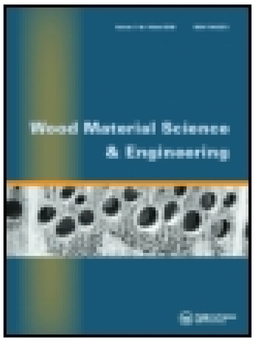

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Dual borate and copper naphthenate treatment of bridge timbers – potential cost savings by various performance enhancements

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ABSTRACT

Dual-treatment technology combining diffusible preservatives with oil-borne preservatives, widely used for crossties in the USA, has now also been commercialized with bridge ties/timbers. In order to understand the implications of these changes, the historic service life of creosote-treated bridge timbers in northern and southeastern USA were considered as well as field-test data for both creosote and copper naphthenate. These were used to estimate potential future service life. Estimates on life expectancy with added borates were also made from published data on performance. Cost–benefit analysis based on creosote and copper naphthenate costs as well as assumptions made from field-test efficacy data suggest cost savings of up to $20 per timber per year of additional service. Service life extension and the resulting cost savings could be achieved in a number of ways: change preservative from creosote to copper naphthenate; increase active ingredient retention; and/or add dual-treatment protection. A preservative change from creosote to copper naphthenate would be the simplest and lowest cost way of increasing service life of bridge timbers, with potential savings to both treater and railroad. An increase in copper retention could also give significant life extension, could be carried out at little additional cost and without increasing bleeding. The addition of borate to protect the heartwood also provides significant assumed increase bridge tie life, and can be used with either creosote or copper naphthenate treatments.

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Capital recovery; creosote; dual treatment; efficacy; sleepers; ties

1. Introduction

Railway bridges and especially bridge ties (sleepers) are often made of wood. Wood has traditionally been more cost effective and is much more environmentally friendly than alternatives such as concrete, steel and composites, as shown in life cycle assessment for ties and poles (Townsend and Wagner 2002, Smith and McIntyre 2011, Bolin and Smith 2013). The wood is preservative treated to protect against decay fungi but also termites and other wood destroying organisms, and thus to ensure adequate service life. Timber bridges exclusively made from untreated wood are rare, most often historic, and always require careful protection by design (Ritter 1990, Pierce *et al.* 2005, Barbier *et al.* 2006).

For 100 years and more, the preservative of choice for railroads has been creosote, but this has seen a number of changes over the years including newer creosote formulations purportedly with lower effectiveness, the addition of borates in the so-called dual-treatment processes, and a change from creosote to oil-borne copper naphthenate, especially in bridge ties. Price changes, environmental considerations and the compelling performance and cost savings for crossties with dual treatment (RTA 2010, Zeta-Tech 2011) has helped spur some of these changes. The Norfolk Southern railroad, for example, recently announced a major commitment to copper naphthenate-treated crossties (Gauntt 2012).

Copper naphthenate has been used as a wood and canvas preservative (think green scout and army tents) since 1903 when it was developed in Denmark, and saw extensive use during the Second World War as a creosote extender. Copper is the active ingredient in copper naphthenate, which is prepared by reacting copper compounds with naphthenic acid in order to solubilize copper metal in oil, just as other metals are converted to organic soaps for use in a variety of applications requiring oil solubility (Brient *et al.* 1995). Copper naphthenate is available in both oil-borne and waterborne formulations, but the oil borne is typically used for ties and poles. Oil-borne concentrates contain 8% Cu and 32% diluent oil, to give a viscous liquid. Wood treaters dilute the 8% Cu concentrate down to ~0.8% Cu, but this can be adjusted in order to achieve greater copper retentions in the treated wood.

Copper naphthenate's major uses today are in the treatment of railroad crossties, bridge ties and timbers, utility poles, pilings and fence posts. It is considered safe enough to be sold in retail for consumer use in the USA. Copper naphthenate formulations have been adopted by the American Wood Protection Association (AREMA). The American Railway Engineering and Maintenance-of-Way Association (AREMA) includes copper naphthenate in their guidelines manual as a treatment for crossties and switch ties. Copper naphthenate can be used to treat air-dried or kiln-dried

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wood and for Boulton drying and treatment of green wood. Approximately 5% of ties in the USA are treated with copper naphthenate instead of creosote. A full and up-to-date review of railway tie treatments with copper naphthenate has been given by Asmus *et al.* (1985), Brient and Webb (2002), Barnes *et al.* (2011) and Brient (2014).

An approach to improving bridge tie preservative treatment is the so-called "dual-treatment": the application of a water-soluble and diffusible borate-based treatment in combination with the traditional oil-borne preservatives (e.g. creosote, copper naphthenate) (Arthur 1967, Amburgey *et al.* 2003, Amburgey and Sanders 2009, Kim *et al.* 2011). Dual treatments are now a common commercial practice in the wooden crosstie industry and there are a number of different methods for combining the two preservative treatments. The various methods, their potential advantages and treatment requirements have been described (Taylor *et al.* 2013).

Dual-treatment combinations of copper naphthenate and borate have been widely used in remedial treatment, in railroad crosstie treatment and have been reviewed recently by Freeman (2013). Dual treatment of crossties with disodium octaborate tetrahydrate followed by an overtreatment with copper naphthenate or creosote was added to American Wood Protection Association (AWPA) Standard U1, Commodity Specification C: Crossties and Switchties in 2013 (AWPA 2016).

Borates have been used successfully as wood preservatives and pest control products for many decades. Advantages of borates include broad-spectrum efficacy against all wood destroying organisms, low cost, low acute mammalian toxicity and a low environmental impact. The chronic toxicity of borates (documented since the 1970s) is similar to that of alcohol in beer or wine, but with obviously less risk of ingestion. For details of boron essentiality and toxicity, see ECETOC (1995) and Lloyd (1998). Adding borates to railroad crossties prior to creosote treatment has been shown to provide significant benefit to railway crossties (Amburgey *et al.* 2003) and utility poles (Dickinson and Murphy 1991). Currently, nearly 50% of the 22 million wood ties produced in the USA are dual treated with an initial diffusible borate application for heartwood protection. The multi-million dollar potential savings possible with this approach especially in the southeast of the USA has been documented (Zeta-Tech 2011). It should also be noted that the inclusion of borate has allowed the industry to reduce typical creosote retention in crossties from, for example, a specified 8 pounds per cubic foot (pcf) or 128 $\mathrm{kgm^{-3}}$ to a specified 6 pcf or 96 $\mathrm{kgm^{-3}}$, so the borate treatment is more than paid for with creosote savings (such a reduction was not used in our calculations for bridge ties here). In order to try to compare creosote and copper naphthenate efficacy, comparative performance retentions have been given in Table 1.

Table 1. Comparative performance retentions for creosote and copper naphthenate derived from long-term field efficacy testing (Brient and Webb 2002, Woodward *et al.* 2011, Lebow *et al.* 2013).

QNAP = Creosote	QNAP = Creosote
0.06 = 10 pcf	0.96 Cu = 160 $\mathrm{kgm^{-3}}$ Creosote
0.04 = 8 pcf	0.64 Cu = 128 $\mathrm{kgm^{-3}}$ Creosote
0.03 = 6 pcf	0.48 Cu = 96 $\mathrm{kgm^{-3}}$ Creosote

Because of the low surface area to volume ratio and the large (refractory) heartwood percentage of bridge ties, pressure treatments with dissolved borate are unlikely to result in sufficient treatment penetration and retentions, especially in green timbers. A high-concentration borate emulsion dip treatment is being used successfully for railway crossties (Kim *et al.* 2011). However, this technology works by allowing the borate to diffuse into the wood after the initial dip treatment (on the un-dried tie) for a number of months during drying, before over-treating with the second preservative. Bridge ties can be different sizes for every bridge, are difficult to stock and so are typically ordered "just in time" per project. For this reason, they are usually dried using a Boulton process: boiling out the water by submerging the green timber in heated preservative, so do not have the many months of drying time to facilitate dip or pressure diffusion approaches.

These problems have been successfully overcome by drilling holes in the timber and filling them with liquid borate preservative. The preservative is then mobilized during the Boulton treatment and results in a very well-treated heartwood (Lloyd *et al.* 2014). Potential concerns of strength loss or possible reduction in mechanical properties caused by the drilling of the holes has been addressed (Taylor *et al.* 2017). This approach has been added to the Norfolk Southern Bridge Tie Specification and commercialized by both Mellott Wood Preserving and Stella Jones Corporation (example is shown in Figure 1).

There are a number of potential ways to increase the protection of bridge ties, including using more or more effective preservatives, or combinations of preservatives (i.e. dual treatment). These options provide a range of potential initial costs but also presumably provide benefits in terms of extended service life. The purpose of this paper is to provide a cost–benefit analysis for a range of bridge tie treatment scenarios.

2. Methods

Four scenarios for bridge ties were developed to examine the implications of various preservative choices and retentions, and the option for dual treatment. To compare the economic benefits of various treatments, the capital recovery is used, which is the annual cost of the tie (Table 2).

- Scenario 1: copper naphthenate instead of creosote as a stand-alone treatment.
- Scenario 2: increased active ingredient concentration for a stand-alone copper naphthenate treatment.
- Scenario 3: borate dual treatment with creosote.
- Scenario 4: borate dual treatment with copper naphthenate.

Bridge tie service life data were supplied by Norfolk Southern railway: replacement is typically needed at 16 years in the south east USA (Georgia and Alabama, AWPA deterioration zones 4–5 = high to severe) and at 26 years in the north east USA (AWPA deterioration zones 2–4 = moderate, intermediate and high) (Hughes 2016); Figures 2 and 3). Replacement interval is the same if bridge ties are in a tangent or

Figure 1. Commercially dual-treated borate (Cellutreat® liquid 50) and copper naphthenate (QNAP®) bridge timbers. Timbers have been rip sawn after borate and plug (BTX®) installation and Boulton treatment, and one half subsequently curcumin sprayed (Smith and Williams 1969) to show the presence of borate (red). For color interpretation of this caption reader should refer online.

curve track, so decay and not physical wear is the likely cause (crossties in curves wear more aggressively than in straight track).

Bridge tie costs were determined by discussions with railroads and tie suppliers. A bridge tie cost is approximately \$200 for a standard 10″ by 10″ by 10′ (25 cm × 25 cm × 3 m) bridge tie (typically of mixed hardwood with at least 60% made up of oak and hickory) and treated with creosote, with an installed cost of at least \$400 with labour. With the additional cost of track time, safety, etc., this probably approximates to \$550 on average (authors' assumption) when other bridge tie dimensions and specialized fabrications are also considered. N.B.: Obtaining exact costs from both treaters and railway companies is difficult.

Scenario 1 assumed that at AWPA standard retentions, copper naphthenate-treated wood lasts for 30% longer than creosote-treated wood. Copper naphthenate-treated wood performance is very good as demonstrated by multiple laboratory, field and in-track studies, and has been shown to last for at least 30% longer than creosote-treated wood. Figure 4 shows one example (Freeman *et al*. 2003).

Scenario 2 assumes that bridge tie life can be extended by using higher retentions of preservative.

For scenario 2, data from Figure 5 were used to justify an assumption of 10 years of increased service life resulting from increased copper naphthenate target retentions (0.04 pcf/0.64 kgm^{-3} Cu to 0.15 pcf/2.4 kgm^{-3} Cu).

For Scenario 3, the work of Dr Terry Amburgey from Mississippi State University (RTA 2010) and documented by Zeta-Tech (2011) suggests an additional 10–20 years' performance life for crossties due to dual treatment with borate. Amburgey's ties are still performing, so the improvement is more than 14 years so far, despite that those ties were treated from the outside-in, and deployed in close-to-ground contact with a high leaching hazard. Bridge ties are treated with borate from the inside-out and so have no surface borate concentration, and are fully above grade, both of which should reduce leaching and improve longevity. In light of this, the authors have assumed 20 years of additional service life, that is, 36 years in the south and 46 years in the north (Table 2).

For Scenario 4, the assumed benefits of using copper naphthenate in place of creosote (30%, Scenario 1) and of dual treatment with borate (20 years, Scenario 3) were considered as additive.

Capital Recovery Factor:

$$A = P\frac{i(1+i)^n}{(1+i)^n - 1}, \qquad (1)$$

where A is the capital recovery, P is the initial cost of the tie, i is the interest rate (3% assumed here) and n is the tie life.

A market rate for a creosote bridge timber was assumed as previously explained at \$550 per timber. Using a creosote cost of \$3.05 per gallon (\$0.79 per l), a copper naphthenate cost of \$2.25 per pound (\$4.95 per kg) and an oil diluent cost of \$1.72 per gallon (\$6.5 per l), the copper naphthenate costs were determined at the two retentions and taken off or added to the cost of the tie. Borate costs of \$20 per tie were applied,

Table 2. Costs, expected service lives, capital recovery and cost savings per year at an interest of 3% for different alternatives to creosote-treated bridge ties.

Tie treatment	Initial cost (\$)	South: Service life (years)	South: Capital recovery (\$)	South: Annual savings (\$)	North: Service life (years)	North: Capital recovery (\$)	North: Annual savings (\$)
Stand-alone treatment							
Creosote at 128 kg/m^3 (baseline)	550	16	43.79	–	26	30.77	–
Copper naphthenate at 0.96 kg Cu/m^3	548	21	35.55	8.24	34	25.93	4.83
Copper naphthenate at 2.4 kg Cu/m^3	553	31	27.65	16.14	44	22.80	7.97
Dual treatment							
Creosote at 128 kg/m^3 and borate	570	36	26.11	17.68	46	23.01	7.76
Copper naphthenate at 0.96 kg Cu/m^{3}and borate	568	41	24.26	19.53	54	21.37	9.39

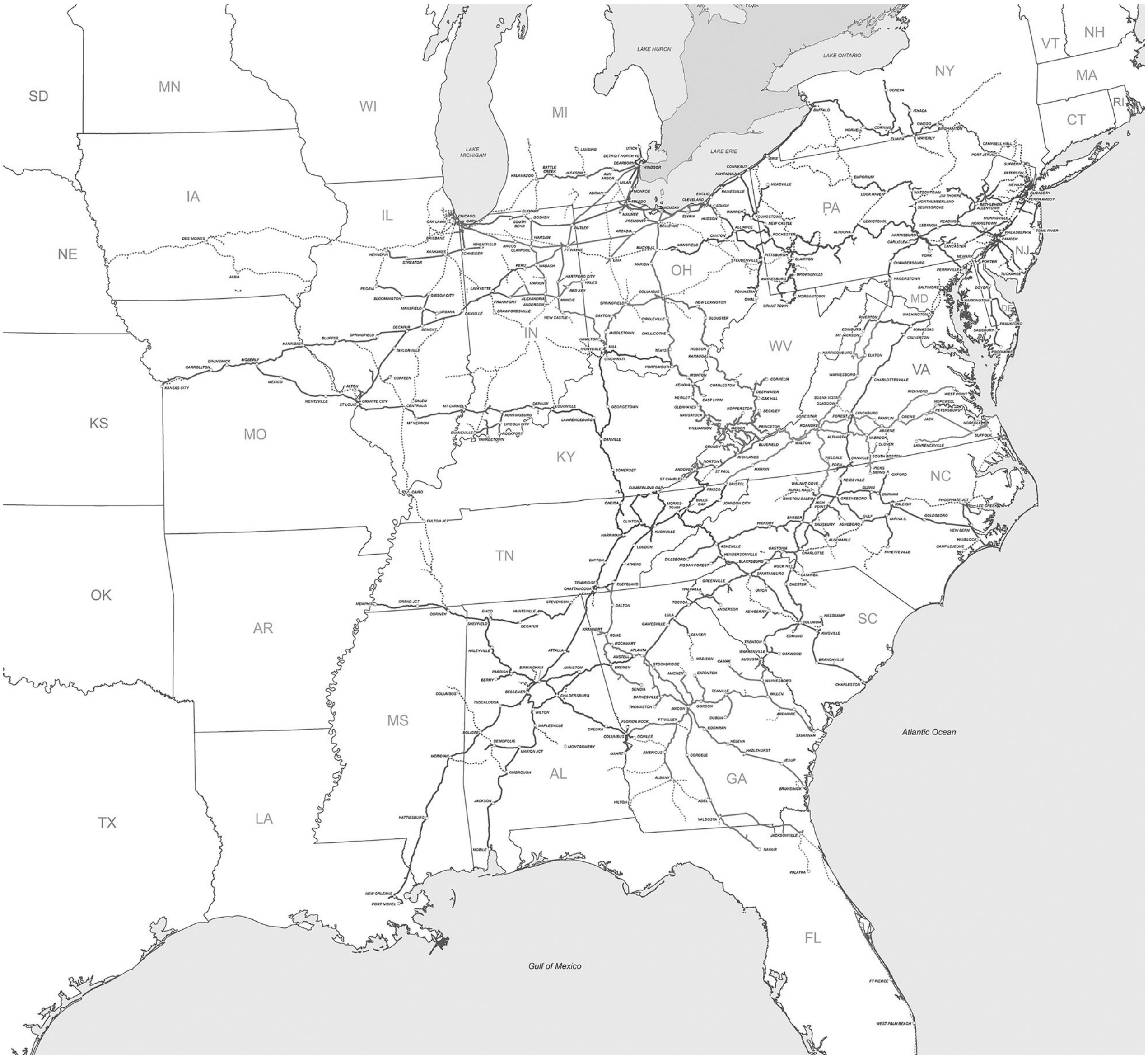

Figure 2. Railroad track routes of Norfolk Southern in USA (Hughes 2017).

to include borate, plug and installation. The capital cost of an additional storage tank to hold copper naphthenate and the pillar drill to drill holes for borate were not applied. Note, railroad specifications, national standards, volume purchasing and freight will impact these costs, but at the time of writing, they were applicable for companies with access to all of the treatment scenarios.

3. Discussion and conclusions

The assumed service life extensions resulting from switching to copper naphthenate, increased loadings and/or dual treatment more than outweigh any additional initial costs, as shown by positive capital recovery over the lifespan of the tie. Although the values will vary with interest rates, the trends will be the same. Savings are greater over the life of the ties when the cost of money (interest rate) is low because of the upfront cost of the ties and treatment (it assumes the money is borrowed or not invested elsewhere over the time period).

Changes to tie treatment can result in savings for all scenarios, in both the southern and northern regions, but potential savings are greater in the south where the decay hazard is higher. A simple change from creosote to copper naphthenate even has an upfront saving of \$2 per tie and yet also gives an additional ~\$5 per year in the north and ~\$10 in the south. An increase in copper retention has little upfront cost and requires no change to treatment plant equipment etc., so this is a sound move for both treatment plant and railroads with savings of more than \$10 in southern climates, but is not really financially justified in the north where simply changing to copper naphthenate at lower retention and obtaining the upfront cost saving is better.

For railroads in regions where copper naphthenate might not be available, adding the borate as part of a Boulton treatment to creosote gives estimated savings in excess of \$15 per year in high hazard climates and more than \$5 per year in

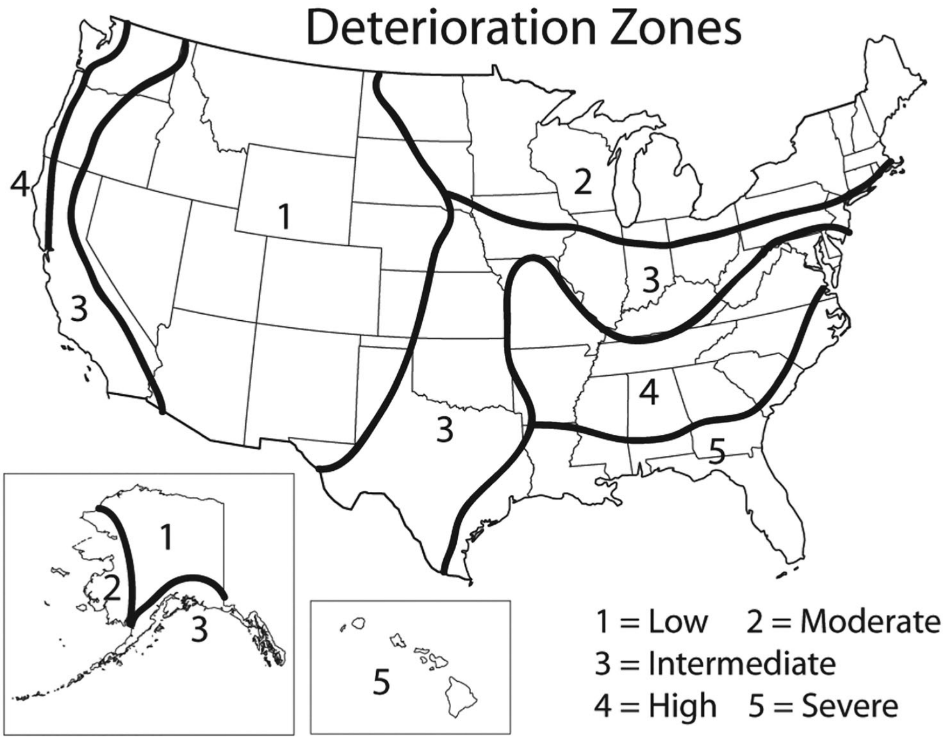

Figure 3. Zones of potential for deterioration of wood used in ground contact in the USA (AWPA U1-11 2016).

lower hazard climates. The few dollars of savings per tie modelled here imply huge potential savings for a railroad, which may own hundreds of bridges, containing many thousands of ties. As an example, for 3000 bridges with 500,000 ties assuming an extra 30 years' service life, would give $300 million savings.

Service life of wood products is difficult to predict, especially when it involves new or developing protection technologies, so the values modelled here are uncertain. For example, it is unknown if the benefits of the treatment options are additive, coincidental or synergistic.

The data presented here, based on our assumptions, clearly demonstrate the incentive for railways to examine their options and make changes that extend tie service life. For those who wish to make different assumptions in terms of costs or longevity improvements, the calculations have been included and the scenarios can be re-modelled.

Regardless of the potential paybacks modelled here, in many circumstances, there will be reluctance to adopt any new technology that requires additional up-front costs. We recognize the prevalence of short-term financial horizons in businesses such as railroads, but we also urge all users to

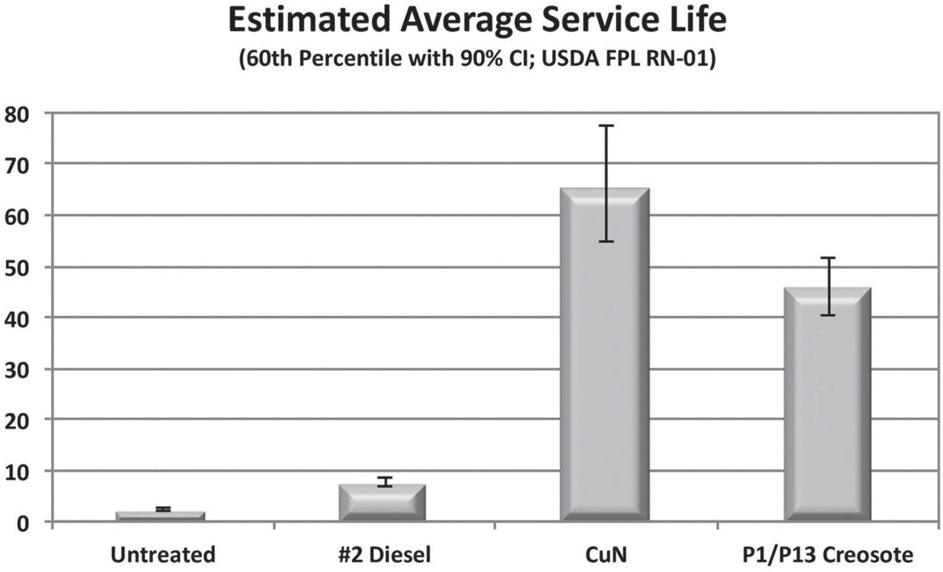

Figure 4. Estimated service life in years for pine posts from a field test in Mississippi, USA, treated with 6 pcf/96 kgm^{-3} Creosote and 0.03 pcf/0.48 kgm^{-3} Cu Copper naphthenate (CuN) and compared to untreated and oil (#2 Diesel) only controls (Freeman *et al*. 2003).

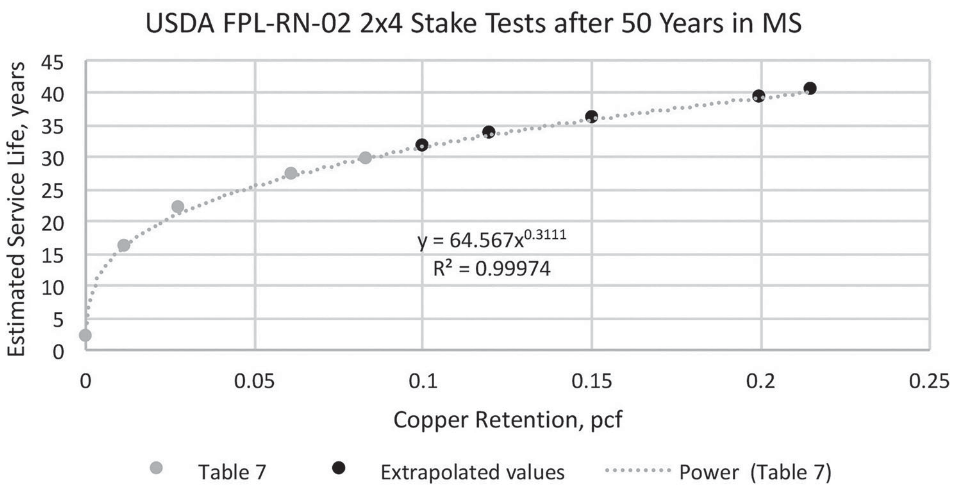

Figure 5. Estimated service life for stakes treated to different retentions of copper, with copper naphthenate in a long-term field test in Mississippi (MS), USA. (Plot 7 is the data taken from table 7 Lebow *et al.* 2013.)

consider the life-cycle costing approaches, such as done here when considering investments in their infrastructure.

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Disclosure statement

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