A PERCEPTIONAL COMPARISON OF WOOD IN SEPARATE INFRASTRUCTURE MARKETS

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ABSTRACT

Perceptions of wood as an infrastructure material were investigated within four distinct market segments and within five geographic regions of the United States. Wood was compared to steel, reinforced and prestressed concrete, aluminum, and plastic on six predetermined factor groups and by thirty material attributes. The foremost factors in material choice decisions were durability, maintenance, and cost. All infrastructure groups rated wood lower in overall material performance as compared to prestressed and reinforced concrete, steel, and aluminum. Only plastic was rated lower than wood in perceived material performance.

Keywords: Perceptions, wood, infrastructure materials, material attributes

INTRODUCTION

The United States infrastructure represents significant opportunities for the forest products industry. Infrastructure markets include the highway, railroad, marine and inland waterway, and electrical transmission systems. In order to compete in the United States (U.S.) infrastructure market, wood manufacturers require information regarding decision-makers' perceptions of wood as an infrastructure material. The American Pulpwood Association estimated that total construction spending in the U.S. exceeded $450 billion in 1996, of which $125 billion was projected to be spent in the transportation sector (Cordova 1995).

Historically wood products have been utilized as the primary construction material in the U.S. infrastructure. However, in several areas wood products' market share has decreased or has been forfeited to other materials (e.g., concrete or steel). In discrete infrastructure market segments, wood products have

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maintained market share or share is increasing. Wood products are currently used for highway guardrails, bridges, sign system parts, sound barriers, buildings for salt storage, railroad structures and ties, marine bulkheads, wharves, docks, piers, electric utility poles, and pole crossarms. These markets are competitive, and several substitute products can be utilized for infrastructure fabrication. Substitute products include composite materials, steel, reinforced and prestressed concrete, aluminum, and plastic. The more important infrastructure markets for wood products include the U.S. railroad system, electric utilities, the highway infrastructure, and the marine and inland waterway groups.

The United States railroad system predominantly uses wood for crossties (RTA 1986), and this market is seeing a growing trend in the use of treated wood ties (Micklewright 1994). Crosstie demand ranges from 15 to 18 million crossties annually (Reynolds 1994). Although wood crossties dominate the market, substitute materials are being used for the fabrication of crossties, such as concrete (Buckett et al. 1987) and steel (Anonymous 1987). Railroad expenditures for track construction and maintenance exceed $7.4 billion annually (U.S. Department of Transportation (USDOT)—Federal Highway Administration (FHA) 1993). Crosstie utilization represents approximately 12% of the hardwood lumber production in the U.S. and poles and pilings represent approximately 1% of the softwood sawtimber produced (Powell et al. 1993).

Electric utilities' wood pole purchases are nearly $600 million annually, and it is estimated that U.S. electric utilities purchase over 2 million new poles each year. In addition, these companies maintain over 12.5 million miles of distribution and transmission lines (Ng 1994).

The United States has the world's largest port system, with nearly 2,500 ports. Marine structures include channels, piers, wharves, storage facilities, and connectors to other modes of transportation. These structures typically require enormous volumes of wood products, which include lumber, timbers, and pilings. The estimated loss of wood in marine structures exceeds $500 million, and nearly $300 million is spent by the U.S. Army Corp of Engineers each year for harbor improvements and maintenance (National Transportation Strategic Planning Study 1991).

The 1990 United States Census reports that in 1988 all government types in the U.S. collected an estimated $69 billion for highway use (National Strategic Transportation Planning Study 1991). Yearly highway construction and maintenance expenditures in the U.S. are approximately $60 billion (USDOT-FHA 1993). Wood products used in highway structures represent less than 1% of all sawtimber produced in the U.S. (Powell et al. 1993). The yearly volumes of all wood products (except timber pilings) utilized in highway construction averaged over 7,400 board feet per million dollars of construction, resulting in nearly 444 million board feet of wood being utilized in highway construction annually (USDOT-FHA 1993). Nevertheless, wood products utilization in infrastructure applications is declining.

For example, from 1986 to 1992 only five states (Indiana, Michigan, New York, Rhode Island, and Wisconsin) recorded increases in the number of timber bridges installed. Other states that installed timber bridges recorded decreases in the number of timber bridges installed. In 1982, the National Bridge Inventory listed over 70,000 bridges constructed with a main span of timber (U.S. Department of Agriculture—Office of Transportation 1989). In 1992 it was reported that there were fewer than 46,000 timber bridges. This represents a decline in timber bridge implementation of over 33% in a ten-year span, and wood usage as a primary bridge construction material decreased 24% from 1986 to 1992 (USDOT-FHA 1992). Additionally, recent studies report that wood products are not perceived as the most desirable bridge fabrication material.

In a 1993 study, State Department of Transportation (DOT) engineers, private consultants, and local officials were surveyed to discern their perceptions of different bridge fabrication materials and their attributes. The materials compared were prestressed concrete, reinforced concrete, steel, and timber. Respondents rated timber lowest (3.7) as a bridge fabrication material, as compared to prestressed concrete (5.8), reinforced concrete (5.4), and steel (4.9). Local officials rated wood highest at 4.0, and state DOT engineers rated wood lowest at 3.3 (1 = below average to 7 = above average). Timber was also rated lowest by these decision-makers on all attributes, which included easy to construct (5.0), pleasing aesthetics (4.9), easy to design (4.6); both environmentally safe and low cost were 4.4, long life (3.8), and both low maintenance and high strength were 3.7 (Smith and Bush 1995). Results from a 1997 study were similar (Smith et al. 1999).

OBJECTIVES

The objectives of this study were to determine the important factors in the material choice decision and the perceptions of wood when selecting infrastructure materials. To analyze these objectives, the following propositions were investigated:

Proposition 1. Infrastructure decision-makers with different educational levels would have different perceptions regarding wood in the design and fabrication of structures.

Proposition 2. Infrastructure decision-makers that have not received wood design coursework or training would have a lower perception of wood as an infrastructure material.

Proposition 3. Infrastructure decision-makers without design standards (guidelines) for wood in infrastructure would have a lower perception of wood in infrastructure than those with standards.

Proposition 4. Infrastructure decision-makers of different ages would have different perceptions of wood as an infrastructure material.

Proposition 5. Infrastructure decision-makers with extensive work experience would have different perceptions of wood in infrastructure than decision-makers with less work experience.

Proposition 6. Decision-makers from different infrastructure groups would have different perceptions of wood as an infrastructure material.

METHODOLOGY

A mail survey was used to collect primary data. Engineering professors, private consulting engineers, state department of transportation engineers, and other professionals were contacted to identify important criteria in the selection of infrastructure materials. Once these criteria were identified, a mail questionnaire was developed and pretested within a sample from the target population. The questionnaire was designed to measure the perceptions of different infrastructure construction materials and discern material selection factors.

Sample development

The sample frame consisted of decision-makers from both the public and private sectors of highway infrastructure, marine and inland waterway systems, railroad systems, and electrical distribution and transmission systems. Individuals responsible within each area of design, construction, or maintenance of each infrastructure system were sampled.

Highway transportation.—The highway transportation group included state DOT; county engineers or county highway groups within each state; and private consulting engineers within each state. A list of state DOT engineers was developed by phone (calls were made to each state DOT office). A listing of county engineers was found in the National Association of County Engineers (NACE) 1995–1996 Membership Directory (NACE 1995) and through phone calls to state DOT offices. Private highway consultants were located through phone calls to state DOT offices and through the American Consulting Engineers Council (ACEC) 1995–1996 Directory (ACEC 1995).

Marine and inland waterway.—The marine and inland waterway group consisted of private consulting engineers, port engineers, and engineers from the U.S. Army Corps of Engineers (USACE). The ACEC 1995–1996 Directory was utilized to locate private consulting engineers in waterway structure design (ACEC 1995). Lloyd's Ports of the World 1995 Directory was used to locate port engineers (Pinchin 1995). Port listings not indicating a port engineer were sent a facsimile requesting the acting port engineer's name and address. The USACE list was developed using the 1996 Department of Defense Telephone Directory (U.S. Department of Defense—Government Printing Office 1996) and the 1996 USACE Directory (U.S. Department of Defense and USACE 1996).

Railroad system.—The railroad system group consisted of civil and structural engineers and decision-makers employed by railroads operating in the U.S. Decision-makers were located utilizing *The Official Railway Guide-1996* (Schneider and Roth 1996). Railroad listings contained Class I, II, and III railroad civil and structural engineers.

Electrical distribution and transmission system.—The electric utility group included distribution and transmission engineers, and decision-makers employed by electrical utilities operating in the U.S. This list included engineers and decision-makers from the following electric utility types: investor owned systems; municipal systems; rural electric cooperative systems; and government (federal, state, and local) systems. The *1996 Electrical World's Directory of Electric Power Producers* was used to develop the list (Schwieger and Hayes 1995).

Questionnaire development

Questions deemed most important in the questionnaire were used to determine the sample size from each infrastructure group. Factor importance and material attribute rating questions were selected as the most important questions. These questions utilized a 1 to 7 rating scale, and the total sample size for each group was based on the following equation given by Ballenger and McCune (1990):

$$n = [(Z/2)^2(\sigma^2)^2]/h^2$$

where

n = required sample size,

$Z/2$ = reliability coefficient,

σ^2 = estimated population standard deviation,

h = tolerance level or precision level which equals the allowable difference between the estimate and population values.

This study utilized a 95% confidence interval, and a sample of 96 (per targeted group) was required for each rating scale question included in the survey for each infrastructure group. This study utilized scaled questions (1 to 7) in order to discern factor importance in material choice decisions and perceptions of materials. Ballenger and McCune's (1990) equation was used to determine precision levels for each factor and mean attribute rating. To achieve the desired precision level of ±0.20, it was determined that 96 respondents were needed per targeted group.

The first section of the questionnaire began with dichotomous and multichotomous questions in order to discern respondent qualifications. Section two asked participants to rate performance factors, and rating questions (1 = below average performance, 4 = average, 7 = above average performance) were utilized to collect data concerning how wood products compared with prestressed and reinforced concrete, steel, aluminum, and plastic. Performance factors included cost, *durability, design, environment, maintenance,* and *innovation.* For example, if decision-makers perceived *durability* to be high, they probably would rate *durability* a 7.

Under each factor heading, questions were asked to determine decision-makers' perceptions regarding a particular material's relationship to different attributes. These questions were also scaled 1 to 7 (1 = not at all, 4 = average, 7 = to a high degree) to discern if wood products possessed the attributes. Each attribute is a factor if a material possesses it. For example, the attribute *corrosion resistance* could be a factor if this attribute is used in the material selection process and is possessed by a material. If *corrosion resistance* was very important to decision-makers, they would mark 7 on the rating scale.

Performance Factors and Material Attributes

(1) *Cost*: Initial, maintenance, repair, and life-cycle costs.
(2) *Durability*: Fatigue, mechanical wear and/or abrasion, weathering, biological decay, fire, and corrosion resistance.
(3) *Design*: Design standards, material availability, ease of construction experience with material, and construction equipment available.
(4) *Environment*: Chemically safe, aesthetically pleasing, disposable or biodegradable, recyclable and reuseable, and low environmental effects of material production.
(5) *Maintenance*: Standard structure designs, ease of field modification, maintenance experience, ease of inspection, and ease of repair.
(6) *Innovation*: In performance, design, durability, environment, and maintenance.

Section three consisted of dichotomous and multichotomous questions. This section was used to collect data regarding state guidelines, wood design coursework, and wood utilization. The last section of the questionnaire utilized open-ended questions to elicit opinions regarding the best opportunities for wood products and to share experience(s) and use of various materials in infrastructure construction.

Pretests were conducted with groups and individuals in various infrastructure groups. Pretests included mailing or faxing questionnaires to twelve individuals from the population and personal interviews with individuals from each segment about the questionnaire. Post-interviews included sessions with individuals in the segments of design, maintenance or rehabilitation, and construction. All individuals were asked to examine the questionnaire, identify potential wording problems, indicate if the instructions were easy to follow, and to ascertain if all relevant factors or attributes were included. The pretest responses were used to clarify question wording and revise the set of material factor and attributes to be examined.

Data collection

A stratified random sample was utilized in this study. The total number of questionnaires mailed to each sample frame was approximately 900 for the highway, and 500 each for the marine, railroad, and the electrical utility group. Highway system engineers were considered different in the areas they manage. Therefore, the questionnaires mailed to the highway system sample frame were increased in order to acquire a larger sample and to determine if there were differences in material perceptions within the highway group. The total number of surveys mailed was 2,400.

A disguised questionnaire with a cover letter explaining the purpose of the study was mailed in January of 1997. None of the correspondence indicated or stated that the study was conducted by the Department of Wood Science and Forest Products at Virginia Tech (it was felt that this might bias respondents' answers or have a negative effect on the response rate). In order to increase the response rate, a reminder postcard was mailed two weeks after the initial survey mailing. This was repeated (a second questionnaire with cover letter) for nonrespondents approximately one month after the initial mailing and another set of reminder postcards two weeks after the second questionnaire mailing (Dillman 1978).

The adjusted response rates for the infrastructure groups were: highway 58.8%; marine and inland waterway 24.3%; railroad 35.8%; electric utilities 28.2%; and the combined infrastructure group was nearly 41%.

Data analysis

Analysis of data began with cross-tabulations, and the range and total sample counts were calculated to identify coding errors, and nonresponse. Multivariate Analysis of Variance (MANOVA) was executed in order to test for significant differences among infrastructure groups, and by education level, age class, wood design coursework, experience, and design guidelines. Rencher (1995) states that "MANOVA consists of a collection of methods that can be used when several measurements are made on each individual object or objects in one or more sample." Univariate or one way analysis of variance (ANOVA) was utilized if significant differences were found utilizing MANOVA. This was in order to define relationships (within each infrastructure group) for factor importance and/or material perception ratings (within and between group differences were determined). For further analysis, Tukey's Honestly Significant Difference (HSD) test was used to determine if there were significant differences between infrastructure groups and within each infrastructure group. An alpha level of 0.05 was utilized throughout the study.

To determine if the data provided by respondents were representative of decision-makers, we investigated for nonresponse bias. Nonrespondents were contacted by telephone to ask for their participation and answer specific questions from the questionnaire. These data were compared to information provided by respondents with corresponding data obtained from the random sample of nonrespondents. No significant differences were found between respondents and nonrespondents. To further test for the presence of nonresponse bias, the Armstrong and Overton method for analyzing time trend responses was utilized (Armstrong and Overton 1977). Early and late respondents were tested across a number of survey questions. No significant differences were found between the two groups' mean perceptions of overall material performance or mean overall factor importance ratings. Early and late respondents were assumed to be similar to respondents and nonrespondents. Therefore, it could be assumed that no significant differences were present between respondents and nonrespondents.

A precision level of ± 0.20 was the parameter to determine precision levels for factor and perceptional ratings. The desired precision levels were achieved for all factor and perception attribute ratings.

RESULTS AND DISCUSSION

Respondents

Nearly 48% of the highway group and 61% of the marine and inland waterway group worked in structure design. Approximately 73% of the railroad group worked primarily in maintenance. Thirty-five percent of the electrical utilities group worked in design and 26% worked in construction. Combining all groups, 40% worked in design and 27% worked in maintenance.

The Bachelor of Science degree (56.9%) was most widely held by respondents and Master of Science (M.S.) degrees followed. Approximately 43% of the respondents indicated receiving formal coursework in wood design (Table 1). Nearly 53% of the marine and inland waterway and 35.8% of railroad respondents received formal coursework in wood design. Of the respondents receiving formal wood design coursework, 32.9% indicated that the course(s) were mandatory.

Steel was the predominant material utilized in construction (80.7%), followed by wood and reinforced concrete. Railroad (97.6%) and electric utility decision-makers indicated the highest use, and highway decision-makers indicated the lowest use of wood in construction (Table 2). The majority of respondents indicated utilizing wood in infrastructure construction in the past three years. More than two-thirds of the respondents indicated that they

TABLE 1. *Demographics and mean perceptional ratings[1] of wood.*

	Number (%)	Rating
Degree		
BA	59 (7.4)	4.64
MA	31 (3.9)	4.90
BS	456 (56.9)	4.25
MS	177 (22.1)	4.07
Other[2]	78 (9.7)	4.73
MANOVA P-value = 0.01 between groups		
Coursework		
Had coursework	370 (43.5)	4.34
Did not have coursework	481 (56.5)	4.32
ANOVA P-value = 0.80 between groups		
Guidelines		
Had guidelines	481 (54.1)	4.31
Did not have guidelines	335 (38.9)	4.36
ANOVA P-value = 0.53 between groups		
Age groups		
30 to 39	123 (14.8)	4.46
40 to 49	309 (37.2)	4.30
50 to 59	305 (36.8)	4.32
60 to 69	93 (11.2)	4.24
ANOVA P-value = 0.55 between groups.		
Experience		
5 years or less	41 (4.8)	4.51
6 to 10 years	69 (8.1)	4.64
11 to 15 years	95 (11.1)	4.09
16 to 20 years	118 (13.8)	4.44
21 to 25 years	173 (20.2)	4.38
25 years or more	359 (42.0)	4.29
ANOVA P-value = 0.06 between groups		

[1] 1 = below average performance, 4 = average, 7 = above average performance.
[2] Other included high school, on the job training, or college experience.

were not planning to use wood in infrastructure construction within the next three years.

PROPOSITION ANALYSIS

To determine if differences existed in decision-makers perceptions of wood products when selecting infrastructure materials, the propositions detailed earlier were investigated. The following sections describe each proposition and respective results.

Proposition 1. Infrastructure decision-makers with different educational levels would have different perceptions regarding wood in the design and fabrication of structures.

Education levels of decision-makers did affect their perceptions of wood products as a construction material (significant differences were found and the proposition was accepted). The mean rating for wood among respondents holding Master of Arts degrees was highest (4.90), while those with M.S. degrees rated wood lowest (Table 1).

Proposition 2. Infrastructure decision-makers that have not received wood design coursework or training would have a lower perception of wood as an infrastructure material.

Decision-makers who participated in wood design coursework did not have different perceptions of wood in infrastructure as compared to those who did have coursework in wood design (significant differences were not found between those who did and those who did not have wood design coursework and the proposition was rejected). Respondents who

TABLE 2. *Material usage in US infrastructure (number and percent).*

Material	Highway group n = 536 (%)	Marine and inland group n = 100 (%)	Railroad group n = 167 (%)	Electric utility group n = 156 (%)	Combined groups n = 959 (%)
Reinforced concrete	472 (88.1)	95 (95.0)	94 (56.3)	53 (34.0)	714 (74.5)
Prestressed concrete	398 (74.3)	71 (71.0)	57 (34.1)	49 (31.4)	575 (60.0)
Steel	449 (83.9)	91 (91.0)	125 (74.9)	109 (69.9)	774 (80.7)
Aluminum	250 (46.6)	64 (64.0)	24 (14.4)	63 (40.4)	401 (41.8)
Wood	371 (69.2)	75 (75.0)	163 (97.6)	150 (96.2)	759 (79.1)
Plastic	142 (26.5)	34 (34.0)	11 (6.6)	14 (9.0)	201 (21.0)

had coursework rated wood 4.34 and those without coursework 4.32 (Table 1). This result contradicts current thought that negative perceptions of wood (as a construction material) exist as a result of decision-makers not being trained in wood design.

Proposition 3. Infrastructure decision-makers without design standards (guidelines) for wood in infrastructure would have a lower perception of wood in infrastructure than those with standards.

Material guidelines are used to set minimum requirements for materials in infrastructure applications. Wood design guidelines appear not to affect decision-makers' perceptions of wood products in infrastructure (significant differences were not found and the proposition was rejected). Respondents who had design standards had above average perceptional rating of wood (4.31) (with 4 being average), while those without standards rating were similar (4.36), (Table 1). These results indicate that perceptions of wood products may not change if design standards are adopted.

Proposition 4. Infrastructure decision-makers of different ages would have different perceptions of wood as an infrastructure material.

Decision-makers' age did not affect the perceptions of wood products as an infrastructure material (significant differences were not found between the age groups and the proposition was rejected) (Table 1). Age groups 40 to 49 years (37.2%) and 50 to 59 years (36.8%) contained the largest number of respondents. Respondents from age group 30–39 rated wood the highest at 4.46. This may indicate that older decision-makers may influence younger decision-makers within an organization; therefore younger officials may have similar perceptions to those of older decision-makers.

Proposition 5. Infrastructure decision-makers with extensive work experience would have different perceptions of wood in infrastructure than decision-makers with less work experience.

Decision-makers' work experience did not affect the perceptions of wood products as an infrastructure material. All infrastructure groups' mean ratings were very close to four (average), and significant differences were not found between any infrastructure experience group, and the proposition was rejected (Table 1). The results appear to indicate that experienced decision-makers' perceptions of wood are no different from those of less experienced decision-makers. More experienced decision-makers may influence younger decision-makers (i.e., peers influence information flow).

Proposition 6. Decision-makers from different infrastructure groups would have different perceptions of wood as an infrastructure material.

The proposition that different infrastructure markets would have different perceptions of wood as a construction material was accepted (Fig. 1, Table 3). Ratings of perceptions are discussed in the next section.

RATINGS OF PERCEPTIONS

The United States infrastructure market was segmented into four discrete groups: highway, marine and inland waterway, railroad, and electric utilities. This methodology was adopted in order to ascertain important material choice selection factors and attributes by group. In addition, the United States was also segmented into five regions in order to ascertain overall factor and attribute importance in material choice selection by region.

Overall perceived material performance

The perceived performance rating for reinforced concrete was the highest at 5.61, and railroad decision-makers rated wood the highest at 5.01. All other materials, with the exception of plastic, were rated higher than wood. Significant differences were found among the market segments in the mean perceptional ratings of wood's overall perceived

TABLE 3. *Mean material performance perceptional ratings*[1] *by US infrastructure respondents.*

Material	Highway group (n = 536)	Marine and inland Group (n = 100)	Railroad group (n = 167)	Electric utility group (n = 156)	Combined groups (n = 959)	Univariate *P*-values
Reinforced concrete	5.69	5.56	5.21	5.36	5.61	<0.01
Prestressed concrete	5.51	5.52	5.15	5.07	5.42	<0.01
Steel	5.20	5.16	5.61	5.80	5.34	<0.01
Aluminum	4.60	4.20	4.01	4.84	4.53	<0.01
Wood	4.02	3.84	5.01	4.92	4.35	<0.01
Plastic	3.83	3.58	3.06	3.43	3.64	<0.01

MANOVA Hotellings T^2-test, P-value < 0.01 among materials and groups.

[1] 1 = below average performance, 4 = average, 7 = above average performance.

material performance. In addition, significant differences were also found in the other material's performance ratings (Fig. 1, Table 3).

Overall perceived factor importance

Durability, maintenance, and *cost* were the most important factors in a material choice decision. *Environmental impact, ease of design,* and *innovativeness of material* were the least important factors. A significant difference was found only for the factor *ease of design.* Electric utility decision-makers rated *ease of design* highest (4.68) (Fig. 2, Table 4). Respondents combined by U.S. regions rated *durability* (6.28) highest, followed by *maintenance* and *cost* (Table 5). No significant differences were found between the regions' material comparison ratings (Table 6).

Perceptional ratings of durability attributes.—Weathering resistance (5.71) and *fatigue resistance* were the highest rated attributes listed under durability by combined groups. This may reflect the fact that materials should be resistant to weathering effects and be capable of carrying and sustaining heavy and/or impact loads. Significant differences were found among the remaining durability ratings (Table 7).

Highway decision-makers rated *weathering resistance* highest at 5.75. Railroads rated *fatigue resistance* (6.11), mechanical *wear* and *abrasion resistance* (5.76), and *fire resistance* (4.61) highest. The marine group rated *corrosion resistance* (5.94) highest, and the utility group rated *biological decay resistance* highest at 5.58 (Table 7).

Wood's *corrosion resistance* was its highest rated durability attribute (by combined groups) at 5.07. Railroad and electric utility decision-makers perceived wood to be more durable than other groups. This appears to be due to both groups' extensive utilization history of wood products. Highway and marine and inland waterway groups indicated wood's service life was frequently shorter than expected. Significant differences were not found for the *corrosion* and *fire resistance* ratings (Table 8).

Highway and marine decision-maker groups both rated *corrosion resistance* highest at 5.11 and 5.10, respectively. Railroad groups rated *fatigue resistance, mechanical wear* and *abrasion resistance,* and *fire resistance* highest. Utility groups rated both *weathering* and *biological decay resistance* highest for wood (Table 8).

Perceptional ratings of design attributes.—Material availability was the highest rated design attribute at 5.90 (Table 7). Respondents indicated that if a material was not available, they then would switch to a substitute product. *Ease of construction* and *standard designs available* are important for reducing fabrication costs, while the latter is important for reduction of research time and the cost of designing a structure.

Marine group decision-makers rated *material availability* highest at 5.85. Utility groups rated *ease of construction,* highway groups rated *design standards available,* and *con-*

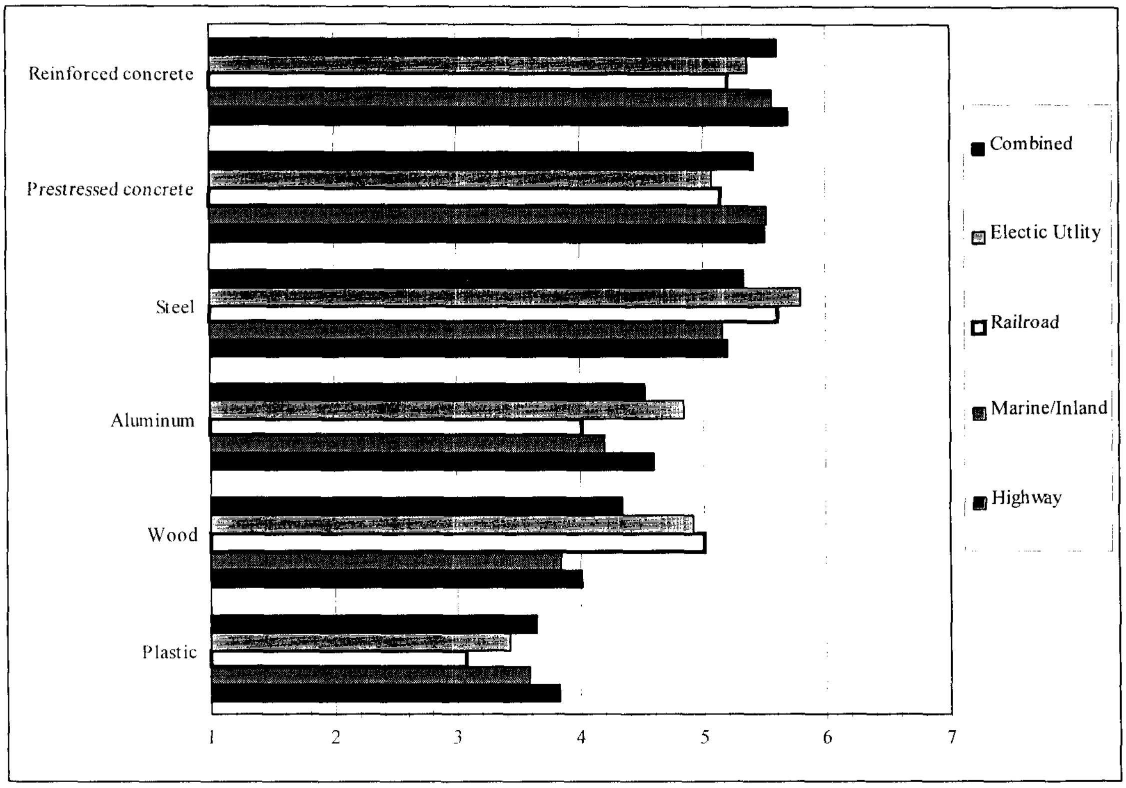

FIG. 1. Mean perceived material performance ratings by U.S. infrastructure group.

struction equipment available was rated highest by the utility group. Both the marine and railroad groups rated *designer's experience with the material* for wood highest (Table 7).

Wood's *construction equipment available* was its highest rated design attribute at 5.71 (Table 8). Electric utilities and railroad decision-makers' perceptional ratings of wood were higher than those of the other groups. Hence, their familiarity and experience with wood may tend to greater utilization of wood products. Also, post-survey interviews indicated that the current *design standards available* for wood products probably are obsolete.

Electric utility groups rated *construction equipment available, ease of construction, design standards available,* and *designer's experience with the material* highest for wood. Railroads groups rated *material availability* for wood highest (Table 8).

Perceptional ratings of environmental attributes.—Chemically safe was the highest rated environmental attribute at 5.52 (Table 7). *Chemically safe* appears to be the highest rated environmental attribute due to decision-makers' responsibility for the structures. For that reason, they do not want to utilize materials that are harmful both to the environment or the public. Significant differences were not found for the ratings *chemically safe* and *low-environmental effects of material production* (Table 7).

Marine group decision-makers rated *chemically safe* highest at 5.66. Highway groups rated *aesthetically pleasing,* railroad groups rated *low-environmental effects of material production,* and *disposable* and *biodegradable* was rated highest by the utility group. *Recyclable* and *reusable* and *percent recycled content of the material* were both rated highest by the railroad group (Table 7).

Aesthetically pleasing was wood's highest rated environmental attribute at 5.20. Highway,

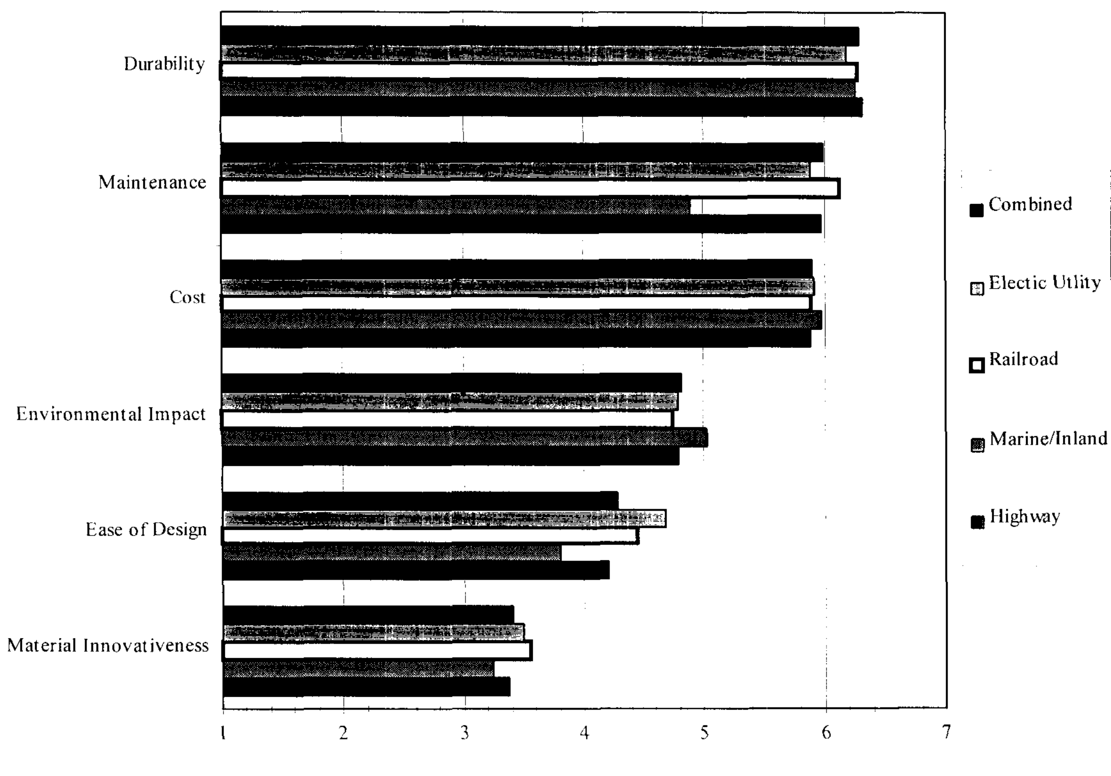

FIG. 2. Mean perceived factor performance ratings by U.S. infrastructure group.

electric utilities, and marine decision-makers held higher perceptions of wood than did the railroad group. These groups work with structures that are in more direct contact or in view of the public than railroads do. The higher perceptional ratings may be due to a greater concern for wood products' effect on the environment (i.e., they may perceive wood products to be more environmentally friendly). Significant differences were not found for the ratings *disposable* and *biodegradable* and *low-environmental effects of material production* (Table 8).

Highway group decision-makers rated wood's *aesthetically pleasing* attribute highest at 5.49. Highway groups also rated *chemically safe, disposable* and *biodegradable,* and *low-*

TABLE 4. *Mean material factor perceptional ratings*[1] *by US infrastructure respondents.*

Factor	Highway group (n = 536)	Marine and inland group (n = 100)	Railroad group (n = 167)	Electric utility group (n = 156)	Combined groups (n = 959)	Univariate *P*-values
Durability	6.31	6.26	6.27	6.19	6.28	0.50
Maintenance	5.98	4.89	6.12	5.88	5.99	0.11
Cost	5.88	5.97	5.89	5.91	5.90	0.82
Environmental impact	4.79	5.02	4.74	4.79	4.81	0.31
Ease of design	4.21	3.80	4.44	4.68	4.28	<0.01
Material innovativeness	3.37	3.24	3.56	3.49	3.41	0.47

MANOVA hotellings T^2-test, *P*-value < 0.01 among factors and groups.

[1] 1 = below average performance, 4 = average, 7 = above average performance.

TABLE 5. *Mean factor perception ratings*[1] *of infrastructure respondents by USDA Forest Service regions.*

Factor	Northeast	Southeast	Midwest	West	Southwest	Combined	Univariate P-values
Durability	6.28	6.31	6.29	6.23	6.23	6.28	0.88
Maintenance	6.00	6.07	5.96	5.90	5.94	5.99	0.48
Cost	5.85	5.92	5.85	5.95	5.96	5.90	0.64
Environmental Impact	4.94	4.87	4.87	4.69	4.79	4.81	0.42
Ease of design	4.03	4.40	4.25	4.37	4.41	4.28	0.03
Material innovativeness	3.38	3.42	3.47	3.25	3.46	3.41	0.78

MANOVA Hotellings T^2-test, P-value = 0.03 among factors and regions.

[1] 1 = below average performance, 4 = average, 7 = above average performance.

environmental effects of material production highest. The railroads rated *recyclable* and *reusable* and *percent recycled content of the material* for wood highest (Table 8).

Perceptional ratings of maintenance attributes.—*Ease of repair* was the highest rated maintenance attribute at 5.69. This attribute appears to be the most important due to the high costs of maintaining structures. In this study, a particular group's utilization history (i.e., a greater use of a material) tended towards higher perceptional ratings. Significant differences were not found for the *maintenance experience* rating (Table 7).

Railroad groups rated *ease of repair* highest at 6.04. Additionally, they rated *maintenance experience, easy inspection,* and *easy field modification* highest. *Standard structure designs available* were rated highest by the utility group (Table 7).

Easy field modification was wood's highest rated maintenance attribute at 5.34. Railroad and electric utility decision-makers perceived wood to be more maintenance friendly than other groups. Again, this may be due to both groups' extensive utilization history of wood products in their operations. Significant differences were not found for the *ease of repair* and *easy inspection* ratings (Table 8).

Utility groups rated *easy field modification* highest at 5.70. Additionally, they rated *maintenance experience* and *standard structure designs available* highest for wood. *Ease of repair* for wood was rated highest by the marine group, and *ease of inspection* was rated highest by the railroad group (Table 8).

Perceptional ratings of innovation attributes.—Material innovativeness was not considered an important attribute; the mean rating was 3.41 (which is below average). This is a result of the high costs of maintaining and replacing structures. Only *innovation in durability* rated above 5, at 5.14. The remaining *innovation* attributes rated slightly above average. Railroad groups rated all innovation attributes highest as compared to other decision-maker groups (Table 7).

Wood's *innovation in design* was its high-

TABLE 6. *Mean material perception ratings*[1] *of infrastructure respondents by USDA Forest Service regions.*

Materials	Northeast	Southeast	Midwest	West	Southwest	Combined	Univariate P-values
Prestressed concrete	5.42	5.68	5.64	5.56	5.75	5.61	0.16
Reinforced concrete	5.22	5.50	5.49	5.38	5.49	5.42	0.10
Steel	5.35	5.29	5.35	5.44	5.35	5.34	0.94
Aluminum	4.60	4.53	4.56	4.45	4.36	4.53	0.78
Wood	4.28	4.23	4.38	4.58	4.36	4.35	0.72
Plastic	3.80	3.54	3.68	3.52	3.61	3.64	0.71

MANOVA Hotellings T^2-test, P-value = 0.58 among materials and regions.

[1] 1 = below average performance, 4 = average, 7 = above average performance.

TABLE 7. *Factor attribute perceived importance ratings*[1] *by US infrastructure respondents.*

Factor Attribute	Highway	Marine	Railroad	Utility	Combined	Univariate *P*-values
Durability						
Weathering resistance	5.75	5.61	5.65	5.69	5.71	0.85
Fatigue resistance	5.76	5.23	6.11	5.30	5.69	<0.01
Mechanical wear or abrasion resistance	5.31	5.27	5.76	5.03	5.34	<0.01
Corrosion resistance	5.76	5.94	4.86	5.22	5.55	<0.01
Biological decay resistance	4.69	4.64	5.51	5.58	4.98	<0.01
Fire resistance	4.11	4.60	4.61	4.05	4.23	0.03
Design						
Material available	5.59	5.85	5.78	5.76	5.90	0.02
Ease of construction	5.59	5.44	5.58	5.61	5.58	0.52
Design standards available	5.52	5.19	5.19	5.35	5.40	0.01
Construction equipment available	5.20	5.11	5.44	5.55	5.29	0.05
Designer's experience with the material	5.24	5.40	5.40	4.96	5.23	0.08
Environmental						
Chemically safe	5.53	5.66	5.46	5.45	5.52	0.64
Aesthetically pleasing	5.11	4.68	3.96	4.91	4.84	<0.01
Low-environmental effects of material production	4.21	4.22	4.45	4.27	4.26	0.81
Disposable/biodegradable	4.00	4.08	4.23	4.32	4.10	0.43
Recyclable/reusable	3.84	3.33	4.21	3.51	3.80	0.01
Percent recycled content of material	3.33	2.67	3.59	2.97	3.25	<0.01
Maintenance						
Ease of repair	5.60	5.54	6.04	5.72	5.69	<0.01
Maintenance experience	5.40	5.59	5.69	5.42	5.47	0.14
Easy inspection	5.40	5.59	5.69	5.42	5.47	<0.01
Easy field modification	5.30	5.09	5.71	5.59	5.39	<0.01
Standard structure designs available	5.22	4.88	5.39	5.52	5.26	<0.01
Innovation						
Innovation in durability	5.09	5.02	5.68	4.84	5.14	<0.01
Innovation in maintenance	4.79	4.72	5.38	4.66	4.86	<0.01
Innovation in performance	4.79	4.58	4.99	4.45	4.74	0.01
Innovation in the environment	4.31	4.19	4.78	3.86	4.30	<0.01
Innovation in design	4.27	4.28	4.30	4.22	4.27	0.96
MANOVA Hotellings T^2-test, *P*-value < 0.01 among attributes and groups						

[1] 1 = below avarage performance, 4 = average, 7 = above average performance.

est rated innovation attribute at 4.17. Wood products were rated average or slightly above average on all *innovation* attributes. Significant differences were found only for *innovation in maintenance*. Railroad groups, as compared to other decision-maker groups, rated all of wood's innovation attributes highest (Table 8).

CONCLUSIONS

This study sought to determine how infrastructure decision-makers perceived wood as an

TABLE 8. *Mean perceived importance ratings*[1] *of Wood attributes.*

Factor Attribute	Highway	Marine	Railroad	Utility	Combined	Univariate P-values
Durability						
Corrosion resistance	5.11	5.10	5.01	4.99	5.07	0.88
Fatigue resistance	4.17	4.17	5.29	4.69	4.46	<0.01
Weathering resistance	3.82	3.90	4.56	4.66	4.11	<0.01
Mechanical wear or abrasion resistance	3.45	3.34	4.61	4.30	3.79	<0.01
Biological decay resistance	3.28	3.22	4.09	4.23	3.58	<0.01
Fire resistance	2.57	2.42	3.23	2.88	2.71	0.14
Design						
Construction equipment available	5.67	5.80	5.51	6.01	5.71	0.26
Ease of construction	5.24	5.55	5.59	5.89	5.45	<0.01
Material available	5.24	5.62	5.71	5.67	5.44	<0.01
Design standards available	5.05	5.34	5.39	5.64	5.24	<0.01
Designer's experience with the material	4.66	5.17	5.45	5.72	5.04	0.01
Environment						
Aesthetically pleasing	5.49	5.27	4.68	4.76	5.20	<0.01
Chemically safe	5.29	5.02	4.79	4.83	5.09	<0.01
Disposable/biodegradable	5.02	4.92	4.52	4.46	4.82	0.06
Low-environmental effects of material production	4.47	3.28	4.10	4.32	4.41	0.09
Recyclable/reusable	3.21	3.28	3.94	3.41	3.39	0.03
Percent recycled content of material	2.66	2.41	3.24	2.86	2.77	0.04
Maintenance						
Easy field modification	5.15	5.54	5.47	5.70	5.34	0.02
Maintenance experience	4.76	5.48	5.62	5.72	5.15	<0.01
Ease of repair	5.03	5.38	5.26	4.92	5.09	0.08
Easy inspection	4.69	4.77	5.23	4.90	4.83	0.53
Standard structure designs available	4.61	5.02	5.24	5.69	4.95	<0.01
Innovation						
Innovation in design	4.28	3.93	4.17	3.99	4.17	0.69
Innovation in performance	4.17	3.85	4.32	4.00	4.13	0.42
Innovation in durability	4.10	3.61	4.59	4.14	4.13	0.08
Innovation in maintenance	4.02	3.98	4.45	4.08	4.10	0.01
Innovation in the environment	4.05	4.08	4.23	3.69	4.02	0.62
MANOVA Hotellings T^2-test, P-value $<$ 0.01 among attributes and groups						

[1] 1 = not at all, 4 = average, 7 = to a high degree.

infrastructure construction material. The results indicate that wood products performance is perceived to be less than other infrastructure materials. Substitute or competing materials were all rated higher, with the exception of plastic. Significant differences were not found between differing infrastructure groups in different United States regions regarding wood products as an infrastructure material. Combined infrastructure groups perceived reinforced concrete to have the highest overall material performance, while wood and plastic

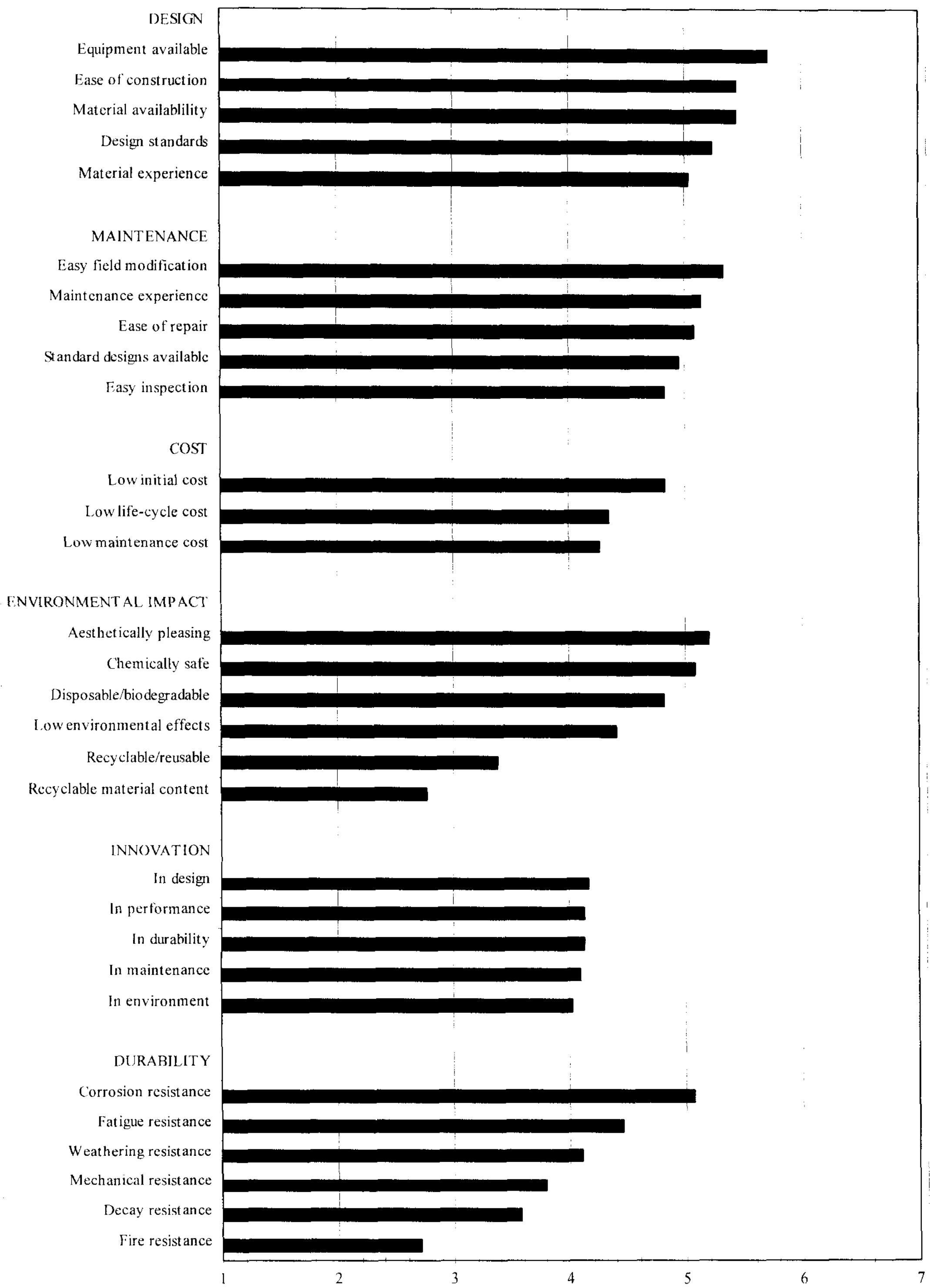

FIG. 3. Perceptional ratings of wood by factor and attributes.

were rated lowest in overall material performance. Infrastructure groups nevertheless rated wood above average in overall perceived performance (Figs. 1 and 3).

Wood products could be improved in several areas in order to compete more effectively in the infrastructure market. First, infrastructure groups perceived wood as an expensive material in *maintenance* and *life cycle costs.* Second, wood products were perceived to have poor durability attributes regarding *fire* and *biological decay resistance.* This finding was supported by post-survey interviews, where participants stated that wood products should be made more fire-resistant and that chemical preservative treatments should be developed to more effectively control, prevent, or eradicate biological decay. Improved chemical treatments should produce wood products that lengthen wood's service life. Third, wood's environmental attributes were perceived to be less *environmentally friendly* as a result of chemical treatments. Supporting this, interview participants stated that treated wood products should be developed that were more environmentally safe. Fourth, structure designers indicated having *low experience* in the design of wood structures. Fifth, most infrastructure officials perceived that wood products were not *recyclable or reusable,* that wood does not have *low environmental effects of material production,* and was not perceived to have a high *content of recycled material.* Infrastructure decision-makers did not perceive wood as *easy to inspect* or to have *standard structure designs in maintenance* available. Sixth, wood was perceived to be least desirable as an *innovative material in performance, design, maintenance,* and *durability.* Manufacturers should strive to improve wood products in the aforementioned areas.

Wood products associations should emphasize educating infrastructure decision-makers on the proper use of wood in infrastructure. The forest products industry as a whole should examine current coursework offerings and consider developing standardized wood design coursework programs throughout the U.S. In addition, there is a need for a wood design textbook specifically oriented towards infrastructure application(s). Timber construction designs should include improved plans for infrastructure applications that will require less maintenance.

Wood products manufacturers must become more cost-effective (i.e., the benefits received by utilizing wood in infrastructure must be greater than costs). Large wood product prices need to be competitive with concrete and steel. Product quality needs to be improved since today's wood products are perceived to be lower in quality than those produced in the past. Additionally, improved and standardized wood grading rules need to be developed for decision-makers. So that those not trained in grading should be able to understand the grading of wood products.

Finally, results from this study indicate that manufacturers of wood products should consider emphasizing three factors: *durability, maintenance,* and *cost.* Manufacturers need to develop promotional marketing strategies and tactics that emphasize wood's durability and the cost differentials between wood and substitute products. These tactics should also stress the ease of maintaining wood products. Additionally, wood products availability to infrastructure decision-makers needs to be increased (i.e., on a wider scope). A directory should be compiled that lists suppliers and their location.

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