Perception versus Reality: An Analysis of Timber Bridge Performance in the United States.

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Abstract

Bridge material selection is one of the most difficult decisions an engineer has to make. Many factors and individuals are often involved in choosing the proper bridge material for a given site and location. Not only physical factors such as strength or lifespan of material, but also site specific factors like roadway alignment and traffic count play important roles in material selection. It is not uncommon for state Department of Transportation engineers, private consulting engineers, and local highway officials all play roles in the material selection process. Each individual may have his/her own perception of bridge materials based upon past experience and education. And little is known how these perceptions influence the choice of materials. In this study perceptions of engineers and highway officials toward timber as a bridge material were compared to the actual performance of timber as reported in the National Bridge Inventory. To accomplish this case studies were conducted in four selected states. Highway officials and engineers in Mississippi, Virginia, Washington, and Wisconsin were surveyed by mail and personally interviewed to capture their perceptions toward timber as it compared to other major bridge materials (prestressed concrete, steel, and reinforced concrete). This information was compared with the actual performance data obtained from the National Bridge Inventory. The results indicate that there is a strong correlation between highway officials' perceptions towards bridge materials and the reported performance of these materials.

Keywords: Perceptions, National Bridge Inventory, timber, steel, concrete, performance.

Introduction

The need for bridge replacement has been well documented (Brungraber et al. 1987, Cheney 1986, USDA 1989). Over 40% of our Nation's bridges are in need of repair or replacement. According to the FHWA (1992) four major structural materials make up over 98% of all bridges in the United States. These include prestressed concrete (15%), steel (36%), reinforced concrete (40%), and timber (8%). However, since 1982 over seventy percent of the replacement bridges have been prestressed or reinforced concrete, while timber and steel were used in less than thirty percent of replacement structures. This suggests that perceptions toward prestressed and reinforced concrete by highway officials are better than that of competing materials.

The United States has more than 3.9 million miles of roadway and 575,000 bridges. In 1967, in response to the collapse of the Silver River bridge over the Ohio River, Congress mandated the implementation of National bridge inspection standards. The individual bridge inspection records constitute the National Bridge Inventory (NBI). The purpose of the NBI is to provide a uniform base of bridge information that can be used to identify those bridges that are most in need of repair and to serve as a basis for allocating Federal Highway Administration (FHWA) funding for bridge replacement or rehabilitation. The NBI is administered by the FHWA in Washington, D.C. Data are updated continuously based on the latest bridge inspection, which are usually completed on a two year cycle.

All too often the evaluation of competing products is limited to tangible characteristics such as price and physical attributes, disregarding intangibles such as consumer perceptions and attitudes (Dickson 1974). However, it is these perceptions that determine a belief about a material, which may influence the design decision. Although the importance of perceptional variables is well established in marketing literature (Green and Carmone 1970, Johnson 1971, Lehmann and O'Shaughnessy 1974), little information is available concerning perceptions of competing bridge materials or actual performance.

Clapp (1990) and Luppold (1990) conducted qualitative studies concerning highway official's perceptions of timber in the Northwest and South, respectively. Both concluded that timber was not perceived well by these officials as a bridge material. Dunker and Rabbat (1992) conducted an extensive analysis of the National Bridge Inventory to compare the performance of prestressed concrete to other bridge materials since 1950. They concluded that prestressed concrete out-performed all other materials in the past 40 years, with timber being the poorest performing material.

Nationwide, the number of timber bridges is declining. Between 1982 and 1992 the number of timber bridges declined from 71,200 to 45,863, an average of 2500 timber bridges per year (Stanfill-McMillan and Hatfield 1992). With a thorough understanding of how timber has performed and how timber is perceived by highway officials, reasons for this decline can be identified.

Objectives

1. Determine highway official's perception of timber as a bridge materials in four states.

2. Evaluate the performance of timber as a bridge material based upon the National Bridge Inventory.

3. Compare the performance of bridge materials to the perceptions of highway officials toward these materials in four states,

Methodology

Perception

To measure the perceptions of highway officials across the U.S., a mail survey was conducted in the winter of 1993. Over 1200 questionnaires were mailed to highway officials in twenty-eight states. These officials were segmented into three groups: State Department of Transportation (DOT) engineers (401 sampled), private consulting engineers (419 sampled), and local highway officials (406 sampled).

To determine if differences exist between geographic regions, five segments were identified. These included the Northwest, South, Midatlantic, Northeast, and Midwest. These five regions accounted for 70% all of the bridges built between 1982 and 1991 (FHWA 1992). These regions were chosen due to their different timber bridge usage, different bridge selection protocol, and different timber resources. The four states studied in depth included Mississippi (South), Virginia (Midatlantic), Washington (West), and Wisconsin (Midwest).

The questionnaire consisted of three sections. The first section used rating scales to collect data concerning perceived overall bridge material performance and the past experiences with various bridge materials. The second section of the questionnaire used rating questions to collect data concerning how did timber compare with prestressed concrete, steel, and reinforced concrete on eight preselected attributes. The third section consisted of multicotomous questions designed to gather information about the respondents. In particular, individuals were asked about past exposure to timber engineering.

The questionnaire was reviewed by knowledgeable civil engineers and university personnel to test its face validity, clarity, and to ensure that no important bridge material selection factor was overlooked. A pretest was then conducted with bridge officials in various groups in Virginia, Wisconsin, and Minnesota. The responses of the pretest were used to clarify question wording and revise the set of material attributes and factors used in the decision making process.

After tabulation of data, in depth personal interviews were conducted in Mississippi, Virginia, Washington, and Wisconsin to further identify highway official's perceptions toward timber bridges and to better understand their material decision making process. Highway officials in each group were interviewed to access their opinions on the use of timber in bridges.

Reality

To identify how the various bridge materials actually performed, the 1992 National Bridge Inventory data were obtained from the Federal Highway

Administration. The NBI is a comprehensive database that maintains inventory records on all bridges in the United States that are over 20 feet or greater in length located on public roads. The NBI is primarily used by individual states and the Federal government for assessing bridge condition and assigning priorities for future projects. It also contains much useful information on the historical trends in bridge construction, adequacy, and longevity. The NBI contains an inventory of over 575,000 bridges, of which approximately 100,000 are culverts. These culverts were not included in this study.

The inventory contains current detailed data on individual bridges which includes such topics as bridge location, configuration, material, age, and condition. Based on inspection data, each bridge in the NBI is assessed a performance rating of structurally deficient (SD), functionally obsolete (FO), or satisfactory. A structurally deficient bridge must meet one of three criteria: the condition of the deck, superstructure, or substructure is rated poor; the structural evaluation or overall bridge condition is rated below a 3; or the waterway adequacy is not sufficient. To a great extent, criteria for rating a bridge structurally deficient are associated with material performance of the superstructure, substructure, or deck.

Structural deficient bridge data were examined to determine the reasons a bridge was classified as structurally deficient (SD). This was done to determine if a relationship exists between the bridge material and the reason for the deficiency. Bridges are classified as SD if they received a low rating in at least one of the five following categories: deck, superstructure, substructure, waterway, or structural evaluation.

After evaluating a bridge against the criteria for a structural deficient rating, the nonstructurally deficient bridges are evaluated against criteria for a rating of functionally obsolete (FO). The criteria for a FO rating require that at least one of five conditions is met: the deck geometry is too narrow for traffic; the vertical or horizontal underclearance is not adequate; the roadway alignment requires substantial reduction in vehicle operating speed; the structural evaluation rating is below a 3; or the waterway adequacy is such that the frequency of flooding is less than that for SD bridges, but still unacceptable. With the exception of the structural evaluation rating, FO ratings are based more on geometry and less on material performance.

Of the approximately 45,800 timber bridges classified by the FHWA, over 37,000 (81%) are timber bridges with timber decks. The remaining 19% have other deck materials on timber bridges. There also exists over 42,000 non-timber bridges with timber decks. These consist primarily of timber decks on steel bridges. For the purpose of this study, only timber bridges with timber decks are considered, because they represent the largest number in this category.

Results and Discussion

Forty percent of all respondents to the mail survey were from state DOT offices, 30 percent were private consultants, and 30 percent were local highway officials. Nearly 70 percent of the respondents reported that their state had standard bridge plans, but only one-third of these respondents mentioned that the plans included designs for timber.

Highway officials were asked to state the materials they had used in the past five years in bridge design or replacement. Eighty-four percent had used prestressed concrete, 79 percent had utilized reinforced concrete, 68 percent had used steel in bridges, and 46 percent had experience with timber during the past five years. Approximately 40 percent of all respondents had taken a formal course in timber design, with one-third saying it was mandatory. Fifty-four percent said they were aware of the recent changes in timber design, with one-half saying these changes had improved their impression of timber as a bridge material.

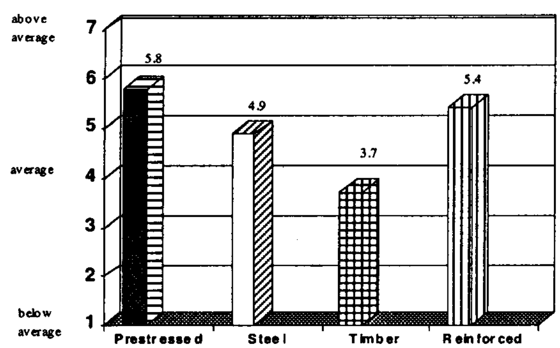

Figure 1. Average rating of bridge material from all 28 states.

Nationwide, prestressed concrete was rated the highest, followed by reinforced concrete, steel and timber (Figure 1). The four states studied also followed this trend. Each state rated prestressed concrete the highest. Steel was rated the highest in Washington (5.1), timber was rated the highest in Wisconsin (4.3). and reinforced concrete was rated the highest in Virginia (6.3) (Table 1). One-way analysis of variance indicated that perceptions by highway officials toward bridge materials do differ significantly by state.

Table 1- Average material performance ratings by highway officials in selected states.

	MS	VA	WA	WI
Pres.	6.2	6.4	5.5	5.3
Steel	4.6	4.3	5.1	4.4
Timber	3.9	3.4	3.3	4.3
Reinfc	5.9	6.3	5.1	5.0

* Rating scale from 1, below average, to 7, above average.

The three decision groups responding from the four states rated prestressed concrete the highest, followed by reinforced concrete, steel, and timber. Steel was rated the highest by state DOT engineers, timber was rated the highest by local highway officials, and reinforced concrete was rated the highest by state DOT officials. One-way analysis of variance indicated that their perceptions of bridge materials were similar across decision groups (Figure 2).

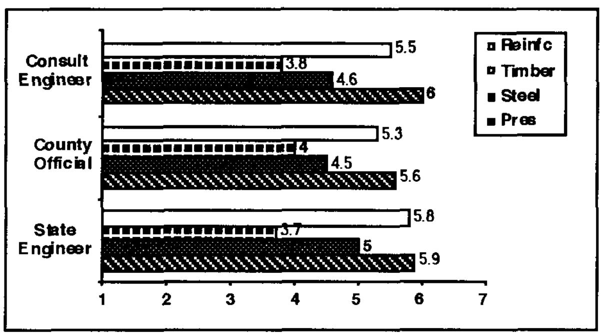

Figure 2. Average material performance rating by decision group in four states.

Eight material attributes were identified by civil engineers across the country as important to material selection for bridges. Timber was compared on a scale from 1 (low) to 7 (high), to other bridge materials on these attributes which included: *Long life, high strength, low maintenance, pleasing aesthetics, environmentally safe, low cost, easy to design, and easy to construct.* These ratings identified areas in which timber must improve its performance to gain increased market acceptance (Table 2).

Wisconsin rated timber highest on five of the attributes: *Long life, high strength, low maintenance, pleasing aesthetics and easy to construct.*

Table 2 - Material attribute rating by state

Attribute	WA	MS	VA	WI	Overall
Long life					
Pres	6.3	**6.4**	5.3	4.5	5.9
Steel	4.9	5.4	**5.6**	4.5	5.0
Timber	3.8	3.7	3.5	**4.4**	4.0
Reinfc	6.0	**6.3**	5.6	5.3	5.8
High strength					
Pres	5.9	**6.5**	5.7	5.6	5.9
Steel	5.8	**6.0**	5.9	5.4	5.7
Timber	3.7	4.0	3.1	**4.3**	3.9
Reinfc	5.1	**6.3**	4.6	5.3	5.4
Low maintnce					
Pres	**6.2**	6.1	5.6	5.5	5.9
Steel	4.0	**4.9**	3.9	3.8	4.1
Timber	3.5	3.7	3.1	**4.7**	3.9
Reinfc	5.8	**6.2**	5.0	5.4	5.6
Pleasing aesthetics					
Pres	5.0	**5.6**	5.3	4.8	5.1
Steel	4.6	**5.4**	5.3	4.7	4.8
Timber	4.8	4.7	4.7	**5.4**	4.9
Reinfc	4.9	**5.8**	5.1	4.7	5.1
Environ. safe					
Pres	5.5	**6.2**	5.7	5.8	5.8
Steel	4.4	4.9	**5.2**	4.1	4.6
Timber	4.5	**4.7**	4.6	4.6	4.6
Reinfc	5.1	4.9	**5.2**	4.6	5.5
Low cost					
Pres	**5.1**	4.6	4.8	4.9	4.8
Steel	3.9	4.2	**4.7**	3.7	4.0
Timber	4.6	**5.0**	3.9	3.7	4.3
Reinfc	4.8	**4.9**	4.5	4.8	4.7
Easy to design					
Pres	5.1	5.1	4.5	**5.2**	5.0
Steel	4.3	4.9	**5.8**	4.6	4.8
Timber	4.8	**4.9**	4.4	4.7	4.7
Reinfc	5.0	**5.4**	5.2	5.0	5.2
Easy to construct					
Pres	**5.6**	5.3	4.9	5.2	5.3
Steel	4.3	4.8	**5.3**	4.6	4.7
Timber	4.8	5.2	4.5	**5.2**	5.0
Reinfc	4.5	**5.3**	4.3	4.3	4.6

Mississippi, which have the most timber bridges of states interviewed rated timber highest in 3 attribute categories: *environmentally safe, low cost, and easy to design.* It can be noticed that Wisconsin was basing their decisions on material attributes, while Mississippi appears to be basing their decision on cost and ease of design.

Table 2 further illustrates that timber is perceived as the poorest bridge material in terms of the following attributes: *long life, high strength, low maintenance, environmentally safe, and easy to design.* Prestressed or reinforced concrete was rated the highest in terms of perceived performance on every attribute. Only steel was rated lower than timber on the attributes of *easy to design, pleasing aesthetics, and low cost.* Analysis of Variance (ANOVA) indicated that no statistical differences existed between the four states on the attributes of *pleasing aesthetics, environmentally safe, easy to design, and easy to construct.* On the remaining attributes measured, differences did exist among the states highway officials.

National Bridge Inventory data were used to determine the actual performance of bridges. Table 3 illustrates the performance rating of bridges by material type and state. Mississippi not only has the most number of timber bridges, but also the most deficient number of timber bridges. Personal interviews in Mississippi revealed that this state does not have standard bridge plans for timber. To receive federal cost sharing revenues, the state only allows bridge projects using standard plans. So the timber bridges in Mississippi may not be being built to HS-20 loading requirements and this may be one reason for the high number of deficient timber bridges in the state.

Virginia has the fewest number of timber bridges (67) and 91% of these were classified as deficient. Virginia also rated timber lower in over-all perceived performance. Virginia does not have standard plans for timber bridges, however it has some designs for the use of timber on steel bridges. Personal interviews indicated that much of the perceptions of timber are based on this use of timber as a decking material on steel stringers or trusses.

Washington, which has 75% of its 912 timber bridges classified as deficient, rated timber the lowest in over-all perceived performance. Washington does not have standard bridge plans for timber and state engineers stress standard plans when allocating federal highway funding.

Wisconsin is the only state that has standard timber bridge plans of those interviewed. More than 80% of its 519 timber bridges have a satisfactory rating. The state also rated timber the highest on perceived performance. Wisconsin also rated timber high on every attribute but *easy to design, low cost, and environmentally safe.* This data indicates that properly designed and constructed timber bridges have a great impact on highway official's perceptions material performance in the bridge application.

Table 3 - National Bridge Inventory ratings of bridge materials by state 1992.

State	Material	# Bridges	Sat. %	#SD %	#FO %
MS	Reinfoc	5387	3922 (73%)	700 (13%)	765 (14%)
	Steel	2940	761 (26%)	1537 (52%)	642 (22%)
	Timber	4045	138 (3%)	3803 (94%)	104 (2%)
	Pres.	2398	2069 (86%)	23 (1%)	306 (13%)
VA	Reinfoc	2712	1538 (57%)	376 (14%)	798 (29%)
	Steel	6527	3885 (60%)	1031 (16%)	1611 (24%)
	Timber	67	6 (9%)	40 (60%)	21 (31%)
	Pres.	845	711 (84%)	16 (2%)	118 (14%)
WA	Reinfoc	3039	1345 (44%)	284 (9%)	1410 (47%)
	Steel	840	233 (28%)	185 (22%)	422 (50%)
	Timber	912	227 (25%)	150 (16%)	535 (59%)
	Pres.	1968	1152 (59%)	150 (8%)	666 (33%)
WI	Reinfoc	3192	2250 (70%)	813 (25%)	159 (5%)
	Steel	5223	2799 (54%)	2046 (39%)	378 (7%)
	Timber	519	419 (81%)	85 (16%)	15 (3%)
	Pres.	2281	1971 (86%)	239 (11%)	71 (3%)

Source: Stanfill-McMillan and Hatfield 1995 from FHWA 1992.

The average age of satisfactory timber bridges in Mississippi, Virginia, and Washington exceeds the average age of other bridge materials. Only in

Wisconsin is the average age of timber less than steel and reinforced concrete. With the exception of prestressed concrete, the average age of structural deficient bridges appears to be similar among material types. Prestressed concrete has lower average age in every state because it is the newest bridge material developed. Mississippi has the lowest average age of structural deficient bridges of all materials, being approximately 34 years. This compared to 46 years in Virginia, 57 years in Washington, and 48 years in Wisconsin. The average age of functionally obsolete bridge materials appear to be independent of material type. (Table 4).

Table 4. Average age (years) of bridges in selected states.

State	Material	# Bridges	Age Sat. (yrs)	Age SD (yrs)	Age FO (yrs)
MS	Reinfoc	5387	21.3	34.0	34.2
	Steel	2940	33.9	39.2	47.2
	Timber	4045	34.3	32.2	31.8
	Pres.	2398	16.7	30.3	28.1
VA	Reinfoc	2712	35.7	57.7	52.0
	Steel	6527	26.2	50.8	41.8
	Timber	67	40.7	53.4	46.1
	Pres.	845	23.3	24.3	26.6
WA	Reinfoc	3039	41.6	48.9	44.2
	Steel	840	35.6	73.4	52.5
	Timber	912	47.9	82.3	51.2
	Pres.	1968	19.5	25.6	20.7
WI	Reinfoc	3192	25.6	56.7	48.3
	Steel	5223	37.9	55.4	48.1
	Timber	519	23.4	48.4	45.8
	Pres.	2281	18.3	29.8	23.4

Source: Stanfill-McMillan and Hatfield 1995 from FHWA 1992.

Timber bridge performance varied more according to route class than other materials. Route class refers to the road classification by the FHWA. Satisfactory timber performance is lower on county highways and city streets. However, timber ranked significantly higher on U.S. Numbered highways, where bridges will be usually designed for the state minimum load capacity (Table 5). The average age of satisfactory timber bridges on State highways is 53 years, which is higher than the average age of all satisfactory timber bridges. More satisfactory timber bridges were found on State and Federal lands than on county and city highways. Again, it can be expected that bridges located on major roads are designed to HS-20 load ratings than bridges built on local road systems.

The design of the timber bridges appears to have an impact on its performance. Throughout the U.S., the most common type of timber design is a stringer/beam/girder, representing nearly 90% of the 37,000 complete timber bridges. However, this design has only 29% satisfactory rating. The second most common design is the timber slab. Nearly 2000 timber bridges fall in this category, but over 85% of these are rated satisfactory. The third most common design is the frame style, which there are over 800 in service. Only 8% of these are rated satisfactory. Although there are numerous other designs, these three types make up over 97% of the timber bridges in service (Stanfill-McMillan and Hatfield 1992).

Table 5. Performance ratings and number of timber bridges by route class throughout the U.S.

		Number of Bridges (%)		
Route Class	Total	Satisfactory	SD	FO
Interstate	66	27 (44%)	28 (46%)	6 (10%)
U.S. Numbered	708	540 (76%)	97 (14%)	71 (10%)
State Hwy.	5117	2177 (43%)	2100 (41%)	840 (16%)
County Hwy	36701	10665 (29%)	21041 (57%)	4995 (14%)
City Street	1580	377 (24%)	874 (55%)	329 (21%)
Federal Land	215	127 (59%)	53 (25%)	35 (16%)
State Land	205	93 (45%)	66 (32%)	46 (22%)
Other	1272	634 (50%)	449 (35%)	189 (15%)
Total	45859	14640 (32%)	24708 (54%)	6511 (14%)

Source: Stanfill-McMillan and Hatfield 1995 from FHWA 1992.

The basis for classification of the bridge as structural deficient (SD) is a good indicator of material performance. Nationwide, the main reason that prestressed concrete is rated SD is due to low ratings on the deck. Reinforced concrete is rated lower on the substructure, steel is rated low on the deck and substructure, while timber is rated low on substructure and load or waterway capacity (Table 6). Nationally, timber bridges had the lowest percentage of deficiency rating for the deck and superstructure. Table 6 shows that 39% of timber bridges were rated SD as a result of inadequate load capacity or waterway adequacy, not as a result of material condition.

Timber bridge data were divided into three categories according to design load ratings. The categories were: design loads of (1) H-20, HS-20, or HS-25, (2) H-10, HS-10 or H-15, and (3) other. Nationwide 58% of timber bridges with timber decks are not coded for a standard design load and of these 28% are satisfactory (Stanfill-McMillan and Hatfield, 1995).

Table 6. Basis for bridge classification as structurally deficient by material (No. & %).

Rating Criteria	Reinfc Concrete	Steel	Pres Concrete	Timber
Deck (1)	1361 (7.3%)	8407 (12.%)	924 (25.8%)	1199 (5%)
Super-structure (2)	1823 (9.7%)	7214 (10.1%)	433 (12.1%)	1462 (6%)
Sub-structure (3)	4976 (26.5%)	11773 (16.8%)	988 ((27.6%)	5112 (20%)
Two of three locations (1,2, or 3)	4358 (23.2%)	13309 (19.0%)	417 (11.6%)	3433 (11.6%)
All three locations (1,2, and 3)	3117 (16.6%)	9054 (12.9%)	164 (4.6%)	3906 (16%)
Load or waterway capacity	3116 (16.6%)	20419 (29.1%)	659 (18.4%)	9597 (39%)
Total	18,751	70,176	3585	24,709

Source: Stanfill-McMillan and Hatfield 1995 from FHWA 1992.

Of the four states studied, nearly all bridges in Mississippi were not designed to the current HS-20 load rating as required by the FHWA for the use of Federal funding (Table 7). Less than 1% of these bridges hold this classification. Nearly all of Mississippi's bridges are classified as structurally deficient. One of the reasons for this SD classification is that the bridges were never designed for the HS-20 loading or traffic on the system has increased to now warrant a higher rating.

In Virginia all timber bridges hold an unknown or less than a HS-20 load rating. Only 5 bridges in the state are classified as satisfactory. Again, since the bridge may never have been designed for the HS-20 rating, it is classified as deficient. Virginia recently built one timber bridge in each highway district under a state timber bridge initiative program. They are currently evaluating these structures to measure cost effectiveness and long term performance.

Table 7. Distribution and rating of timber bridges

State Rating	H-10, HS-10, HS-15 No. (%)	H-20, HS-20, HS-25 No. (%)	Other No. (%)
Mississippi	2644 (70%)	2 (<1%)	1143 (30%)
Satisfactory	74 (3%)	0	42 (4%)
SD	2497 (94%)	1 (50%)	1078 (94%)
FO	73 (3%)	1 (50%)	23 (2%)
Virginia	25 (38%)	0	41 (62%)
Satisfactory	2 (8%)	0	3 (7%)
SD	11 (44%)	0	29 (71%)
FO	12 (48%)	0	9 (22%)
Washington	347 (64%)	120 (22%)	71 (13%)
Satisfactory	9 (3%)	7 (6%)	11 (15%)
SD	49 (14%)	18 (15%)	15 (21%)
FO	289 (83%)	95 (79%)	40 (56%)
Wisconsin	23 (24%)	49 (52%)	23 (24%)
Satisfactory	14 (61%)	46 (94%)	7 (30%)
SD	8 (35%)	2 (4%)	14 (61%)
FO	1 (4%)	1 (2%)	2 (9%)

Source: Stanfill-McMillan and Hatfield 1995 from FHWA 1992.

In Washington 120 of the states 538 timber bridges were designed for an H-20 or higher rating. Of these structures, nearly 80% are classified as functionally obsolete. In general, functional obsolete bridge ratings are based more on geometry and less on material performance. Again, although Washington has a large number of deficient timber bridges, it may not be due to the type of material, but the original design of the bridge.

Wisconsin has the most timber bridges designed to the HS-20 rating of those states interviewed. Of those bridges designed to HS-20 or higher, 94% are classified as satisfactory and those with a lower bridge rating had over 60% satisfactory rating. Wisconsin is a state where counties have an active bridge maintenance program. These results suggest that timber bridges that are designed to current standards and maintained properly, will perform well. And this performance will have a direct result on the perceptions of highway officials.

Perception vs. Reality

The results of this research indicate that there is a strong correlation between highway official's perceptions of timber bridges in the four states studied and reported performance of bridges. In Mississippi where nearly all timber bridges are deficient in one area, perceptions of timber were quite low. However, personal interviews in Mississippi reveal that most timber bridges are built to no design criteria. The state DOT requires that Federal funds be allocated only to those bridges that state standard plans exist. There are no standard plans for timber in Mississippi. Although numerous timber bridges are being built in the state, highway officials are basing their decision on low cost and easy construction, not on longevity or good design. Highway officials rated timber the highest on the attributes of *environmentally safe, low cost, and easy to design.* Highway officials interviewed stated that timber bridges were only lasting 25 to 30 years and timber is a high maintenance material. These officials believe that prestressed concrete is the most cost effective material (averaging $30 sq./ft.) and timber offers no competitive advantage in bridge construction.

Virginia had the fewest number of timber bridges of the states studied, but their engineers still had a poor perception of timber. Most timber is used as a decking material on steel bridges, and engineers' perceptions have been based primarily on this factor. Highway officials in Virginia rated timber lowest on six of the eight material attributes measured. Of the 67 timber bridges in the state, only 6 are classified as satisfactory. However, none of these bridges currently have a HS-20 rating. And over 60% have no rating on the structure at all. Virginia was the only state interviewed where the state DOT controlled over 97% of all the roads. The state does not have standard plans which include timber. Most bridges are designed by state engineers in one of nine highway districts. When interviewed, engineers stated that maintenance problems and poor performance have been problems with timber.

Washington has the second largest number of timber bridges of those states interviewed. However, their highway official's perception of timber was the poorest. Only 25% of Washington's timber bridges are rated satisfactory. Of these bridges, nearly 60% are classified as functionally obsolete. And the average age of Washington's timber bridges exceeds 50 years. The average age of satisfactory timber bridges exceeds that of all other bridge materials. Over 75% of their bridges have less than an H-20 rating. Although state highway officials have a poor perception of timber and its attributes, the bridges that are in service appear to have performed well and are rated low because of design criteria, not material performance.

The state with the most satisfactory timber bridges is Wisconsin. Over 80% of Wisconsin's timber bridges are rated satisfactory. This state had the highest perceptional rating of timber also. It is the only interviewed state that has standard bridge plans for timber and regularly builds timber bridges using FHWA funding. This states' highway officials rated timber the highest of all states on the attributes of *longlife, high strength, low maintenance, pleasing aesthetics, and easy to construct.* The average age of Wisconsin's deficient bridges was quite similar to reinforced concrete and steel. Over 90% of the timber bridges that have a HS-20 or above rating are rated as satisfactory. This states' counties are in charge of rural bridge maintenance. Wisconsin is the only one of the four states that have seen an increase in timber bridge use since 1986.

Conclusion

This study sought to determine how the performance of timber as a bridge material as reported by the FHWA's National Bridge Inventory compared to highway official's perceptions of timber in four selected states. Nationally, timber was rated the poorest in perceived performance by all highway officials. It was also rated lowest by officials in the four states studied.

Prestressed concrete was rated highest, followed by reinforced concrete, steel and finally timber.

Timber bridges were rated higher in structural deficiency and as functionally obsolete in three of the four states. However, a closer look at these ratings indicate that most of the timber bridges were rated low since they were not designed to HS-20 loading requirements. Nearly 40% of the timber bridges rated structurally deficient were based upon inadequate load capacity or waterway adequacy. In other words, the reported performance of timber in the NBI is based on factors which may not be a result of the material performance, but more on initial design practices.

In Wisconsin, the only state which has standard bridge plans, over 80% of timber bridges were rated satisfactory. This state rated timber higher in perceived performance that the other three states. Timber bridges on Federal and State Highways were timber bridges are more likely to be built to higher standards. The average age of satisfactory timber bridges was quite similar to other materials. The average age of deficient bridges was also similar, independent of material type.

In conclusion timber bridges are perceived not to perform well, but the NBI data indicates that in those areas where perceptions are poor, timber bridges have not been designed to current standards. Where timber has been designed properly (Wisconsin) perceptions and performance are rated as higher than the other states measured. This research indicates that future timber bridges built to current HS-20 loading requirements should perform better and influence the perception of highway officials in a positive manner. It is recommended that highway officials base their material choice decision not only on their perception of timber, but also on why timber is rated low in the NBI.

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Acknowledgments

This research was funded by the USDA Forest Service Northeastern Area State and Private Forestry in Morgantown, WV, the Cooperative State Research Service, USDA Agreement No. 90-38420-5232, and the Center for Forest Products Marketing at Virginia Tech. The authors would like to thank these agencies and all participants for their time and support of this project.

In: Ritter, M.A.; Duwadi, S.R.; Lee, P.D.H., ed(s). National conference on wood transportation structures; 1996 October 23-25; Madison, WI. Gen. Tech. Rep. FPL- GTR-94. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.