, which are usually Grade 3 or 5 reject ties used for a very light tonnage track, short lines, and industrial sidings.

The basic material cost of a tie is the cost of the untreated piece of lumber or green tie. This cost is very much subject to the competitive demands for the wood by pallet, flooring (oak), furniture and export markets. As a result, new housing construction puts pressure on the price, but with a lag of 6 to 9 months. The major railroads' usually buy ties through a green broker or the tie dealer at a cost of :

- Grade 5 ties $12.50 to $20.00
- Grade 4 ties are about $1 less
- Grade 3 ties $9.00 to $10.00
- Industrial grade ties $4.00-$6.00 (depending on the size)

Due to competitive pressure, the price of green ties is subject to a swing of about plus or minus 15 percent. December 1994 prices have been used in this analysis. With the possible exception of pine, the price of timber seems to be independent of the type of wood. Treatment companies also buy green ties for sale, as a treated product, to the smaller railroads.

TRANSPORTATION TO TREATMENT PLANT

Since the majority of ties are supplied by small saw mills and the quantity from each mill would not warrant railroad service, green ties are often transported to the treatment plant by truck. For larger mills and longer distances, rail is often used. In some cases there are collection points where several mills truck to a rail siding. In terms of total ties carried, the split between truck and rail is now about 50-50.

Truck transport costs about $1.50 per truck mile (200 ties per truck) for distances up to 150 miles, (with an average of 75). Since it is unlikely that the treatment plant is at the sawmill site, a minimum cost of $22.50 per load must be assumed. Therefore, the cost range is $0.11 to $1.13 with an average cost of $0.56 per tie.

For rail transport, the distance involved ranges from 150 to 700 miles, with an average of 300 miles; but the cost depends on who owns the untreated ties. For railroad-owned ties, the incremental on-line cost is $0.0125 per ton mile. The untreated tie weight is 225 pounds, so the cost is 0.14 cents/mile/tie, or $0.22 to $1.02 per tie with an average of $0.44. For treater or railroad owner (but not on-line ties), the cost will be, for large quantities, around $0.035 per ton mile or $0.59 to $2.76 per tie.

The most usual case is a combination of trucking and on-line rail, and with a 50-50 split, the average will be $0.50 per tie. However, the range can be $0.11 to $2.76.

The paperwork cost associated with purchasing a tie (such as purchase orders) is usually around 2.5 percent of the green tie price.

PROCESSING THE TIES

Once at the tie plant, there are several options that affect the cost of processing, such as incising, seasoning method, type of boring, and amount of treatment. Also, the cost obviously depends on the efficiency of the plant, the percentage capacity the plant is operating at, local labor costs, and the size of the order.

Equipment Costs						
		Manual	On/Off	Single	Double	
Equipment	Cost/Shift		Cost	Cost	No.	Cost
Back Hoe	$140.00		$140.00			
Ballast Regulator	$230.00				1	$230.00
Crane, Rail	$290.00					
Push Cart	$2.00		$2.00	$2.00	2	$4.00
Rail Anchor Applicator	$130.00				1	$130.00
Rail Lifter	$18.00		$2.00	$18.00	2	$36.00
Spike Driver, Auto	$260.00			$260.00	2	$520.00
Spike Driver, Manual	$15.00		$15.00			
Spike Puller	$15.00		$15.00	$15.00	2	$30.00
Tamper	$280.00			$280.00	1	$280.00
Tie Crane	$155.00			$155.00	2	$310.00
Tie Inserter	$240.00			$240.00		
Tie Remover	$165.00			$165.00		
Tie Remover/Inserter	$390.00				2	$780.00
Tie Unloader	$380.00					
Truck, Section	$75.00	$75.00				
Total per Shift		$75.00	$174.00	$1,135.00		$2320.00
No. Personnel		3	7	19		36
Labor and Benefit Cost/Shift		$630.00	$1,470.00	$3,990.00		$7560.00
Total		$705.00	$1,644.00	$5,125.00		$9880.00

The basic cost for unloading, trimming, sorting, and stacking is about $0.50 to $0.75, depending on the facilities and plant utilization.

The cost of inspection depends upon inspection location. If a tie is inspected at the saw mill, then there is a substantial amount of traveling, and, typically, an inspector will only inspect 200,000 ties per year at a cost of about $60,000 or $0.30 per tie. If, on the other hand, the ties are inspected at the tie plant, then an inspector can inspect about 500,000 ties at a minimum cost of $0.10 each. There is a clerical function involved in inspection and acceptance, but this is considered part of the overall inspection cost. Today, most inspection takes place at the treatment plant.

Incising the tie is a process where the green tie is run through rollers with small teeth on them, making a series of small cuts in the wood. This facilitates quicker seasoning and enables the preservative material to penetrate further into the tie. The cost of this optional process is $0.10 to $0.20 and 60 to 80 percent are incised, so the cost range would be $0.00 to $0.20 with an average of $0.15.

Another option is to pre-drill the tie. Roughly 50 percent of treated ties are predrilled, either to locate spikes or to allow the treatment to penetrate into the area under the tie plate that is most subject to decay. The cost is $0.50 to $0.75, so the range of costs is $0.00 to $0.75, with a weighted average of $0.31.

Railroads also determine the percentage of ties to which anti-split devices are applied. Most railroads only install the device on ties in need. 'S' irons and dowels have been almost completely superseded by end plates, which cost $2.00 to $2.50 when applied. They are applied on 10 to 50 percent of the ties, so the cost can be as high as $1.25, with an average of $0.45 per tie. If the railroad is in an area where wood is subject to splitting, then they may go to the expense of end plating 100 percent of the ties. Since this is not a common practice, it is not considered in this analysis.

There are three methods of seasoning a tie prior to treatment: air drying, Boultonizing, and vapor drying. Though air drying can be the cheapest, when the inventory cost of storing the wood is considered, it may not be.

add $0.50 a tie when loaded into gondolas and $0.75 a tie when the bundles are loaded on flat cars.

A compilation of the elements that go to make up the cost of a Grade 5, 8-foot 6-inch black tie for the low, average, and high cases are: $19.91, $26.91, and $39.66 respectively. A complete listing is shown as Appendix 1.

Quantities of ties that are purchased on a 'spot' basis are almost always from the tie treater's stocks, meaning that the treater has paid the freight charge and has carried all the financial costs, but is not sure when the ties will be sold. So, if the treater bought green ties 9 to 12 months ago on the hope that demand will be high and it is not, there will be a buyer's market. But if there are more buyers than sellers, then the price will obviously be higher to compensate for when the treater has an overstock. This is only fair, since the treater is taking a substantial financial risk. As a result, for small orders of about 50,000 ties or less, the buyer could pay anywhere from a slightly less than the large quantity long-term contract price to a premium of up to 20 percent.

As mentioned earlier, there are three basic ties used today; Grade 5, Grade 3, and Industrial. In addition, there are the lengths of 8 feet, 8 feet 6 inches, and 9 feet. The principal difference between grades is the cost of the green timber. There is 23 percent less timber in a Grade 3 tie, but because of the premium on Grade 5 ties, the price difference is actually about 33 percent. The industrial grade ties can be a variety of sizes, since such things as splits and decay can be the reason a tie is down graded. As a rule, they are about 42 percent of the cost of a Grade 5 green tie. Since lower grade ties are generally smaller and lighter, transport, cylinder and preservative costs will be a little less. However, optional processing, such as end plating, and handling costs will be similar.

The green tie prices for an 8-foot tie are about $0.95 less than an 8-foot 6-inch, while a 9-foot tie is $0.95 more. Table 1 shows the "average" case costs for a black tie in the various grades and lengths compared to the standard average tie cost of an 8-foot 6-inch Grade 5 tie.

Table 1. Cost of Specific Size and Grade Ties ($)

Length	8-foot 0-inch	8-foot 6-inch	9-foot 0-inch
Grade 5	25.67	26.91	28.15
Grade 3	20.27	20.72	-
Industrial	16.70	17.32	-

INSPECTION FOR REPLACEMENT

Selecting the tie for replacement is generally a two phase process. In the latter part of the year before, the road master will submit a tie condition report giving the number of bad ties in a specific section of track. This information is consolidated by the General Office with data from other road masters. Then, based on financial resources and line priority, the number of replacement ties will be allocated to a given track segment. At the same time, the installation schedule will be developed, as will the plans for the purchase of the new ties and the tie replacement program for the division or system tie gangs.

Shortly before the delivery of the new ties, most railroads assign a tie inspector to determine which ties should be replaced, in conformity with the given number of allocated ties. This the inspector does by performing a walking, visual inspection of the track.

A typical inspector will examine 5 to 7 miles of track per day, depending on the condition of the ties. The annual cost of the inspector, including expenses, will be about $75,000 per year. So, if he is inspecting track with only 400 bad ties per mile, the cost per bad tie will be $0.12, but if he is inspecting 1000 bad ties per mile, the cost will be $0.07 per tie. The most common situation is 800 ties per mile and at a rate of about 5.5 miles per day.

PLANNING COSTS

Considerable effort goes into allocating resources, and planning the purchase, distribution and assignment of tie gangs for the replacement of ties. It is also necessary to coordinate the other maintenance activities, such as rail gangs and surfacing with the tie gangs. Planning costs are very difficult to estimate, although it is safe to say that the more time spent planning, the lower the production cost. A range of planning inputs could be zero to 5 labor hours per 800 ties, with an average of about 3 labor hours per 800 ties installed, or zero to $0.22 per tie, with an average of $0.13 per tie.

TRANSPORTATION - Tie Plant to Installation Site

Ties are generally delivered in a block of cars. Seldom, if ever, are they delivered in unit train quantities. The cost of transportation is dependent on whether it is an on- or off-line haul. While there does not appear to be any difference in the freight rates of green versus black ties, perhaps there should be, since the black ties leave a car in a very dirty state, to the point where railroads tend to keep tie cars in dedicated service. The on-line cost is about $0.0125 per ton mile or $.0014 per tie mile. The delivery distance ranges from zero if a work train distributes ties directly from the plant to up to 2000 miles (in the United States). The average appears to be around 450 miles, so the cost will range from zero to $2.93, with the average at $0.66. Foreign line freight costs around $0.035 per ton mile, but the distance involved is not as long. The maximum number of miles is 1500 with an average of 400. In monetary terms, foreign line freight costs zero to $5.91 with an average of $1.58.

UNLOADING COSTS

For 100 years, ties were unloaded from a work train by hand. After experimenting with several different methods, railroads have standardized on a crane that 'walks' along the tops of the tie gondola. The machine costs $380 per day, so it is necessary to unload at least a minimum of ties to be able to justify the expenditure. Where ties are to be installed by hand, usually small quantities per mile, the ties are unloaded by hand or with a rail crane.

There will be a variation in the cost of mechanical unloading, depending on the density of distribution and track possession, ranging from 10 to 14 cars per shift (375 ties per car). Assuming a work train cost of $1,500 per shift (4-person crew and a locomotive) the cost range would be $0.36 to $0.50 per tie with an average of $0.42.

Other methods, such as manual unloading from a work train, costs about $1.70 a tie, while using a rail crane to unload two gondolas costs $1.43 a tie.

OTHER TRACK MATERIAL (OTM) COSTS

Spikes

When using an automatic spike setter, driver spikes must be in perfect condition. To prevent production delays caused by jammed spikes, most railroads use 100 percent new spikes on their high production tie gangs. A reasonable assumption for new spike usage for a single, on/off track and a manual gang is 75 percent, 50 percent and 20 percent, respectively. The old spikes will have a scrap or reclaim value.

The cost of the spikes required for a new tie also depends on the number of spikes per plate (2,3,4, or 5). A new spike costs $0.25 and the average reclaim/scrap value will be $0.10. According to Table 2, the range of cost will be:

Table 2. Cost of Spikes Required for a New Tie

	Low	Average	High
Manual	$0.12	$0.18	$0.30
On/Off gang	$0.30	$0.45	$0.75
Single gang	$0.45	$0.68	$1.13
Double gang	$0.60	$0.90	$1.50

Tie Plates

When ties are replaced, it is usually found that 2 to 5 percent of the tie plates are broken or damaged, and must be replaced. This cost is not really assignable to the tie unless the tie has been allowed to deteriorate into a badly cut plate condition. So, assuming 20 percent of the ties have this failure, then between 0.004 and 0.01 percent should be charged to tie replacement, $0.05 to $0.12 per tie.

Anchors Anchor failure is also not the result of tie condition. However, when ties are replaced, between 2 percent and 5 percent of the anchors are lost and replaced at a cost of between $0.03 and $0.07 per tie.

In summary, OTM cost for a tie replacement ranges from $0.68 to $1.69, with an average of $0.81 per tie. However, since the high-cost installation option is manual, the cost associated with manual installation will be $0.68.

METHODS AND INSTALLATION COST

At present, there are about 120 tie gangs working on Class I railroads, and an additional 50 on the Class II Railroads. Between them, it is estimated that nearly two hundred replacement methods are being used. Choosing the appropriate method depends on a number of factors, including density of replacement, traffic and train density, section length to be retied, single versus multiple track, the number of employees reporting for work that day, as well as the machines available for work.

Each installation method can be classified under four basic principles: manually or with the aid of a small machine, on-track/off-track machinery, single, and double gang. A discussion of each method appears below.

To assign an installation cost for each method, the machines used to install ties must be thoroughly analyzed — a task too complicated for the scope of this analysis. The approach used here will determine the likely cost ranges for each of the basic methods, as well as the range and approximate weighted average, and typical installation cost.

The Influences on Production

Equipment and labor costs are heavily influenced by production, or the number of ties installed in a shift. Production, in turn, depends on track possession time, number and condition of ties to be replaced, location of track (double, on an embankment, and so forth), and the general condition of the ballast.

Possession Track possession time will vary typically from 4 to 7.5 hours. For railroads with single and double track, the average is about 6.5 hours. Normally, at least 15 minutes should be allowed for both start-up and shut-down. Often, the poorer the tie condition, the better the track possession time. With the on/off track equipment, the crew might be on the track for 8 hours, but only work 6 to 7 hours.

Number of Ties to be Replaced and Condition As the number of ties per mile to be replaced increases, travel distance between ties is shortened. As a result, more ties will be installed in a shift. However, as the number of bad ties increases, there is a greater statistical chance that bad ties will appear in clusters. Large clusters slow production because of: reduced productivity of individual machines, difficulty correctly locating new ties and restrictions on the number of consecutive ties that can be removed at one time, depending upon the type of track. As a general rule, the higher the number of bad ties, the worse the condition is likely to be. If, for example, the tie breaks up when being removed, the replacement operation will be slowed.

Other factors influencing tie replacement production:

Number of Tracks The center track of a three-track line will be more difficult to replace ties on than a single track line.

Location A track on an embankment will be more challenging than one on a flat terrain. The new ties can slide down the embankment, making them difficult to retrieve.

Ballast Condition It is more difficult for machines to operate in muddy cemented ballast than in clean ballast.

Given these factors, and allowing 15 minutes for each start-up and shut-down, the range of ties replaced in a shift for the different mechanized methods is shown in Table 3, which follows:

Table 3. Range of Ties Replaced in a Shift Using Various Mechanized Methods

	Low	Average	High
Manual	6	8	10
On/Off Track	100	120	150
Single Gang	500	600	700
Double Gang	800	1100	1300

A few railroads have very large tie gangs that install up to 3000 ties per day. However, the vast majority of tie gangs are in the categories listed in Table 3. Larger tie gangs are generally less efficient per unit of labor due to their complexity. Their chief advantage is their ability to obtain track time and spend as few days in a territory as possible.

Capital Recovery

The life of a modern piece of track maintenance machinery is determined by wear and tear and/or technical obsolescence. The machines used to install ties range from the automatic spike driver that has approximately an 8-year life, to the ballast regulator that, after 8 years, can be overhauled and still be good for a least another 6 years. The cost of capital recovery obviously depends on usage. For the United States, the range of usage is generally between 150 and 250 shifts per year. Often forgotten in determining capital recovery is the shelf inventory that will be required to maintain a machine. For the purposes of this analysis, a discount rate of 10 percent has been used. A machine life— ranging from 7 to 14 years (anything with a life over 8 years)— will be rebuilt in the 8th year of life. A shelf inventory of 10 to 15 percent of the original cost is also considered.

Equipment Maintenance Cost

Committee 27 of the American Railway Engineering Association established a "rule of thumb" for equipment maintenance cost of 10 to 30 percent of the original cost per 200 shift-year. The actual percentage depends on the engine power, whether the machine is used constantly, and machine stress or punishment it absorbs during working cycles.

Fuel Cost

Fuel consumption for a track machine is based on the engine size as well as the equipment load on the engine. It can be calculated using 0.4 pounds/h.p.-hr. and 7.2 pounds of fuel per gallon.

A summary of total machinery costs, and total by type of gang, is shown in Table 4. The summary accounts for manual, on/off track, single and double gang which are $75, $190, $1135, and $2320, respectively.

Table 4. Equipment and Labor Cost per Shift

			Cost/Shift by Gang			
Equipment	Cost/ Shift	Manual	On/Off	Single	No.	Double
Back Hoe	$140		$140			
Ballast Regulator	$230				1	$230
Crane, Rail	$290					
Push Cart	$2		$2	$2	2	$4
Rail Anchor Applic.	$130				1	$130
Rail Lifter	$18		$2	$18	2	$36
Spike Driver, Auto	$260			$260	2	$520
Spike Driver, Manual	$15		$15			
Spike Puller	$15		$15	$15	2	$30
Tamper	$280			$280	1	$280
Tie Crane	$155			$155	2	$310
Tie Inserter	$240			$240		
Tie Remover	$165			$165		
Tie Remover/Insert	$390				2	$780
Tie Unloader	$380					

Equipment	Cost/ Shift	Manual	On/Off	Single	No.	Double
Truck, Section	$75	$75				
Total per Shift		$75	$174	$1135		$2320
No. Personnel		3	7	19		36
Labor and Benefit Cost/Shift		$630	$1470	$3990		$7560
Total		$705	$1644	$5125		$9880

Labor Cost

At present, the average Class I railroad labor rate, including fringe benefits, is $210 a day. Therefore, the typical crew cost for the manual, on/off track, single and double gang would be $630, $1410, $3990 and $7560, respectively (per day).

Substance and Travel Cost

The crew for the manual and on/off track method would normally be a section gang with little traveling and no subsistence cost. However, the single and double gangs would be usually a division and/or system gang with a per-diem living, as well as traveling expenses to and from the work location.

The exact amount of these costs will depend on a number of factors, including: distance to the work site, union agreements, job location, and whether camp cars or motels are used for boarding the workers.

These costs, of course, could be negligible if the gang is working directly from its home base. However, the costs would be very expensive if lodging and food were involved - about $50/day ($80/day for the general foreman) per person. It also depends upon whether the gang is spending 4 or 5 nights each week away from home. Thus, the range of travel and subsistence costs can be from $0 to as much as $2.25 per tie installed.

Start-Up and Relocation Costs

At the beginning and end of a work season, several track gang days are lost in: unloading/loading operations, troubleshooting, training, and so on. An assumption is made that a total of 4 such days are lost, and that 2 gang days are also lost between each job to compensate for moving between work sites.

It was noted earlier that depending on the location, a work season can have from 150-250 shifts. With a production range of 500 to 1300 ties per shift, 150 to 1200 ties per mile, a season's production will fall between 57.7 and about 500 miles of track covered (it is unlikely a double gang will be used for less than 700 ties per mile and the full 250 days). The continuous length of the usual tie program can very between 5 and 75 miles. There are typically two to seven relocations, with a total of 4 to 14 days lost, respectively, including start up and shut down (8 to 18 days per season). There will not only be days paid which are not worked, but the equipment capital recovery will not be chargeable to work performed. The manual or on/off track gang will incur zero cost, since they are usually made up of section personnel working from within the section. The double gang, working only 150 days, with 18 lost days, at a low production rate of 800 ties per day will be the highest. The average would be the single gang, working 200 days and losing 13. The cost range is $0 to $1.68, with an average of $0.64 per tie.

METHODS OF INSTALLATION

Manual

For 100 years, ties have been replaced completely manually using a pick, shovel, and spike maul. Strange as it may seem, 8 percent of all cross ties are still replaced by hand or with the assistance of a small machine that can be lifted off the track. A typical section gang will replace between 6 and 10 ties per worker per day, depending on travel time, ballast condition, etc. With a small machine costing up to $15,000, the production can be increased to 8 to 12 ties per worker. The section men would not require subsistence, so the cost range for the tie replacement would be $23.50 to $39.17.

On Track/Off Track Method

The basic principle of this method is that the machines can leave the track (self-propelled) to allow trains to pass. Within this grouping will be either a specially equipped back hoe at $65,000 or a small self-propelled remover inserter at about $70,000. These machines can be used by themselves, but it is advisable to also use a small spike puller and a small spike driver, so as not to hold up the primary machine. This type of gang has a production of 100 to 150 ties per shift. The crew, usually section personnel, consists of seven men. The primary benefit of this method is for light installation of 25 to 300 ties per mile or, where train density is very high, the cost per tie, equipment, tools, labor and fuel ranges from $10.96 to $16.44 per tie.

The Single Gang

Over the years, machines have been manufactured to perform almost every function of a tie gang. So, when a gang is assembled with basically one of every machine, you have a mechanized single-tie gang. The gang will usually consist of seven pieces of machinery costing around $580,000 and 19 men. This type of gang, depending on a number of factors discussed above, can install between 100 and 175 ties per on-track hour, or 500 to 700 ties per shift. Usually, the gang such as this operates on a divisional basis and incurs travel expenses and per-diem as well as the labor cost. Cost per tie for equipment, tools, labor, and fuel, ranges from $7.32 to $10.25.

The Double Gang

Each of the seven machines in a single gang has a different production capacity, so logically one machine—the slowest—sets the pace of the whole gang. The theory then is if the slowest machine is "doubled," the overall gang production will increase to the speed of the next slowest machine and so on. Eventually there comes a point of diminishing return. A typical double gang will have two of at least 50 percent of the machines. This gang will have machinery worth about $1,000,000 and a gang of 36 men. However, depending on the combination of machines, costs can go as high as $1,500,000 and the number of men up to 80. Production yields 200 to 300 ties per on-track hour, and typically averages 800 to 1300 ties per 8-hour shift. Double gangs, which are usually system gangs, require subsistence and per-diem. The cost per tie for equipment, tools, labor, and fuel, is $7.60 to $12.35.

PICKING UP SCRAP TIES

Because few railroads still take out tie in three pieces, this approach is not considered. Scrap ties are picked up with a burro crane either individually or in bundles. If bundling occurs during the tie insertion process, then the cost of bundling will be $0.70 per tie. The primary reason for bundling ties is to facilitate their sale or reuse, and to minimize track possession time for picking up ties.

The production rate for picking up ties depends on a number of factors, such as whether ties are stacked in a location adjacent to the track, and how far the ties are from a siding where the gondolas can be stored. Using a six-worker crew, a rail crane, and two gondolas, between 1000 (if they are spread out) and 2000 ties can be picked up per shift. The average cost will be $1.04

per tie. The cheapest tie scrap pick-up once involved burning them at the side of the right of way, but this is no longer permitted.

PICKING UP OTM

This is usually done with a rail crane, equipped with a magnet and a crew of four. In a shift, they can pick up OTM from between 4000 and 8000 ties, depending on the number of spikes per tie that were replaced, at $0.14 to $0.28 per tie.

DISPOSAL OF SCRAP TIES

The disposal cost is subject to much discussion and analysis. The financial impact on the railroad ranges from a substantial positive cash contribution to substantial cost.

A scrap tie contains about 1.5 million BTUs of energy, some ballast, often broken spikes and maybe an anti-split device. The fuel value of the tie is about $2.00, but few railroads seem to be taking advantage of this fact. It is only a matter of time before they do. In some states, ties must be disposed of in an approved landfill, which costs the railroads up to $3.00 per tie. Whole ties have a large range of possibilities. The highest positive benefit is to cascade the tie into a light branch line.

If the tie is removed whole, it can be sold for agricultural (fence posts, grape arbors, etc.) and landscaping purposes. The maximum wholesale value of these ties is around $4.00, delivered to a rail siding in an urban area. So, under the best case scenario, the railroad could be getting $4.00 minus transportation ($0.10) or $3.90 each. A large quantity of ties are not near urban areas, so the average selling price is probably about $2.50. The national average cost of tie disposal is nearly zero dollars.

SURFACING

The only surfacing included in this analysis is the tamping of the newly inserted ties. Surfacing of the entire track is dependant on the original surface quality and the number of ties replaced. With large jobs, the surfacing gang is able to utilize the same block of track time as the tie gang.

NEW TIE LOSSES

A certain percentage of new ties purchased never get installed for the following reasons:

- **Damage due to rough handling into and out of the tie car**
- **Poor quality control at the tie plant** - (At the present time, only a few railroads have a statistically sound QC Program and, as a result, ties are accepted that do not qualify. Most of these poor quality ties are installed anyway. They just do not last as long. Only a small percentage are not installed.)
- **Failure before installation** - If a tie is placed on the shoulder in a very dry environment and left in the hot sun for a long time, (3 months, for example) they have been known to split to the point of failure.
- **Theft.** This is a particularly serious problem in an urban area. Theft rates of 2.5 percent are not unheard of.
- **Fire.** In dry areas where grass fires are common, 2 percent losses are possible, especially if the ties are left on the shoulder for any length of time.
- **Loss.** This cause is common when the track is on an embankment, especially a brush covered embankment. The new ties slide down the embankment and are not found or are not retrievable.

Losses occur at the rate of about 0.1 percent, with the average being probably 0.5 percent and the worst case about 3 percent. These losses have to be applied to the black tie cost, transportation and unloading costs and, therefore, can range from $0.02 to $1.42 with an average of about $0.15.

COST OF TRAFFIC DELAYS

Traffic delay costs result when any slow order is posted on the track because of the tie replacement operation. There can also be delays from other sources, for example, necessary train fleeting. Traffic delay costs, then, can range from $0 to a very considerable amount. Unfortunately, such costs are quite difficult to quantify, and are beyond the limitations of this analysis. However, these costs do exist and probably range between $0 and $1000 for every mile of track (800 ties) replaced. The effect of the seasoning method on train delay costs is minimal.

The shorter average tie life of Boulton and vapor dried ties suggest that they will cause more tie replacement related train delays per MGT than will the air-dried ties. Maintenance policy is likely to have a larger role in determining train delay costs.

SUMMARY

The total cost of installing a cross tie, in replacement, ranges from $27.07 to $90.58, with the likely national average of $40.80. At the extreme end of the range, all of the cost components are either the highest or the lowest. This is possible, but unlikely. The low cost would be an air-dried, softwood tie installed by a double tie gang, in a location close to the timber source and the treatment plant, with the scrap tie being sold. The average is an air-dried, hardwood tie, treated about 75 miles from the timber source and installed by a single tie gang, about 450 miles from the treatment plant, with a zero tie disposal cost. The high cost tie is an oak, vapor dried tie treated about 700 miles from the timber source and installed by hand, about 2,000 miles from the treatment plant, with a high tie disposal cost.

The cost of installation is clearly the most significant single factor in replacing a tie and the one that deserves the most scrutiny. One of the other things identified by this analysis is that many of the components of the cost of replacing a tie are on the order of pennies, but it should be remembered that some railroads are buying on the order of 2 million ties a year, which means one cent saved in the cost is $20,000 per year!

Fundamental to any analysis of installation are determining basic data, such as capital recovery, machinery, and maintenance costs.

Comments on Methods

The cost ranges of each of the methods is shown in Figure 2, together with the approximate percentages of the ties installed by each of the methods. From this a national weighed average of approximately $9.50 can be calculated.

It is noticeable that the lowest cost double gang is greater than the lowest cost single gang. This cost difference exists because the possibility is greater that the single gang will be working from its home base, eliminating the need for per-diem. That a double gang would work from its home base is unlikely. It is also exponentially more difficult to manage a double gang than a single gang. Whether the double gang is the most economical method of installing ties is questionable, but in heavy train density territory, track possession is at a premium; for this reason, there is definite value to this method.

A tie from a heavy density line may be mechanically worn out, but still have much of its decay life. If installed in a branch line, the tie may last 20 or more years. On a discounted basis, this tie may be worth about $15.00. The number of ties in this category at the present time is small, it is not considered in the low-cost scenario.