Stephen T. Smith, P. E.
7080 Landmark Place
Helena, MT 59601
Phone and FAX: (406)449-6216
Email: stephentsmith@wildblue.net

Economic Evaluation of Treated Wood and Galvanized Steel Guardrail Posts

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1 Introduction

This paper has been revised and reissued to make corrections and address comments made by Washington State Department of Transportation (WSDOT) in their Issues Review dated May 1, 2013. Significant changes include discussion of wood variability, change to baseline service life of 50 years for preserved wood and galvanized steel posts, and correction of calculated cost per mile per year in text and Tables 2 and 3.

The Western Wood Preservers Institute (WWPI) requested that Stephen Smith, P.E. prepare an economic evaluation comparing the life cycle costs of treated wood and galvanized steel guardrail posts. This study uses data from and is directly applicable to WSDOT, but is also generally applicable to other states and the U.S. Federal Highways.

Both wood and steel guardrail posts are installed and used in the same manner to accomplish the same goal; support the guardrail and resist the forces imposed when vehicles hit the guardrail. Both have outer dimensions of approximately 6- by 8-inches, are installed directly into the ground, are 6-feet in total length, extend above ground-line 32-inches, are spaced 6-feet 3-inches (6.25-feet), use blocks measuring approximately 6- by 12- by 14-inches, and have the guard rail attached at each post with one 5/8-inch diameter galvanized steel through-bolt. Blocks used with wood are also typically wood, but blocks for steel posts may be either wood or of composite material.

Unlike Washington State, the U.S. Department of Transportation's Federal Highway Administration and most other states allow installation of either treated wood or galvanized steel guardrail posts based on lowest installed cost. Most new guardrail installations in the U.S. use treated wood posts. In 2007, an estimated 31 million board feet[1] (2 million cubic feet) of lumber was treated with waterborne preservative in the U.S. for highway construction. This equates to approximately 750,000 sets of guardrail posts and blocks. An additional 64 million cubic feet of timbers (greater than 4-inch square) were treated with waterborne, at least some of which were probably also for highway use. It is likely that at least 1 million and probably 2 million new treated wood guardrail posts, supporting 1,200 to 2,000 miles of guardrail, are installed every year in the U.S.

Factors affecting the life cycle costs of posts primarily are purchase and installation costs, average service life, salvage value, and internal rate of return (equivalent interest rate applied to investments). This paper addresses these factors in relation to the transportation authority's guardrail post selection.

[1] Vlosky, R.P. Statistical Overview of the U. S. Wood Preserving Industry: 2007. Louisiana State University, Forest Products Development Center, February 16, 2009.

In 2011 WSDOT shared with WWPI a Life Cycle Cost Comparison of treated wood and galvanized steel posts that was used, in part, to justify WSDOT's decision to move away from use of treated wood guardrail post in favor of galvanized steel posts. That study concluded that the life cycle costs of steel were approximately 5% less than for wood posts. Review of the WSDOT Life Cycle Cost Comparison revealed that the study included assumptions for service life that dramatically impact the study outcome and conclusions. This paper will also address this previous study.

2 Characteristics of Wood and Steel Guardrail Posts

2.1. Treated Wood Posts

The standard wood post for Type 31 Beam Guardrail is shown in the WSDOT Standard Plans C-20.10-00 and C-1b and is covered by 2012 Specification 9-16.3 and 9-09.2 and .3. Posts are 6- by 8-inch in cross section and 6-feet long, unless otherwise specified. Posts are of Douglas fir, hem fir, or southern yellow pine and treated with creosote (10 pcf), pentachlorophenol, ACA, ACZA, or CCA (all at 0.5 pcf) in accordance with AASHTO M 133 and AWPA standards.

Note that the current 2012 WSDOT Standard Specifications, Section 8-11.3(1) A, Erection of Posts, states; "*New installations of guardrail shall have steel posts or as otherwise shown in the Plans*." Thus, the current default position of WSDOT is that only steel guardrail posts may be used.

Wood posts generally are not driven into the ground. Instead, accepted practice is to drive a 6- by 8-inch spud into the ground to make the hole, pull the spud, and then set the wood post into the formed hole to the correct final depth, tamping the surrounding soil as needed. Direct driving of the wood posts often would result in excessive damage to the posts or poor alignment. After posts are installed to correct positions, blocks and W-beam guardrails may be installed.

WSDOT expects that most guardrail posts will remain in service, without being moved, for up to 50 years. Following such service life, it is reasonable to assume that such posts are not suitable for reuse. Service life of guardrail posts may be ended due to reasons other than age related decay or corrosion. Posts may be removed due to road widening, alignment changes, or to raise the guardrail following repaving. (Guardrails typically are required to be raised after the elevation of the pavement is increased by 4-inches or more.) In some instances, posts that have been in use for a small fraction of expected life, such as less than 10 to 15 years, may be saved and reinstalled as posts for new guardrail. In this situation, most wood posts (greater than approximately 95%) can be successfully removed and reused. Since wood posts are not driven, there is little damage from installation. The wood preservative is effective in preventing decay and insect attack. It is reasonable to expect wood posts to provide a total of approximately 50 years of service, even if removed and reinstalled once in this time period. WSDOT estimates that early removal of posts is rare, at less than 1.5% annually for the approximately 1,700 miles of beam guardrail in the system. One contractor reported removing approximately 12 miles of guardrail annually, so the statewide total is likely up to 10 times or 120 miles annually, but only some of this would be newer material. Thus, up to approximately 25 miles of guardrail or 21,500 posts are replaced each year that may have significant remaining service life.

The effectiveness of wood preservation in extending the service life of wood in ground contact is well understood and documented. Preservation in accordance with the American Wood Protection Association (AWPA) Standards, as is required by WSDOT specifications, assures a long service life. Posts treated with various preservatives were shown to provide excellent service, often more than 50 years, in a high decay hazard location.[2] Tests of treated wood stakes, generally 2"x4" or smaller, also show long term protection in high decay hazard locations.[3] CCA treated hem-fir posts have shown excellent service life in field tests by Oregon State University[4]. Thus, it is reasonable to expect that wood posts preserved according to specifications will provide service of approximately 50 years if not otherwise damaged or removed. If removed following less than approximately 15 years in service, an additional 15 to 30 years of service can reasonably be expected.

WSDOT has expressed great concern about the **variability** of service life that they expect of wood posts due to observations of decay in posts. Wood's natural variability is addressed in the way design codes determine strength values for wood. This also makes understanding difficult. Safety factors are applied to wood strength values to assure that even the weakest pieces of lumber or timber are strong enough to meet designed uses. For example, allowable bending stress first considers the 95% exclusion limit to set the minimum, meaning that 95% of samples would be stronger than the set minimum. Then an additional safety factor and other use factors are applied. The result is that for hem-fir, the representative modulus of rupture (MOR) is 11,300 psi[5], but the design allowable bending stress (F_b) is 1,150 psi[6], or approximately 10% of the MOR. Thus, the allowable bending moment applicable to a treated, select structural, hem-fir 6x8 post is approximately 114,000 pound-inches (lb-in). The likely moment to break this post, based on the MOR, is approximately 700,000 lb-in (six times more than the design allowable value). The comparable values for an A36 steel, W6x9 section, galvanized post are design bending moment of approximately 120,000 lb-in and likely moment to bend the post (at yield stress) of approximately 200,000 lb-in. Thus, the likely force to break a sound wood post is more than three times more than the force to bend over a steel post. The design value for a wood post is slightly less than (95%) that of the steel post. Further, for the minority of posts that begin to decay while in use, preserved wood posts tend to decay first in the interior, where preservative did not penetrate. Loss of strength in the interior has minimal effect on bending strength, since the outer preserved wood contributes most to bending strength. Posts with limited internal decay are usually still suitable for use and have not failed. Thus, while wood's inherent variability is acknowledged, the safety factors used more than make up for the weaker fraction of the wood post population.

The typical service life of treated wood posts was recently put to test at Oregon State University (OSU)[7]. Posts showing visible signs of decay were preferentially selected from bundles of posts removed by a project in Bellingham Washington after 20 years in service. The 84 selected posts were examined for depth of preservative penetration and degree of decay and tested to determine

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[2] Freeman M., Crawford, D., Lebow, P. and Brient, J. A comparison of Wood Preservatives in Posts in Southern Mississippi: Results from a Half-Decade of Testing [Journal]. - [s.l.] : American Wood Preservers' Association, 2005. - Proceedings: Vol. 101.
[3] Woodward B., Hatfield, C., and Lebow, S. Comparison of Wood Preservatives in Stake Tests, 2011 Progress Report [Report]. - Madison, WI: USDA Forest Products Laboratory, 2011.
[4] Morrell, J.J., D.J. Miller, and P.F. Schneider. 1999. Service life of treated and untreated fence posts. 1996 post-farm report. Research Contribution 26. Forest Research Laboratory, Oregon State University, Corvallis, Oregon, 24 p.)
[5] Forest Products Laboratory. 2010. Wood handbook—Wood as an engineering material. General Technical Report FPL-GTR-190. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 508 p.
[6] National Design Specification (NDS) for Wood Construction with Commentary and Supplement: Design Values for Wood Construction 2005 Edition.
[7] Morrell, J.J., Love, C.S., Clauson, M, and Sinha, A. Condition of Chromated Copper Arsenate Treated HJem-fir Guardrail Posts after 20 Years in Service in Western Washington State. Prepared for Western Wood Preservers Institute. Nov. 2012

preservative retention and Modulus of Rupture (MOR). Only three (4%) of the 20-year old posts had MOR results less than the AASHTO standard. Posts without visible decay pockets (48%) still demonstrated strength (per MOR testing) nearly as high as new posts. The MOR values from this testing support maximum bending moments of 289,000 and 220,000 lb-in for new and 20-year old used preserved wood posts, respectively, moments higher than would cause steel posts to fail. Given these results for the worst of the 20-year old posts taken out of service, it is likely that the vast majority of these 20 year old posts could be reinstalled with an expectation of providing another 20 or more years of service in a guardrail system.

Even after final removal from guardrail service, posts can be recycled to other uses. Petersen Brothers, Inc. (a WSDOT contractor) reports that they can usually sell such posts for fencing or landscaping uses and they often use them as dunnage to support concrete traffic barriers in their yard (a very structurally demanding use). Depending on the market, used treated wood may be recycled as fuel. However, if the used posts are not suitable for use as structural wood, then disposal as non-hazardous solid waste is most likely.

2.2. Galvanized Steel Posts

The same WSDOT plans cover steel posts. They are formed of W6x9 steel shapes and are galvanized per ASTM A36 or ASTM A992 and AASHTO M 111. Posts are also 6-feet long, unless otherwise specified.

Steel posts are generally driven into the soil. A base plate is positioned on the ground that has the "H" shape of the post cut to guide the post as it is driven. A drive head is used to prevent damage to the top of the post. As posts are driven, it is common for rocks to cause the post bottom to bend or deflect slightly. The final position may be adjusted by applying pressure at the top.

Following 10 to 15 years in service, steel posts typically do not suffer from excessive corrosion. However, if removal is required for highway changes, steel posts can rarely be reused. Deformation of the H-shape, particularly near the drive tip, is usually enough to prevent driving the post through the base plate. Additionally, deformed tips tend to cause deflection of the post as it is driven, resulting in crooked and unacceptable installation. Thus, even if only installed for a short time, steel posts usually cannot be reused. Steel posts that are galvanized appropriately according to specifications are known to provide good service life if not removed or damaged. Data for galvanized steel in soil contact indicate that continuous service of 50 years is a reasonable expectation[8]. However, road changes that require removal and reinstallation of guardrails, though rare, will result in a reduction of the average service life.

Steel posts removed from service may also offer some beneficial use options, such as for fencing. However, welding of galvanized steel is problematic. Most such steel is collected and recycled as scrap steel.

[8] American Galvanizers Association, 2011. Service Life of Galvanized Steel in Soil Applications. Website: http://www.galvanizeit.org/images/uploads/publicationPDFs/Galvanized_Steel_Performance_in_Soil.pdf. Accessed June 2, 2011.

3 Costs of Wood and Steel Posts

Approximate costs for treated wood and galvanized steel posts (per private communication with a contractor) are summarized in Table 1. The "Cost" basis values are approximate prices paid by contractors to purchase the materials from suppliers. Those are marked up by 21% to include installation and profit for the contractors to reflect the amount as bid to WSDOT. Last, these amounts are rounded for use in the life cycle cost model.

Confirmation of costs was attempted by reviewing WSDOT bids. For example, WSDOT Contract number 8259, March 2012, awarded the bid for 330 posts at $55.20 each and blocks at $7.75 each. The WSDOT Engineer's estimates were $60 and $10 each, respectively. However, the WSDOT since clarified that these were bid to replace existing guardrail, so were not indicative of typical post costs for new guardrail system bids. Estimated costs for wood posts and blocks are based on data provided by companies that supply treated wood posts in Washington State.

Table 1- Post and Block Costs

Item Description	Basis	Treated Wood	Galvanized Steel
Post	Cost	$ 18.50	$38.22
Block	Cost	$ 4.36	$7.28
Bid markup (install & profit)		21% Assumed	
Post	Bid	$ 22.39	$46.25
Block	Bid	$ 5.28	$8.81
Post	Rounded	$ 23.00	$47.00
Block	Rounded	$ 6.00	$9.00

WSDOT states that typical per linear foot bid pricing in 2009 of installed guardrail systems were $21.50 for wood post and $24.75 for steel post guardrail systems. This indicates an increased cost for steel posts of $3.25 per foot or $20.31 per post and block set (at 6.25-feet spacing). This evaluation uses costs per post and block of $29 for wood and $56 for steel, indicating a difference of $27. Thus, this evaluation assumed a wood to steel difference approximately $7 more than the WSDOT did. Given all the assumptions, market conditions, and other variables involved, the cost values are reasonably in agreement. The potential impact of this difference is explored through sensitivity analysis in Table 3.

The life cycle costs of post systems are modeled using the "Rounded" costs from Table 1 and assumptions as discussed below:

- Service Life is assumed to be the same for both wood and steel with an average of 50 years. Sensitivity analysis is used to consider alternate service life scenarios.
- Bolt cost is based on the steel at $2.00/pound for 5/8-inch diameter steel 22-inch long for wood posts and 14-inch long for steel posts. Nuts and washers are assumed the same for either and not included in the costs.
- Salvage values are calculated using the weight of steel for posts and bolts at the approximate current value of scrap steel of $500/ton ($0.25/pound). Wood posts are assumed to have an average value of $5.00 each for fence, landscape, or dunnage use.

- Interest rate is set at 4%, a typical value used to represent the time value of money for government investments.

The Guardrail Posts Life Cycle Costs Model is shown in Table 2. As shown, the annual cost of ownership for wood posts supporting guardrail is approximately $1,300 per year per mile of guardrail. The cost of galvanized steel posts is approximately $2,300 per year per mile, 80% more than for wood.

Table 2 - Life Cycle Cost Model

Description	Units	Treated Wood	Galvanized Steel
Post cross section		6 x 8-inch	W6 x 9
Post Length	feet	6.00	6.00
Spacing	feet	6.25	6.25
Weight	pounds	80	54
Block cross section	inch	6 x 12	6 x 12
Block length	inch	14	14
Block material		wood	composite
Through bolt- 5/8" galv.	inch	22	14
	pound	1.91	1.22
Costs			
Post	each	$ 23.00	$ 47.00
Block	each	$ 6.00	$ 9.00
Bolt assembly	each	$ 3.83	$ 2.44
Total per post	each	$ 32.83	$ 58.44
Total per L.F.	$/L.F.	$ 5.25	$ 9.35
Total per mile	$/mile	$ 27,733	$ 49,367
Life Cycle Cost Evaluation			
Service life	years	50	50
Salvage value	$/post set	$5.48	$13.80
Interest rate		4%	4%
Equivalent annual payment	$/yr/post	$ (1.50)	$ (2.70)
Eq. Ann. Payment/mile	$/yr/mile	$ (1,270)	$ (2,283)

Sensitivity testing is used to consider the impact of alternate assumptions on the cost model. Alternative assumptions are considered while others remain unchanged from those in the model as shown above. Alternative scenarios include:

- Decrease the service life of wood to half that of steel; 50 years for steel and 25 for wood. This duplicates the service life assumptions of the study provided by the WSDOT.
- Decrease the service life of steel to half that of wood; wood 50 & steel 25 years.
- Decrease service life of both post materials to 25 years.
- Use wood block with steel post, so that block costs are the same for each.
- Increase the cost of wood posts approximately 50% from $23 to $35.

- Increase the cost of wood posts to $35 **and** decrease service life of wood posts to 25 years.
- Match WSDOT costs by decreasing steel post cost $7 from $47 to $40 and keep service lives of both at 50 years.
- Match WSDOT scenario by decreasing steel post cost $7 from $47 to $40 and decreasing service life of wood to 25 years.

The results of these sensitivity tests are shown in Table 3. These results demonstrate that given significantly different assumptions, treated wood posts continue to offer substantial cost savings relative to galvanized steel posts under current market pricing. Assuming that steel lasts twice as long as wood (as in the study provided by WSDOT), indicates steel would still cost approximately 25% more than wood. With the extreme and unsupported set of assumptions that wood costs 50% more than the current price and that it only lasts 15 years (compared to a reasonable estimate of 50 years), steel is still only 5% less expensive. Using the assumption that wood provides twice the service life of steel, demonstrates steel would cost approximately 2.5 times more than wood.

Table 3 - Guardrail Post Sensitivity Results

Sensitivity Scenarios Results	Changes	Treated Wood	Galvanized Steel
Baseline	None	$ (1,270)	$ (2,283)
Longer life for steel	Wood: 25 yr	$ (1,814)	$ (2,283)
Longer life for wood	Steel: 25 yr	$ (1,270)	$ (3,308)
Short life for both	Life: 25 yr	$ (1,814)	$ (3,308)
Use wood block for both	Wood block on steel post	$ (1,270)	$ (2,170)
Wood post cost up 50%	Wood post at $35	$ (1,724)	$ (2,283)
Wood cost up and life shorter	$35 and 25 yr	$ (2,438)	$ (2,283)
WSDOT based costs	$40 steel post, 50 yr lives	$ (1,270)	$ (2,018)
WSDOT based costs and service lives	$40 steel post, 25 yr lives	$ (1,814)	$ (2,018)

Results in this evaluation clearly are very different than the previously completed Life Cycle Cost Analysis provided to WWPI by WSDOT. There are two primary differences. That analysis used installed prices of $21.50 and $24.75 per linear feet of guardrail system using treated wood and galvanized steel posts, respectively. (These values support the cost of steel post guardrail systems being $6.70 more than for wood post systems.) They also estimated the service life of wood posts as 25 years and of steel posts as 50 years. This is contrary to experience that shows wood posts last at least as long as steel posts.

4 Conclusion

Test data and experience indicate that preserved wood guardrail posts will provide service lives averaging approximately 50 years, equal to that expected of galvanized steel. With equal service life, treated wood guardrail posts and blocks support highway guardrail systems at approximately 60% of the cost of galvanized steel posts with composite blocks.

Contractor experience indicates wood posts are rarely damaged during installation and can usually be successfully reinstalled after removal. Steel posts typically are damaged by driving them into the ground, so most cannot be reused. As a result of their ability to be installed with minimal damage and the potential for direct reuse, in cases where early removal is involved, treated wood posts offer additional service life not possible with steel posts.

The annual cost of ownership to WSDOT for treated wood guardrail post systems is approximately $1,300 per year per mile of guardrail. The cost for equivalent steel post systems is approximately $2,300 per year per mile, or $1,000 more than for wood.

The cost of post systems are relatively small compared to the cost of the Type 31 W-Beam Guardrail at approximately $22 per linear foot ($116,000 per mile). WSDOT is unnecessarily spending more money by specifying only steel posts when equal service life and lower cost can be obtained by allowing competitive bidding of treated wood guardrail post systems.