Chapter 4

Determining Decision Makers' Perceptions of Materials in United States Highway Infrastructure Market

The Highway Infrastructure Market

The United States highway system provides an opportunity for the wood products industry due to the many possibilities for the use of wood in highway structures. Wood products can be used in heavy, direct contact highway transportation structures such as guardrail systems, sign systems, bridges, culverts and retaining walls. Also, wood could be used in the supportive highway structures such as salt storage sheds, fencing, sound barriers and formwork/falsework. The 1990 census estimated that the 1988 funding collected by all governments for highway use amounted to over $69 billion (National Transportation Strategic Planning Study 1991). Highway structures may be built of wood products, but the highway infrastructure market was highly competitive and many structures are being constructed of alternative materials such as steel, reinforced concrete, prestressed concrete, aluminum and plastic. In order to compete more effectively in the US highway market, wood products manufacturers need current information about decision makers in charge of design, construction and maintenance of highway structures. Manufacturer's need to know why engineers and administrators choose materials implemented in today's highway infrastructure. Once this information is documented, wood products manufacturers can develop strategies and to compete more effectively in the highway infrastructure market.

The highway market and its decision-makers were assessed using a mail questionnaire sent to 912 highway officials in three distinct groups. These groups included State DOT engineers (335), private consulting engineers (276) and county/local highway officials (301). After the mail questionnaires were analyzed, personal interviews were conducted in four states (Georgia, Indiana, Maine and Montana). These interviews were used to clarify results found with the questionnaire and to further understand the US highway market. Decision-makers personally interviewed included State DOT engineers, private consulting engineers and county/local highway officials. The methodology as outlined in chapter 2 was followed in this study.

Study Objectives

This study identified how materials for use in highway structures were chosen and determined the decision-makers' perceptions of various materials in different infrastructure markets. The ultimate goal was to determine markets for wood in the infrastructure of the United

States. To reach this goal, several hypotheses were tested. First, it was hypothesized that many decision-makers in highway markets were not educated in using wood in design and construction. This lack of education could cause the decision-makers to have poor perceptions of wood products in highway structure design and construction. Second, it was hypothesized that highway decision-makers without standards for wood products designs in highway structures would have a lower perception of wood in highway structures than those with standards for wood. Third, it was hypothesized that decision-makers in the highway market with greater work experience would have a different perception of wood in highway structures than decision-makers with less work experience. Finally, it was hypothesized that highway decision-makers in different highway markets (State DOT, private consultants and county/local officials) would have different perceptions of wood as a highway structure material. Specific objectives used to meet the overall purpose and test the hypothesis were to:

1) Identify the factors important in the material choice decision in selecting infrastructure materials.

2) Determine the perceptions of wood in various infrastructure applications by different infrastructure decision makers.

3) Develop strategies for increased wood use in infrastructure markets.

The analysis of perceptional rating and material factor ratings of the highway respondents met the first two objectives: first, which factors were important in the material choice decision; second, what were the perceptions of wood in various infrastructure applications by different level of decision makers. The factors analyzed were separated into six distinct factor groups:

1) cost group: *low initial cost*, *low maintenance cost* and *low life-cycle cost*;

2) durability group: *fatigue resistance*, *mechanical wear/abrasion resistance*, *fire resistance*, *corrosion resistance*, *weathering resistance* and *biological decay resistance*;

3) design group: *design standards available*, *material available*, *ease of construction*, *designer's experience with material*, and *construction equipment available*;

4) environmental group: *chemically safe*, *aesthetically pleasing*, *disposable/biodegradable*, *low environmental effects of material production*, *recyclable/reusable* and *percent recycled content of material*;

5) maintenance group: *standard structure design's available*, *field modification easy, ease of repair, experience in maintenance with material* and *inspection easy*;

6) innovativeness of material group: *innovative in performance, innovative in design, innovative in maintenance, innovative in durability* and *innovative in the environment*.

Each factor is an attribute when possessed by a material. For example, *corrosion resistance* may be a factor used by a highway decision-maker when deciding on materials for highway noise barrier construction. The factor, *corrosion resistance*, also can be an attribute when possessed by a material such as plastic.

The mean importance of all factor ratings was determined using a 1-7 scale (1 = not important; 4 = average importance; 7 = above average importance). For instance, if the factor *corrosion resistance* was very important to a highway decision-maker, that person would mark a 7 on the importance rating scale.

The mean perceived ratings for all materials possessing attributes directly related to these factors was measured on a 1-7 scale. A rating of 1 indicated that a material did not possess the attribute at all and a 7 rating indicated that the material possessed the attribute to a high degree. For example, if the highway decision-maker thought plastic highly possessed the attribute, *corrosion resistance*, then the individual may give a 7 rating for plastic possessing that attribute.

Weighted mean ratings for material attributes were used to attach importance to each materials attribute ratings. If a factor was not important to an individual, then the perceived attribute rating corresponding to that factor should not be important. Weighted mean perceived attribute ratings provide an individual's material attribute rating and the importance of that attribute to the individual's group at the same time. Weighted mean perceived attribute ratings were determined by multiplying a mean factor importance rating for a highway group with each respondents perceived attribute rating corresponding to that factor and then calculating the mean of these individual weighted ratings. The scale possibilities could then range from 1, which indicated that a material did not possess the attribute at all, to 49, which indicated that a material possessed the attribute to a high degree. For example, a highway group's mean factor importance rating for *corrosion resistance* was 6.55, meaning this was a very important factor to the highway group. One individual in that highway group gave plastic a 7 rating for possessing the attribute *corrosion* *resistance*, indicating the person thought plastic possessed that attribute very highly. The mean factor rating for *corrosion resistance* (6.55) and individual's perceived attribute rating for plastic possessing *corrosion resistance* (7.00) were multiplied together for a weighted mean perceived *corrosion resistance* rating for plastic of 45.85. This single weighted mean perceived attribute rating demonstrates that plastic highly possessed the attribute corrosion resistance and that the attribute was important to the highway group.

Multivariate Analysis of Variance (MANOVA) was used to simultaneously explore the relationship between several categorical independent variables (the highway groups) and two or more metric dependent variables (highway groups' factor and perceived material attribute ratings). Once relationships had been determined using MANOVA, Analysis of Variance (ANOVA) was used to define relationships within each highway group and among each highway group. Tukey's honestly significant difference (HSD) test was used to determine where differences were located between highway groups and within highway groups. A significance level of 0.05 was used throughout the study.

Results and Discussion

Data entry errors were checked using variable ranges and mean ratings. Possible answers ranged from one to seven for the mean scores and one to forty-nine for weighted mean scores. When any mean ratings or ranges were found not within these known ranges, the individual survey(s) in question was located and corrections were made.

Demographics and Material Use:

Data analysis began with summary statistics from highway respondents demographic data. Highway respondents were separated into three groups: State DOT engineers (216); county/local officials (113); private consulting engineers (162). The response rates for each highway groups were: State DOT, 64.4%; county/local officials, 37.5%; private consulting engineers, 58.7%; combined highway groups, 58.8%.

Respondents were asked if the worked in design, construction, maintenance or other types of work. State DOT engineers were evenly separated across the four types of work. Private consulting engineers worked mostly in design (93.8%), while the county/local officials worked mainly in maintenance (40.7%) (Table 59). The highest percentage of highway respondents held a bachelor of science (BS) degree (60.6%) or master of science (MS) degree (25.5%) (Table 60). Less than one-half of highway respondents (44.7%) had formal course-work in wood design. State DOT engineers had the lowest percentage of formal course-work discussing wood design (40.7%). Of those who did have formal course-work in wood design, the percentage of highway respondents that said the course(s) were mandatory was about one-third (34.4%). State DOT engineers had the lowest percentage of mandatory course-work discussing wood design (28.1%) (Table 61). Highway respondents in the age groups 40 to 49 years (34.3%) and 50 to 59 years (35.5%) represented the largest age categories (Table 62). The 25 or more years of work experience group contained the highest percentage of highway respondents in all highway groups (58.4% of State DOT engineers; 40.0% of private consulting engineers; 42.9% of county/local officials; 48.8% of combined highway groups) (Table 63). Two-thirds of highway respondents (66.7%) said they had guidelines for the use of wood products in highway design, construction or maintenance. County engineers were the highest percentage of respondents stating that they have guidelines for wood use (73.6%), while the State DOT had the lowest percentage (64.2%) (Table 64).

Respondents primarily used wood in the construction of highway guardrails (77.8%), signs/sign posts (73.3%), pedestrian bridges (47.0%) and noise barriers (39.7%). Many respondents said they worked with formwork and falsework (35.2%), which was expected because of the large amount of concrete construction in the US highway system. The percentage of highway respondents who have worked with structures in other transportation areas was not expected. Many highway respondents worked with piers (21.0%) and railroad bridges (22.2%). The highway group with the broadest work experience in highway structures was the State DOT engineers. State DOT engineers had consistently high percentages of respondents working on highway structures including noise barriers (60.6%), highway guardrail (77.8%), signs/sign posts (75.0%), salt storage buildings (38.4%), pedestrian bridges (51.9%) and formwork/falsework (40.3%) (Table 65).

Materials most used by highway respondents in construction were reinforced concrete (96.1%), steel (91.4%) and prestressed concrete (81.1%). These three materials were followed closely by wood which was used by 75.6% of highway respondents. County/local officials (78.8%) and State DOT engineers (78.2%) had the highest use of wood in highway construction.

Private consulting engineers had the lowest use of wood in highway design and construction (69.8%) (Table 66).

Highway respondents were asked if they had used wood in the last three years in design, construction or maintenance of highway structures. A large percentage (71.3%) of highway respondents said they had used wood in highway structures in the past three years. The lowest percentage use was the private consulting engineers (60.8%) (Table 67). Private consulting engineers often are hired by State DOTs and county/city governments for highway work. Therefore, private consulting engineers may only use wood in highway construction when requested to by the State DOTs or county/local governments.

Highway respondents were asked if they had used engineered wood products for highway construction in the past three years and if so, what type of engineered wood products they had used. One-half of highway respondents (51.3%) had used engineered wood products in highway structures. State DOT engineers had the highest percentage use of engineered wood products in the past three years (55.7%) (Table 67). Glue-laminated timber (35.6%) and plywood panels (21.4%) had the highest use in highway structures in the past three years. State DOT engineers had the highest percentage use of glue-laminated timber (40.7%) and plywood panels (27.3%) (Table 68).

Highway groups were asked if they had plans to use wood products in structure design, construction or maintenance in the next three years. More than half of highway respondents (58.6%) were planning to use wood in highway structures in the next three years. State DOT engineers had the highest percentage responding that they had plans to use wood in highway structures (63.8%). Private consulting engineers had the lowest percentage for having plans for using wood in highway structures (51.0%) (Table 67).

Test of Hypotheses:

Differences in the highway decision-makers' education levels could cause differences in perceptions of wood in highway structures. First, it was hypothesized that respondents with higher levels of education would have different perceptions of wood products in highway structures than respondents with lower education levels. Highway respondents were tested for differences in their mean perceptions of wood's overall material performance according to their education level. They were grouped according to their college degree: group one included BS/BA degrees and group two included MS/MA degrees. There were not enough highway respondents who possessed doctorate degrees or high school diplomas as their highest education level to include them in the test. Wood products had mean overall perceived material performance ratings in the average range (3.97 and 4.05 for the bachelors and masters degrees, respectively). The two education level groups were not significantly different in mean perceived overall material performance for wood. Therefore, the hypothesis that respondents with different education levels would have different perceptions of wood products was rejected for highway respondents (Table 69).

Education of respondents could have affected their perceptions of wood in highway applications. The second hypothesis was that those respondents without education in design with wood products would have a lower perception of wood than respondents with coursework in design with wood products. Table 70 has the mean perceived overall material performance rating for wood between the two groups. No significant differences were found between those highway respondents who did and did not have coursework in wood design and the hypothesis was rejected.

These two findings regarding the education of highway respondents indicated that education level and education in wood design had little effect on decision-maker's perceptions of wood in highway structures. The highway interview participants had slightly different ideas about education in wood products than that demonstrated by the survey results. Interview participants in Indiana, Maine and Montana said greater education of highway decision-makers needed to occur for more wood to be used in highway structures. This education officials discussed may not be in design of structures with wood products, but education in best utilization of wood or best applications for wood in highway structures. Therefore, wood products manufacturers and associations may want to direct education to inform decision-makers of the following: best geographic locations to use wood products, wood product supplier locations, structure types that can best be built with wood, species of solid wood and engineered wood products that could best be used in highway structures, types of materials which were compatible with wood in composite structures, and maintenance of wood structures.

Guidelines for materials were used to set minimum requirements for use of materials in highway structures and to lower the risk of failure in those structures. Therefore, having guidelines for wood in highway use could affect a highway decision-maker's perception of wood in highway applications. The third hypothesis was that highway decision-makers without standards, or guidelines, for wood products designs in highway structures would have a lower perception of wood in those structures than decision-makers with standards. Highway respondents with guidelines for wood in highway structures gave wood a perceived overall material performance rating of (4.08), while those without guidelines had a mean rating of (3.89). These ratings were not significantly different and the hypothesis that highway decision-makers without guidelines for wood products would have a lower perception of wood in highway structures than those with guidelines was rejected (Table 71).

These results indicated that highway decision-makers perceptions of wood products were not greatly influenced by guidelines. The highway interview case studies discussed three situations which may explain why guidelines were not influencing decision-makers perceptions of wood. First, the guidelines for wood in highway structures may be present, but may be obsolete. If guidelines were obsolete they could increase risk of structure failure. Having obsolete guidelines was the same as not having guidelines at all, and the decision-maker's perceptions of the overall performance of wood could not improve because obsolete guidelines were present. Second, interview participants said guidelines for wood products were often difficult to understand or apply. If decision-makers do not understand the guidelines or were not sure if the guidelines apply in an important situation, then they would not be sure that minimum standards were being met. Therefore, they feel they were taking unnecessary risks using wood because they are unsure of the standards, and the decision-makers' perceptions of wood would not change because guidelines were present. Third, guidelines may be present, but the highway decision-maker may not be familiar with them. Therefore, the decision-maker's perceptions of wood in highway structures may remain unchanged whether or not guidelines were present.

The age of a highway decision-maker could affect that person's perceptions of different materials used in highway structures. The fourth hypothesis was that perceptions of wood products could be different among the highway decision-makers of different ages. No significant differences among the age groups of highway respondents were found and the hypothesis that there would be differences among the different age groups of highway respondents was rejected (Table 72). One possible reason for this could be that older respondents were training younger respondents within an organization. This caused the younger respondents to have similar perceptions of wood in highway structures as older respondents.

Work experience may have had an effect on highway decision maker's perceptions of structural materials. A decision-maker with greater work experience may have worked with more material types or seen more materials in use. This person may have higher or lower perceptions of wood because that person has had experience with more materials. The fifth hypothesis was that decision-makers with greater work experience in highways will have different perceptions of wood than decision makers with less work experience. The mean perceived overall material performance ratings for wood were determined for five experience groups and is illustrated in Table 73. All mean ratings were very close to average, and no significant differences were found between any highway respondents experience group. The hypothesis that highway decision-makers in different age groups would have different perceptions of wood in highway structures was rejected. The results indicate that just because a decision-maker has been working longer, this person's perceptions of wood's overall performance in highway structures was no different from a person who had not worked as long. One possible reason for this finding was those who have more work experience usually were the leaders in an industrial organization. These leaders may have decided which materials would be used in highway structures and they may have trained those decision-makers with less work experience. This supports results of a timber bridge study found by Smith and Bush (1995) that indicate that peers are the number one method engineers hear of new information. Therefore, those more experienced decision-makers may have influenced the less experienced decision-makers, causing the two groups not to be significantly different on their perceptions of wood in highway structures.

The sixth hypothesis stated different markets would have different perceptions of wood as a construction material. The highway market could be separated into three distinct markets: State DOT engineers, highway consulting engineers and county/local officials. State DOT engineers work with primary roads and interstate highways. County/local officials work with secondary roads and county roads. Private consulting engineers usually are employed by the State DOTs or county/local officials, and therefore may have to work with structures on intestate highways, primary or secondary roads. The next sections of this study will discuss factors important in material choice decisions for highway structures and perceptions of wood in highway applications by different levels of decision makers (State DOT engineers, private consulting engineers and county/local officials). These results will be used to test the hypothesis that different highway markets would have different perceptions of wood as a construction material.

Overall Factor Importance:

The overall factors rated for importance in decisions on highway construction materials were: *cost*, *durability*, *maintenance*, *ease of design*, *environmental impact* and *innovativeness of material*. On a 1-7 scale, *durability* was rated the most important overall material decision factor with a mean importance rating above average (6.32) for the combined highway groups. This was followed by *maintenance* (5.99), *cost* (5.87), *environmental impact* (4.76), *ease of design* (4.24), and *innovativeness of material* (3.37) (Table 74).

Differences were found between the highway groups' mean perceived overall importance ratings for *durability*, *maintenance*, *environmental impact* and *innovativeness of material*. County/local officials had a significantly higher mean perceived rating for *durability* (6.44) than private consulting engineers (6.21). County/local officials had a significantly higher mean perceived importance rating for *maintenance* (6.22) than State DOT engineers (5.94) and private consulting engineers (5.89). Also, county/local officials had significantly higher mean perceived importance ratings for *innovativeness of material* (3.60) than private consulting engineers (3.13). State DOT engineers had significantly higher mean perceived importance ratings for *environmental impact* than private consulting engineers. There were no differences between highway groups for mean perceived overall factor importance ratings for *cost* and *ease of design*. Within group analysis found that State DOT engineers and private consulting engineers had significantly higher mean perceived overall factor importance ratings for *durability* than other overall decision making factors. County/local officials had significantly higher ratings for *durability* and *maintenance* than all other overall decision making factors (Table 74).

Discussion of Overall Factor Importance:

Wood products manufacturers competing in the highway market need information on what factors are important to highway decision makers. The results demonstrated that *durability*, *maintenance*, and *cost* were the most important factors to a highway decision maker in choosing a structure material. Officials had importance for *ease of design*, *environmental impact*, and *innovativeness of material* in material choice decisions to a certain extent, but not as much as *durability*, *cost* and *maintenance*. The interview case studies demonstrated that *environmental impact* of materials was becoming more important as more environmental regulations were being implemented for both disposal of treated wood and its use in structures near water. This indicates that wood products manufacturers may wish to include aspects of material durability, maintenance and cost in their marketing strategy to compete more effectively in the highway market. Also, they may want to include environmental impact and ease of design in their strategy development, but not place as much emphasis on these factors. Innovativeness of material was considered below average in importance to officials and therefore manufacturers may want to consider this factor last in marketing strategies.

Manufacturers may be marketing wood products to separate groups in the highway system, including the State DOT engineers, private consulting engineers, and county/local officials. It was found that differences were present among highway groups importance for overall material choice factors. County/local officials had higher importance for *durability* than private consulting engineers. They had higher importance for maintenance than both private consulting engineers and State DOT engineers. Even though the county/local officials had higher importance for *maintenance* and *durability* than other highway groups, these two factors were very important to each highway group. This suggests that manufacturers may wish to increase marketing efforts in durability and maintenance when developing strategies directed toward county/local officials. It also indicates that manufacturers should not ignore durability and maintenance when developing marketing strategies for working with State DOT and private consulting engineers.

Overall Material Performance:

The participants rated reinforced concrete, prestressed concrete, steel, aluminum, wood and plastic for overall perceived performance based on their past experiences. Highway groups mean perceived overall performance ratings is presented in Table 75. Materials with the highest mean perceived ratings for overall performance by the combined highway groups were prestressed concrete (5.68), followed by reinforced concrete (5.52), steel (5.19), aluminum (4.62), wood (4.04) and plastic (3.82).

The highway groups differed significantly on the mean perceived overall material performance ratings. This could be attributed to significant differences among the highway groups for prestressed concrete, aluminum and plastic (Table 75). The hypothesis that different markets could have different perceptions of wood as a construction material was tested with the three highway groups' overall material performance ratings for wood. No significant differences were found among the highway groups mean perceived overall performance ratings for wood, and the hypothesis was rejected with perceptions of overall material performance.

Within each highway group, wood (4.04 for combined highway groups) had the second lowest mean perceived overall material performance ratings. Significant differences were found within each highway groups' mean perceived overall material performance ratings. Private consulting engineers rated wood (4.09) significantly lower in mean perceived overall performance than prestressed concrete (5.69), reinforced concrete (5.46) and steel (5.23). State DOT engineers, county/local officials and the highway groups combined rated wood significantly lower than prestressed concrete, reinforced concrete, steel and aluminum in mean perceived overall performance (Table 75).

Discussion of Wood Products Overall Material Performance:

Material performance is the ability of a material to carry out the required tasks in a structure. In the highway market, performance includes not only the ability of a material to work in a structure, but the material's durability, maintenance and cost as well. Wood was perceived by decision-makers to have the second lowest overall material performance in highway structures. This suggests to improve competitive position in the highway markets, manufacturers should improve the durability, maintenance and cost of wood products. Highway officials did not differ in their perceptions of wood material performance. This suggests to compete in any highway market manufacturers may want to improve wood products performance.

Perceptional Ratings of Cost Factors:

Three cost factors considered when making a choice for materials by highway officials included *low initial cost*, *low maintenance cost*, and *low life-cycle cost.* The highway groups combined gave *low life-cycle cost* the highest mean perceived importance rating (5.64), followed by *low maintenance cost* (5.53) and *low initial cost* (5.06) (Table 76). Differences were found among the highway groups' mean perceived ratings for cost factor importance. State DOT (5.67) and private consulting engineers (5.44) had significantly lower ratings for *low life-cycle cost* than did county/local officials (5.87). Mean perceived importance factor ratings for *low life-cycle cost* and *low initial cost* were not significant different in any highway group. *Low life-cycle cost* and *low maintenance cost* were significantly more important than *low initial cost* for each highway group (Table 76).

Discussion of Cost Factors:

In order to improve marketing strategies for the highway market, wood products manufacturers need information on what costs are most important to officials. Highway officials had the highest importance for life-cycle cost because it included both maintenance and initial costs. This indicates that manufacturers may want to improve marketing strategies so that highway officials initial, maintenance and life-cycle costs with structural materials will be reduced.

Differences among cost factor importance in different highway markets may be important to wood products manufacturers who are marketing to more than one highway market or are beginning to direct marketing efforts to a new highway market. State DOT engineers and private consulting engineers perceived *low life-cycle cost* to have higher importance than did county/local officials. County/local officials had greater importance for *low maintenance costs* than did State DOT and private consulting engineers. This indicates that manufacturers may want to develop marketing strategies that lower *life-cycle cost* when marketing to the State DOT and private consulting engineers. When marketing to the county/local officials, manufacturers may wish to develop strategies that lower maintenance costs of structures.

Perceptional Ratings of Cost Attributes:

Highway groups rated the following materials for possession of cost factors as perceived attributes: reinforced concrete, prestressed concrete, steel, aluminum, wood and plastic. The hypothesis that different highway groups would have different perceptions of wood as a construction material was tested using mean cost attribute ratings for wood. The hypothesis that different highway market groups would have different perceptions of wood as a construction material was tested using the cost attribute ratings for wood. No significant differences were found among highway groups' mean importance ratings for wood on any cost attribute. Based on the mean perceived low *initial*, *maintenance* and *life-cycle cost* attribute ratings for wood, we rejected the hypothesis that different highway groups would have different perceptions of wood as a construction material.

Materials with the highest *low initial cost* rating and therefore the lowest perceived initial cost as perceived by the combined highway groups were reinforced concrete (4.71), prestressed concrete (4.67), steel (4.53) and wood (4.51). These mean *low initial cost* ratings were not significantly different from each other, but as a group were significantly higher than plastic (4.05) and aluminum (4.03). All highway groups rated wood high in possessing the attribute *low initial cost* [State DOT engineers (4.31), private consulting engineers (4.75) and county/local officials (4.55)] (Table 77).

Prestressed concrete (5.62) and reinforced concrete (5.52) had the highest mean perceived *low maintenance cost* ratings by the combined highway groups. Prestressed concrete and reinforced concrete were significantly higher than all other materials in mean perceived *low maintenance cost* ratings for each highway group. Each group had the lowest mean perceived *low maintenance cost* rating for wood [State DOT engineers (3.94), private consulting engineers (3.81) and county/local officials (4.28)] (Table 77).

The highway groups had the same perceptions of wood's *low initial cost*, *low maintenance cost*, and *low life-cycle cost* in highway construction. The combined highway groups' rank order mean perceived *low life-cycle cost* ratings for materials were prestressed concrete (5.59 - meaning it had the lowest perceived life-cycle cost), reinforced concrete (5.51), steel (4.88), aluminum (4.88), plastic (4.19) and wood (4.00). In each highway group, prestressed concrete and reinforced concrete had the highest mean perceived *low life-cycle cost* ratings. The mean perceived *low life-cycle cost* ratings for prestressed concrete and reinforced concrete were significantly higher than all other materials. Wood had the lowest mean perceived *low life-cycle cost* ratings by each highway group [State DOT engineers (4.04), private consulting engineers (3.91) and county/local officials (4.02)] (Table 77).

No significant differences were found in the highway groups' weighted mean perceived *low initial cost* rating (1-49 scale) for any materials. Wood ranked fourth lowest in weighted mean perceived *low initial cost* ratings for the combined State DOT engineers and the private consultants, while wood's rating by the county/local officials was not significantly different from any other material. There were significant differences among the highway groups' weighted mean perceived *low maintenance cost* ratings for wood. County/local officials had weighted mean perceived *low maintenance costs* for wood (25.12) significantly higher than State DOT (21.72) and private consulting engineers (20.30). Wood had the lowest weighted mean perceived *low* *maintenance cost* rating for each highway group. Significant differences among highway groups were located in perceived weighted mean *low life-cycle cost* ratings for wood. Although differences were indicated among highway groups' weighted mean perceived *low life-cycle cost* ratings for wood, no differences were found using Tukey's HSD test. Wood had the lowest weighted mean *low life-cycle cost* ratings by each highway group (Table 78).

Discussion of Cost Attributes

The results suggest that manufacturers may wish to incorporate changes in marketing plans to improve competitive position in the highway market. Perceptions of *low initial cost* for wood were the same as alternative materials. There has been little initial cost savings with wood in highway structures when compared to alternate materials, and interview participants in Georgia and Indiana said the cost per unit strength of wood was high. Wood had the lowest mean rating for *low maintenance cost* by all the highway groups, which means it had the highest rated maintenance cost for any material. Wood had the lowest *low life-cycle cost* rating (meaning it had the highest life-cycle cost) by all highway groups because *life-cycle cost* was composed of all costs types. Wood had high *initial* and *maintenance* costs, so its *life-cycle cost* was rated high across all groups. For wood to be competitive in highway markets, manufacturers may need to reduce the cost of large wood products such as piles and timbers. They may want to develop market strategies that incorporate tactics that decrease highway officials maintenance costs with wood. These tactics could be improving maintenance education of highway officials or offering maintenance services to highway officials. Finally, manufacturers need to lower the life-cycle costs of wood products in highway markets, which could be accomplished by decreasing initial, maintenance and disposal costs of wood.

Perceptional Ratings of Durability Factors:

Durability factors examined for their perceived importance in making a construction material decision included were: *fatigue resistance, mechanical wear/abrasion resistance, fire resistance, corrosion resistance*, *weathering resistance* and *biological decay resistance*. The multivariate Hotellings p-value indicated that differences were present among the mean importance ratings for either *fatigue resistance* or *mechanical wear/abrasion resistance*. Although differences were indicated by the multivariate test, no differences were located among the highway groups' mean importance ratings for either *fatigue resistance* or *mechanical wear/abrasion resistance* using univariate tests and Tukey's HSD test. The State DOT engineers had mean importance ratings for *corrosion resistance* significantly higher than county/local officials ratings.

All *durability* factor ratings by the combined highway groups were above average (4.00). Within the combined highway group, *weathering resistance* (5.80), *fatigue resistance* (5.78) and *corrosion resistance* (5.75) were the most important factors. The combined highway group rated these factors significantly more important than *fire resistance* (4.10) and *biological decay resistance* (4.77). State DOT engineers had the highest importance ratings for *corrosion resistance* (5.95), *fatigue resistance* (5.91) and for *weathering resistance* (5.76), which were significantly more importance than their ratings for *biological decay resistance* (4.61) and *fire resistance* (3.99). Private consulting engineers had the highest importance ratings for *weathering resistance* (5.80), *corrosion resistance* (5.64), and *fatigue resistance* (5.70), which were significantly higher than their importance ratings for *biological decay resistance* (4.74) and *fire resistance* (4.27). The county/local officials had the highest mean importance ratings for *weathering resistance* (5.86), *fatigue resistance* (5.66), *corrosion resistance* (5.54) and *mechanical wear/abrasion resistance* (5.53). They rated these factors significantly higher than *fire resistance* (4.09) (Table 79).

Discussion of Durability Factors:

The most important factors to the highway groups were *weathering resistance*, *fatigue resistance* and *corrosion resistance*. *Weathering resistance* was important because of the large amount of freeze/thaw damage that can occur with structures. The other weathering damage agent was from ultraviolet light, which can damage some materials, such as plastic and wood. *Fatigue resistance* was important because there was a need for materials to maintain structure strength under the harshest conditions present today. Therefore, materials must be fatigue resistant to compete in highway markets. *Corrosion resistance* was important because of the high use of steel in the US highway system. *Fire resistance* pertained more to wood and plastic used in highway structures. Being that these materials were not used as frequently as less flammable concrete and steel in highway structures, *fire resistance* was not that important to the highway groups.

Biological decay resistance primarily pertains to wood used in highway structures. Many highway decision-makers were not using wood in highway structures, so they were less concerned with biological decay of wood.

Wood had the second lowest *fatigue resistance* rating by the combined highway groups for two main reasons. Interview participants perceived wood to have lower strength per unit than concrete or steel. Wood was rated second lowest for perceived *mechanical wear/abrasion resistance* primarily for the wear it receives when used in as a bridge deck surface. Also, mechanical wear/abrasion occurred when wood piles were abraded by stream debris and thawing ice. Wood has the second lowest perceived *fire resistance* ratings for the obvious reason that wood, especially treated wood, was flammable. Wood was rated high for *corrosion resistance* because it did not corrode. Wood had low mean *weathering resistance* ratings due to ultraviolet light damaging exposed wood surfaces and damage by freeze/thaw cycles. Wood has a low rating for perceived *biological decay resistance* because wood (even treated wood, in some instances) was attacked by many organisms.

Perceptional Ratings of Durability Attributes:

Highway groups rated the following materials for possession of durability factors as perceived attributes: reinforced concrete, prestressed concrete, steel, aluminum, wood and plastic. The hypothesis that different highway groups would have different perceptions of wood as a construction material was tested using mean durability attribute ratings for materials. No significant differences were found among the highway groups mean perceived ratings for materials possessing any of the durability attributes (Table 80). Therefore, perceptions of materials possessing a durability attribute should be the same for each highway group.

Each highway group had the highest mean perceived *fatigue resistance* ratings for prestressed concrete (5.69), reinforced concrete (5.48), and steel (5.26). These materials had significantly higher mean perceived *fatigue resistance* ratings than wood (4.20) and plastic (3.79) by each highway group. Wood was given the second lowest rating of all materials for *fatigue resistance* (Table 80).

The materials rated highest by each highway group for mean perceived *mechanical wear/abrasion* resistance were prestressed concrete (5.40), steel (5.39) and reinforced concrete (5.36). Each highway group had significantly higher mean perceived *mechanical wear/abrasion* *resistance* ratings for these materials than wood (3.46) or plastic (3.45). Wood had the second to lowest mean perceived *mechanical wear/abrasion resistance* rating by the combined highway groups (Table 80).

Each highway group has the highest mean perceived *fire resistance* rating for reinforced concrete (5.87) and prestressed concrete (5.75). Each highway group's mean perceived *fire resistance* ratings for these materials were significantly higher than mean perceived ratings for steel (4.95), aluminum (4.12), wood (2.56) and plastic (2.23). Wood had the second to lowest mean perceived *fire resistance* rating for each highway group with its rating below average (Table 80).

Highway groups rated materials for *corrosion resistance*, and the materials with the highest mean perceived ratings were plastic (5.52), prestressed concrete (5.30) and reinforced concrete (5.16). Also, the combined highway groups had a high mean perceived *corrosion resistance* rating for wood (5.13). The highway groups' mean perceived rating for wood was not significantly different from prestressed and reinforced concrete, but significantly lower than plastic. Wood products had the third lowest mean perceived *corrosion resistance* ratings by the highway groups, but its rating was still above average (Table 80).

The highest mean perceived *weathering resistance* ratings were for prestressed concrete (5.59), reinforced concrete (5.41) aluminum (5.38). These mean ratings were significantly higher than mean ratings for steel (4.84), plastic (4.43) or wood (3.86). Highway groups had the lowest mean perceived *weathering resistance* rating for wood (Table 80).

Each highway group had the highest mean perceived *biological decay resistance* ratings for prestressed concrete (5.81), reinforced concrete (5.81) and aluminum (5.74). Each highway group had mean perceived *biological decay resistance* ratings for these materials significantly higher than wood(3.32). Wood products had a below average rating for *biological decay resistance* and had the lowest mean perceived rating of all materials in each highway group (Table 80).

Durability attribute ratings were weighted by the durability factors (Table 81). Significant differences were located among the highway groups' weighted mean perceived ratings of materials for *fatigue resistance* and *fire resistance*. These significant differences were not attributed to weighted mean perceived ratings for wood, so there were no differences in highway groups weighted mean durability ratings for wood. No other significant differences were found among the highway groups weighted mean perceived ratings of materials for other weighted durability attributes. Wood had the second lowest weighted mean ratings for *fatigue resistance* (24.28) for combined highway groups. Highway groups' weighted mean *fatigue resistance* rating for wood was significantly lower than reinforced concrete and prestressed concrete. Their weighted mean *mechanical wear/abrasion resistance* rating for wood (18.29) was second to the lowest, and this rating was significantly lower than the rating for prestressed concrete, reinforced concrete and steel. Highway groups had the second lowest weighted mean *fire resistance* rating for wood (10.52) and this rating was significantly lower than reinforced concrete, prestressed concrete, steel and aluminum. The weighted mean *corrosion resistance* by highway groups for wood (29.46) was among the highest ratings of materials and was not significantly different from plastic, prestressed concrete, reinforced concrete and aluminum. Wood had the lowest weighted mean perceived *weathering resistance* rating (22.36), which was significantly lower than weighted mean ratings for all other materials. Highway groups weighted mean perceived *biological decay resistance* ratings for wood were the lowest of all materials (15.86). This weighted mean rating was significantly lower than weighted means for all other construction materials (Table 81).

Discussion of Durability Attributes:

Highway officials had high importance for durability in a material choice decision. Their perceptions of wood possessing durability will affect their decision to use wood in structural applications. Therefore, manufacturers will need information on their perceptions of wood durability to compete effectively in the highway markets. Officials perceived wood to be lower in fatigue resistance than alternate materials due to their perceptions that it had lower strength than other materials. They perceived wood to have lower *mechanical wear/abrasion resistance* because wood was a softer material than alternate materials and was abraded more easily by debris and vehicles. This type of damage was primarily seen in wood bridge decks with no wearing surface. Officials perceived wood to be among the least fire resistant materials due to the fact that it was flammable. They perceived wood to be among the most *corrosion resistant* materials. Officials perceived wood to be among the least *weathering resistant* materials due damage it receives from ice and ultraviolet light. They perceived wood to be the least *biological decay resistant* material due to the many problems they have had with decay organisms damaging wood structures even when chemically treated.

Durability factors were highly important to the highway officials in a material choice decision and they perceived wood to be among the least durable materials. Therefore, manufacturers may wish to increase the durability of wood in order to improve their competitive position in the highway market. Manufacturers may wish to promote wood more in areas where *fatigue resistance* in wood is not a problem such as post materials or they may need to develop more fatigue resistant wood composites for highway use. They may wish to promote the use of wearing surfaces on wood bridge decks or protective structures for bridge pilings where the most *mechanical wear/abrasion* of wood occurs. Manufacturers may wish to improve the fire resistance of wood products used in highway structures by developing and promoting fire retardents for wood structural materials. The low perceived weathering resistance for wood may require manufacturers to develop structural designs that have better water drainage. It is suggested that wood products manufacturers may wish to improve chemical wood treatments to increase wood's *biological decay resistance*. The *corrosion resistance* of wood could be a promotional tool for manufacturers to use in areas with high road salt use. No differences were found among the highway groups' perceptions of the durability of wood. This indicates that the wood products manufacturers may wish to improve durability of wood if they are marketing to State DOT engineers, private consulting engineers or county/local officials.

Perceptional Ratings of Design Factors:

Design factors tested for their perceived importance in making a highway construction material decision were: *design standards available*, *material available*, *ease of construction*, *designer's experience with material* and *construction equipment available*. No significant differences were found among the highway groups' mean importance ratings for *material available* (5.99), *ease of construction* (5.61) and *design standards available* (5.55). These factors had significantly higher mean factor importance ratings by the combined highway group than *designer's experience with material* (5.24) and *construction equipment available* (5.19). No significant differences were found among the highway groups' the mean factor importance ratings for *construction equipment available*. Univariate analysis among the highway groups indicated differences were present in highway groups' mean factor importance ratings for *designer's experience with material*, but no differences were found using Tukey's HSD (Table 82).

Discussion of Design Factors:

Design factors were not as important as *durability, maintenance* or *cost* factors, but were still above average in importance to highway officials. Therefore, wood products manufacturers may want to include design factors in their highway market strategies. Manufacturers will want to know the importance of different design factors to highway officials so they may be able to center their marketing efforts. *Material available* was the most important design factor because it limits materials used in a highway project from the beginning. *Ease of construction* had a high importance rating because it reduced construction costs. *Design standards available* lowers the cost of designing a structure and decreases risks of structure failure. Manufacturers may want to make changes their marketing strategies by adding material availability, ease of construction and design standards as objectives in their marketing strategy. Although significantly lower in importance than the design factors just described, *designer's experience with materials* and *construction equipment available* were above average in importance and should not be left out of marketing strategies.

Perceptional Ratings of Design Attributes:

Highway groups rated the following materials for possession of design factors as perceived attributes: reinforced concrete, prestressed concrete, steel, aluminum, wood and plastic. The hypothesis that different highway groups would have different perceptions of wood as a construction material will be tested using mean design attribute ratings for materials.
The hypothesis that different highway markets would have different perceptions of wood in construction was tested using the highway respondents' mean perceived design attribute ratings and weighted mean perceived design attribute ratings. No significant differences were found in the highway groups' mean perceived ratings of wood for the any mean design attribute rating. Therefore, the hypothesis was rejected for perceived design attribute ratings for wood and this research indicates that highway markets did not differ in their perceptions of wood as a construction material.

Significant differences were found among the highway groups mean perceived *design standards available* ratings for reinforced concrete, aluminum and plastic, but not for wood. Combined highway groups had the highest mean perceived *design standards available* for reinforced concrete (6.17), steel (6.12) and prestressed concrete (6.07) The combined highway groups' mean ratings for these materials were significantly higher than wood (5.03), aluminum (4.99) and plastic (3.64). The mean perceived *design standards available* ratings for plastic were below average for each highway group [county/local officials (3.99), the State DOT engineers (3.73) and the private consulting engineers (3.32)]. Each highway group had mean perceived *design standards available* ratings for steel, reinforced concrete and prestressed concrete significantly higher than aluminum, wood and plastic. Combined highway groups had an above average rating for *design standards available* ratings for wood (5.03) (Table 83).

Significant differences were found among the highway groups mean perceived *material available* ratings for reinforced concrete and aluminum, but not for wood. Highest mean ratings by the combined highway groups were for reinforced concrete (6.31), prestressed concrete (6.03) and steel (6.03). Each highway group had mean perceived *material available* ratings for prestressed concrete, reinforced concrete and steel significantly higher than aluminum (5.05), wood (5.26) or plastic (4.18). Combined highway groups' mean *material available* rating for wood was third lowest (Table 83).

No significant differences were found among the highway groups' mean *ease of construction* ratings for any materials. Combined highway groups had the highest mean *ease of construction* ratings for steel (5.64), prestressed concrete (5.52) and reinforced concrete (5.47). Mean ratings for these materials were significantly higher than aluminum (5.07) and plastic (4.52). Highway groups had mean perceived *ease of construction* ratings for wood (5.26) grouped with reinforced concrete. The mean perceived rating by combined highway groups for wood was significantly lower than prestressed concrete and steel, but significantly higher than plastic (Table 83).

Significant differences were indicated among the highway groups' mean perceived *designers' experience with materials* rating for reinforced concrete and aluminum, but not for wood. Combined highway groups had the highest mean perceived *designers' experience with material* rating for reinforced concrete (6.05), steel (5.82) and prestressed concrete (5.71). The mean perceived rating for wood was third lowest (4.69) by the combined highway groups. Within the State DOT engineers group, the materials with the highest mean perceived *designers' experience with materials* ratings were reinforced concrete (5.97), steel (5.82) and prestressed concrete (5.82). These mean ratings were significantly higher than aluminum (4.54), wood (4.48) and plastic (3.29). Private consulting engineers highest mean perceived *designers' experience with* *materials* were for reinforced concrete (6.28) and steel (6.03). These mean ratings were significantly higher than wood (4.58), aluminum (3.71) and plastic (2.71). County/local officials had the highest mean ratings for reinforced concrete (5.89), prestressed concrete (5.71), steel (5.56) and wood (5.19). These mean ratings were significantly higher than aluminum (4.07) and plastic (3.09). (Table 83).

Significant differences were found among the highway groups' mean perceived *construction equipment available* ratings for materials. Although differences among the groups were indicated, the univariate tests indicated differences perhaps could be present with prestressed and reinforced concrete, but no differences were found using Tukey's HSD test. Combined highway groups had the highest mean *construction equipment available* ratings for reinforced concrete (5.96), steel (5.83) and wood (5.67). The combined highway groups' mean ratings for wood not significantly different from reinforced concrete and steel. These mean ratings were significantly higher than aluminum (5.28) and plastic (4.82). State DOT engineers had the highest mean perceived *construction equipment available* ratings as a groups for reinforced concrete (5.98), steel (5.84), prestressed concrete (5.72) and wood (5.62). Their mean rating for reinforced concrete was significantly higher than aluminum (5.35) and plastic (4.90). Private consulting engineers had the highest rating for reinforced concrete (6.18), steel (5.99), wood (5.85), prestressed concrete (5.81) and aluminum (5.39) were significantly higher than plastic (4.59). No significant differences were located within the county/local officials mean construction equipment available ratings for any materials (Table 83).

Significant differences were located among highway groups weighted mean ratings for wood in the following design attributes: *design standards available*, *designer's experience with material*, and *construction equipment available*. Private consulting engineers had significantly higher weighted mean *construction equipment available* (30.99) and *design standards available* (29.65) ratings for wood than State DOT engineers' mean ratings for *construction equipment available* (28.60) and *design standards available* (26.45). County/local officials had significantly higher weighted mean perceived *designer's experience with materials* for wood (28.26) than private consulting engineers (24.55) and State DOT engineers (22.60) (Table 84).

Each highway group had weighted mean perceived ratings for wood third lowest for *design standards available.* Highway groups' weighted mean perceived rating for wood (27.93) was significantly lower than reinforced concrete (34.23), steel (33.97) and prestressed concrete (33.68).

The combined highway groups had weighted mean perceived *material available* ratings for wood (31.48) significantly lower than reinforced concrete (37.78), prestressed concrete (36.10) and steel (36.09). Highway groups weighted mean perceived *ease of construction* ratings by combined highway groups for wood (29.57) were third highest and significantly lower than ratings for prestressed concrete (31.01) and steel (31.68) (Table 84).

County/local officials had weighted mean perceived *designer's experience with materials* ratings for wood (24.60) grouped with other highest rated materials including reinforced concrete (31.74), steel (30.51) and prestressed concrete (29.92). State DOT engineers (22.60) and private consulting engineers (24.55) had weighted mean perceived ratings for wood second and third lowest in *designer's experience with material*, respectively. Also, they had weighted mean perceived *designer's experience with materials* ratings for wood significantly lower than reinforced concrete, steel, or prestressed concrete. State DOT engineers had weighted mean perceived *construction equipment available* ratings for wood (28.60) grouped with the highest rated materials, including reinforced concrete (30.44), steel (29.72) and prestressed concrete (29.12). Private consulting engineers had this same weighted mean rating group for wood a high rated material, but included aluminum in the grouping as well. No significant differences were found among county/local officials' weighted mean perceived *construction equipment available* rating for wood and other materials (Table 84).

Discussion of Design Attributes:

Design attributes for wood may lower costs and risks associated with a structure design, which makes design attributes highly important to highway decision-maker. Manufacturers need to know the decision-makers' perceptions of wood products, what can be accomplished to improve these design attributes or how can these attributes be used to improve their highway marketing strategies. Mean perceived *design standards available* ratings for wood were high for the highway groups because design standards were available to the highway groups. Wood design standards may be perceived to be less available than standards for other materials due to their possible obsolescence or designer's difficulty in understanding them. Wood had a lower rating for *material available* than concrete or steel due to the perception that it was more difficult to acquire the needed sizes of wood for highway construction. Wood had relatively high perceived *ease of construction* due to less specialized labor and construction equipment requirements. The mean *designer's experience with materials* rating for wood was low due to the lower use of wood in highway structures as stated by interview participants. Highway groups mean *construction equipment available* ratings for wood were relatively high because the equipment needed to construct with wood was relatively widespread. These design attributes of wood may could affect its use in highway structures, and therefore, wood products manufacturers may wish to take action to incorporate them in their highway market strategy in order to improve competitive market position.

Manufacturers may need to improve their marketing strategy by developing means that will change the perceptions of wood design attributes. They first may want to make sure that highway officials have the wood products available in the specifications required for highway structures. Manufacturers may need to develop/research ways to make construction with wood easier and they may want to make sure that design standards are available which meet the current highway needs. Other, less important changes in strategy suggested to the manufacturers are to develop ways to increase highway structure designer's experience with wood. This could be accomplished through seminars and education of designers on wood, but experience will increase as more wood products are used in highway structures. It is suggested that manufacturers implement the perceptions that construction equipment is available for wood products in their promotional campaigns as well. No differences were present among the different highway groups' perceptions of wood possessing any design attributes. Therefore, manufacturers may want make these same recommended adjustments to their marketing strategies if they are marketing to the State DOT engineers, the private consulting engineers, or the county/local engineers.

Perceptional Ratings of Environmental Factors:

The environmental factors tested in this study were: *chemically safe* (meaning non-toxic to the environment), *aesthetically pleasing*, *recyclable/reusable*, *percent recycled content of material*, *disposable/biodegradable* and *low environmental effects of material production*. The combined highway groups' mean environmental factor importance ratings in material choice decisions are in Table 85. The rank order of these factors as rated by the combined highway groups was: *chemically safe* (5.52), *aesthetically pleasing* (5.11), *low environmental effect of material production* (4.15), *disposable/biodegradable* (3.95), *recyclable/reusable* (3.91), and *percent recycled content of material* (3.40). Combined highway groups had mean factor importance ratings for *chemically safe* that was significantly higher than all other mean factor importance ratings. Their mean factor importance rating for *aesthetically pleasing* was significantly lower than the mean importance of *chemically safe*, but significantly higher than all other environmental factors (Table 85).

Discussion of Environmental Factors:

Although less important to highway officials than *durability*, *maintenance* and *cost*, *environmental impact* factors were still highly important to highway officials and may need to be considered in marketing strategies. To do this, wood products manufacturers require specific information about which design attributes are important to highway decision-makers. *Chemically safe* had the highest environmental factor rating for the obvious reason that materials used in the highways should be safe chemically, as well as structurally. Interview participants said that aesthetically pleasing highway structures would be more easily accepted by the public and therefore, *aesthetically pleasing* was important to the highway groups. The factors *low environmental effects of material production*, *recyclable/reusable* and *percent recycled content* received average or below average ratings because they were relatively new environmental concepts, and have not become a priority to highway decision-makers. These new concept environmental factors could become more important as more engineered wood products are used in highway structures or as more environmental regulations are adopted within the transportation markets. To compete effectively in the highway market, wood products manufacturers may wish to incorporate chemical safety and aesthetics into their marketing strategy. They may also wish to use aspects of *low environmental effects of material production*, *recyclable/reusable* and *percent recycled content* in their strategy, but not place as much importance in these factors.

Perceptional Ratings of Environmental Attributes:

Highway groups rated the following materials for possession of environmental factors as perceived attributes: reinforced concrete, prestressed concrete, steel, aluminum, wood and plastic. The hypothesis that different highway groups would have different perceptions of wood as a construction material was tested using mean environmental attribute ratings for materials. No significant differences were found among the highway groups' mean perceived ratings for any materials, including wood, for any of the environmental attributes. Therefore, the hypothesis was rejected and highway groups were assumed to have the same perceptions of wood possessing environmental attributes.

Combined highway groups had highest mean perceived ratings for prestressed concrete (5.85) and reinforced concrete (5.83) possessing the attribute *chemically safe.* These ratings were significantly higher than highway groups' *chemically safe* ratings for all other materials. Highway groups had mean perceived ratings for aluminum (5.64) were significantly higher than wood and plastic. They had mean perceived *chemically safe* ratings for steel (5.48) and wood (5.26) significantly higher than plastic (4.84). Wood had the second lowest mean chemically safe rating by the highway groups (Table 86).

Combined highway groups had the highest mean perceived ratings for prestressed concrete (5.55), followed by wood (5.50) and reinforced concrete (5.50) for the attribute *aesthetically pleasing*. The mean perceived ratings for these materials were significantly higher than highway groups mean perceived *aesthetically pleasing* ratings for aluminum (5.25) and plastic (4.63). Highway groups had mean perceived *aesthetically pleasing* ratings for steel (5.35) and aluminum significantly higher than plastic. Combined highway groups rated wood among the highest group for having the attribute *aesthetically pleasing* (Table 86).

Combined highway groups had the highest mean perceived *disposable/biodegradable* ratings for wood (5.01), which was significantly higher than mean ratings for all other materials. They had mean perceived ratings for aluminum (3.95) significantly higher than prestressed concrete (3.47) and plastic (2.88). Their mean perceived *disposable/biodegradable ratings* for steel (3.82), reinforced concrete (3.55) and prestressed concrete were significantly higher than plastic (Table 86).

Low environmental effects of material production had the highest mean perceived ratings by the highway groups for prestressed concrete (4.73) and reinforced concrete (4.72). These materials had mean perceived *low environmental effects of material production* significantly higher than steel (4.09), aluminum (4.04) and plastic (3.57). Highway groups had mean perceived ratings for wood (4.47) grouped with steel, and aluminum. These mean ratings were significantly higher than mean ratings for plastic (3.57) (Table 86).

Combined highway groups had the highest mean perceived *recyclable/reusable* ratings for aluminum (5.07) and steel (4.91). These mean perceived ratings were significantly higher than mean perceived *recyclable/reusable* ratings for plastic (4.12), reinforced concrete (3.73), prestressed concrete (3.47) and wood (3.30). Combined highway groups had mean perceived *recyclable/reusable* ratings for plastic significantly higher than wood. Combined highway groups had the lowest mean perceived *recyclable/reusable* rating for wood (Table 86).

The highest highway groups mean perceived ratings were for aluminum (4.50), steel (4.27) and plastic (4.21). These mean perceived ratings were significantly higher than those for reinforced concrete (3.24), prestressed concrete (3.04) and wood (2.74). Combined highway groups had mean perceived *percent recycled content of material* ratings for reinforced concrete significantly higher than wood. Highway groups had the lowest mean perceived *percent recycled content of material* ratings for wood (Table 86).

No significant differences were found among the highway groups weighted mean perceived *chemically safe*, *aesthetically pleasing* and *low environmental effects of material production* ratings for wood. Combined highway groups had weighted mean *chemically safe* ratings for wood (29.07) significantly lower than prestressed concrete (32.35), reinforced concrete (32.19) and aluminum (31.19). Their weighted mean perceived *aesthetically pleasing* rating for wood (28.14) was not significantly different from the other highest weighted mean rated materials, including prestressed concrete (28.39) and reinforced concrete (28.11). Also, combined highway groups weighted mean perceived *low environmental effects of material production* ratings for wood (18.58) was not significantly different from the highest mean rated materials, including prestressed concrete (19.67) and reinforced concrete (19.61). Significant differences were found among highway groups weighted mean ratings for wood possessing the following attributes: *disposable/biodegradable*, *recyclable/reusable* and *percent recycled content of material*. State DOT engineers had significantly higher weighted mean perceived *disposable/biodegradable* ratings for wood (20.86) than private consultants (18.15). County/local officials had significantly higher weighted mean perceived *recyclable/reusable* ratings for wood (15.81) than State DOT engineers (12.72) and private consulting engineers (11.26). Although differences were indicated among highway groups' weighted mean perceived *percent recycled content of material* ratings for wood, no differences were found in the weighted mean ratings using Tukey's HSD (Table 87).

Discussion of Environmental Attributes:

Environmental effects of materials play an important part in highway officials materials choice decisions, although they are less important than *durability*, *maintenance* and *cost*. Therefore, manufacturers may want to consider improving their marketing strategies to include environmental aspects of wood. To do this, manufacturers need to know the highway decision-makers' perceptions of wood products possessing environmental attributes. Highway groups had the second to lowest mean perceived *chemically safe* ratings for wood due to wood preservative chemicals. Interview participants perceived oil-borne chemicals to be especially harmful to the environment and to people. Officials perceived wood to be highly *aesthetically pleasing* because wood has aesthetic appeal to the public and fits natural settings. Highway groups perceived wood to be the most *disposable/biodegradable* material because it biodegrades more easily than other construction materials. There was some contradiction with this finding as several interview participants said that disposal of treated wood was becoming difficult as new regulations have prevented treated wood from being sent to landfills. Highway groups' mean ratings for *low environmental effects of material production* may be rated with steel and aluminum because of the environmental problems that have been caused with poor timber harvesting practices. Environmental effects of producing wood products with poor harvesting practices have been highly publicized, which lowered the highway decision-makers perceptions. There have been few promotional campaigns to recycle solid wood products, so highway decision-makers' perceptions of solid wood's recyclability, especially treated wood, was low. Wood products had the lowest *percent recycled content of material* ratings for the obvious reason that solid wood products were natural products not containing recycled materials.

Manufacturers may wish to consider changing their highway market strategy to account for the highway decision-makers' perception of wood possessing design attributes. Manufacturers may want to focus their efforts to improve wood products' chemical safety. This could be accomplished by development and use of more environmentally friendly, but still effective, chemical wood preservatives. Manufacturers may wish to use highway officials perceptions that wood is aesthetically pleasing in promotional campaigns. Although less important than chemical safety and aesthetics, manufacturers may consider implementing recycling programs for solid wood products. Promotional/educational programs on the best management practices may be used by manufacturers to improve perceptions of environmental effects of wood production.

Manufacturers may want to develop engineered wood products that contain recycled material or develop programs that allow the reuse/resale of used wood products. No differences were located among highway groups perceptions of wood possessing environmental attributes. Therefore, manufacturers may want to assume that highway decision makers do not differ on their environmental perceptions of wood and similarly adjust their marketing strategy if they are marketing to State DOT engineers, private consulting engineers or county/local officials.

Perceptional Ratings of Maintenance Factors:

Maintenance factors examined in this study were: *standard structure designs available*, *field modification easy*, *ease of repair*, *experience in maintenance with material* and *inspection easy*. Significant differences were present among highway groups' mean factor importance ratings for *ease of repair* and *experience in maintenance with materials*. County/local officials had significantly higher mean importance ratings for *ease of repair* (5.80) than private consulting engineers (5.42). State DOT engineers had significantly higher mean importance ratings for *experience in maintenance with materials* (5.52) than private consulting engineers (5.15) (Table 88).

No significant differences were found among the highway groups' mean importance ratings for *standard structure designs available* (5.25), *field modification easy* (5.31) and *inspection easy* (5.07). Combined highway groups had the highest mean factor importance ratings for *ease of repair* (5.61) and *experience in maintenance with materials* (5.40). Their mean importance ratings for *ease of repair* were significantly higher than mean ratings for *field modification easy*, *standard structure designs available* and *inspection easy*. State DOT had the highest mean importance ratings for *ease of repair* (5.65) and *experience in maintenance with materials* (5.52). Their mean importance rating for *ease of repair* was significantly higher than *standard structures designs available* (5.33), *field modification easy* (5.31) and *inspection easy* (5.10). State DOT engineers' mean importance rating for *experience in maintenance with materials* was significantly higher than *inspection easy*. No differences were located in private consulting engineers mean importance ratings for any maintenance factors. County/local officials had the highest mean importance ratings for *ease of repair* (5.80), *experience in maintenance with* *material* (5.52) and *field modification easy* (5.44). Their mean importance rating for *ease of repair* was significantly higher than *standard structure designs available* (5.33) and *inspection easy* (4.90) (Table 88).

Discussion of Maintenance Factors:

Maintenance is one of the most important factors to highway decision-makers in a material choice decision. Manufacturers of wood products will need to know what aspects of maintenance is most important to highway officials in order to compete effectively in this market. Highway officials had the highest importance for e*ase of repair* because the majority of their maintenance is not used to prevent structural damage, but to repair or replace damaged structures. They had high importance for *experience in maintenance with materials* due to the cost and time savings in maintenance provided by experience. Highway structural materials that are *easier to modify or inspect* hopefully will lower maintenance costs, and therefore each highway group had high importance ratings for these factors. *Standard structures designs in maintenance* would help in quick structure repairs, lower the cost of repairing a structure (the decision maker does not have to reinvent the structure design) and lower a decision-maker's liability with that structure. Although some maintenance factors were more important than others, each of these maintenance factors were above average in importance to highway officials and should be considered in development of marketing strategies.

In order to fine tune marketing strategies, manufacturers should know if different highway groups had different importance for maintenance factors. Significant differences were found among the highway groups' mean factor ratings for *ease of repair* and *experience in maintenance with materials*. Private consulting engineers work little in maintenance of highway structures. Therefore, their importance ratings for maintenance of highway structures were less than State DOT engineers and county/local officials. This caused State DOT engineers and county/local officials to have higher importance for *ease of repair* than private consulting engineers. Also, this could cause State DOT engineers to have significantly higher mean *experience in maintenance with materials* than private consulting engineers. This indicates that manufacturers should emphasize *ease of repair* and *experience in maintenance with materials* in their highway marketing strategies especially when working with State DOT engineers and county/local officials.

Perceptional Ratings of Maintenance Attributes:

Highway groups rated the following materials for possession of maintenance factors as perceived attributes: reinforced concrete, prestressed concrete, steel, aluminum, wood and plastic. The hypothesis that different highway groups would have different perceptions of wood as a construction material would be tested using mean maintenance attribute ratings for materials. Significant differences were present among highway groups' mean perceived ratings for wood possessing *field modification easy*, *ease of repair*, and *experience in maintenance with material*, and we failed to reject the hypothesis. This indicates that there were differences among the highway groups' perceptions of wood as a construction material.

Significant differences were indicated to be present among the highway groups' mean *standard structure designs available* for materials, but no significant differences were located for wood using univariate p-values. The mean ratings for prestressed concrete (5.34), reinforced concrete (5.56) and steel (5.42) were significantly higher than mean ratings for wood (4.61), aluminum (4.60) and plastic (3.61). Combined highway groups had the third lowest mean standard structure designs available ratings for wood (Table 89).

Significant differences were found to be present among highway groups mean perceived *field modification easy* ratings of materials. State DOT engineers had mean perceived *field modification easy* ratings for wood (5.02), steel (4.71) and reinforced concrete (4.70) significantly higher than aluminum (4.16), prestressed concrete (3.75) and plastic (3.60). Private consulting engineers had mean perceived *field modification easy* ratings for wood (5.13) and steel (4.89) that were significantly higher than aluminum (4.32), plastic (3.70) and prestressed concrete (3.29). County/local officials had mean perceived *field modification easy* rating for wood (5.48) significantly higher than all other materials tested. County/local officials had significantly higher mean perceived *field modification easy* ratings for wood than did State DOT engineers. Although there were differences among the highway groups' mean perceived *field modification easy* rating for wood, the combined highway groups consistently had wood rated highest of all materials. Combined highway groups had mean perceived *field modification easy* rating for prestressed concrete significantly lower than any material tested (Table 89).

Significant differences were found among highway groups' mean perceived *ease of repair* ratings for materials. Combined highway groups had mean ratings for wood (5.04) significantly higher than all materials except steel (4.91). They had mean ratings for steel significantly higher than aluminum (4.18), prestressed concrete (3.82) and plastic (3.59), but not reinforced concrete. State DOT engineers had mean perceived *ease of repair* ratings for wood (4.91), steel (4.90) and reinforced concrete (4.81) significantly higher than aluminum (4.17), prestressed concrete (3.94) and plastic (3.52). Private consulting engineers had mean perceived *ease of repair* ratings for steel (4.93) and wood (4.90), significantly higher than all other materials. County/local officials had mean perceived *ease of repair* ratings for wood (5.46) significantly higher than all other materials. County/local officials had significantly higher mean perceived *ease of repair* ratings for wood than did State DOT engineers and private consulting engineers (Table 89).

Significant differences were located among the highway groups mean perceived *experience in maintenance* with material ratings. Combined highway groups had the highest mean perceived *experience in maintenance with material* ratings for reinforced concrete (5.37) and steel (5.31). They had mean ratings for reinforced concrete significantly higher than all materials except steel. They had mean ratings for steel significantly higher than wood (4.78), aluminum (3.96) and plastic (2.93). State DOT engineers (5.48) and private consulting engineers (5.11) had significantly higher mean ratings for steel. Also, State DOT engineers (5.44) and private consulting engineers (5.12) had significantly higher mean ratings for reinforced concrete than for all other materials except steel. County/local engineers mean ratings for *experience in maintenance with material* were significantly higher for reinforced concrete (5.50), steel (5.36), wood (5.19) and prestressed concrete (5.04) than aluminum (4.00) and plastic (3.13). County/local officials had significantly higher mean *experience in maintenance* ratings for wood than private consulting engineers (4.40). Highway groups' mean rating for *experience in maintenance* with materials for wood was consistently in the middle, not as high as reinforced concrete but usually significantly higher than aluminum and plastic (Table 89).

No significant differences were located among highway groups mean perceived ratings for *inspection easy* with any material tested. Combined highway groups had the highest mean perceived *inspection easy* ratings for steel (5.23) and reinforced concrete (5.19). These mean ratings were significantly higher than means for all other materials. Wood's mean rating (4.72) by the highway groups was significantly higher than plastic (4.17), and was significantly lower than steel, reinforced concrete, prestressed concrete (4.83) and aluminum (4.82). Combined highway groups lowest mean perceived *inspection easy* rating was for plastic, which was significantly lower than the means for all other materials (Table 89).

No significant differences were found among highway groups' weighted mean ratings for wood for the attributes *field modification easy* and *inspection easy*. Combined highway groups had highest weighted mean perceived *field modification easy* rating for wood (27.44), which was significantly higher than weighted mean ratings for all other materials. They had weighted mean perceived *inspection easy* ratings for wood (23.96) significantly lower than steel (26.54), reinforced concrete (26.37), prestressed concrete (24.51) and aluminum (24.46), but significantly higher than plastic (21.17) (Table 90).

Significant differences were found among highway groups' weighted mean perceived ratings for wood with the following attributes: *standard structure designs available*, *ease of repair* and *experience in maintenance with materials*. County/local officials had significantly higher weighted mean perceived *standard structure designs available* rating for wood (25.77) than private consulting engineers (22.67). Although differences were found among the highway groups, each highway group had weighted mean perceived ratings for wood that were not significantly different from the lowest rated materials, including aluminum and steel. Each highway group had weighted mean perceived *standard structure designs available* ratings for wood that were significantly higher than plastic. County/local officials' weighted mean perceived *ease of repair* rating for wood (31.67) significantly higher than State DOT (27.74) and private consulting engineers (26.60). Each highway group's weighted mean perceived *ease of repair* ratings for wood was not significantly different from the other highest rated material, steel. Private consultants' weighted mean perceived *experience in maintenance with material* rating for wood (22.65) was significantly lower than State DOT engineers (26.63) and county/local officials (28.65). County/local officials' weighted mean perceived *experience in maintenance with material* rating for wood was not significantly different from the highest rated materials, including: reinforced concrete (30.35), steel (29.57) and prestressed concrete (27.80). State DOT and private consulting engineers' weighted mean perceived *experience in maintenance with material* ratings for wood were significantly lower than the highest rated materials, reinforced concrete and steel. Also, their weighted mean ratings for wood were significantly higher than aluminum and plastic (Table 90).

Discussion of Maintenance Attributes:

Maintenance attributes of structural materials were highly important to highway officials. Therefore, manufacturers will need to know what the perceptions of wood products are in order to change market strategies and improve their competitive position. Manufacturers should make improvements to their marketing strategies by looking at the most important factors: *ease of repair, experience in maintenance with materials* and *field modification easy*. Wood was perceived to be the most *easy material to repair and modify* because highway officials have the equipment and knowledge available to repair wood products. Highway officials perceived maintenance personnel to have less experience with maintenance of wood since it is being used less than alternative materials in highway structures. Highway groups may have rated wood low for *standard structure designs in maintenance available* for the same reasons wood had low design standards available. As stated by the interview participants, the standards for maintenance of wood highway structures were not available and those that were available were obsolete. Highway groups had the same mean perceived *inspection easy* ratings for wood because they each have similar experience in inspecting wood products. Difficulties in proper inspection of wood structures caused highway groups mean ratings for *inspection easy* wood structures to be low. This indicates that manufacturers may wish to improve marketing of wood products by utilizing the highway officials' perceptions that wood was easy to repair and easy to modify in the field. They may want to develop current maintenance standards for wood and make sure that standards are available to the highway market. Also, manufacturers may need to develop inspection methods or improve highway maintenance personnel education in wood structure inspection. Finally, manufacturers may wish to educate highway maintenance personnel in the proper maintenance of wood structures which will increase their experience in maintenance with wood.

Manufacturers may be marketing wood products primarily to one highway group or marketing to more than one highway group. Therefore, manufacturers need to know if specific groups had differences in their perceptions of wood's maintenance attributes. County/local officials perceived wood to be more *easy to modify in the field and repair* than did State DOT engineers and private consulting engineers. County/local officials had significantly higher mean *experience in maintenance* ratings for wood than private consulting engineers. This indicates than manufacturers need to improve education on proper maintenance of wood structures especially with the State DOT and private consulting engineers.

Perceptional Ratings of Innovation Factors:

Innovation factors examined in this study related directly to the overall factor groupings and included: *innovative in performance*, *innovative in design*, *innovative in maintenance*, *innovative in durability* and *innovative in the environment*. Significant differences were found among the highway groups for each mean innovative factor importance ratings. County/local officials and State DOT engineers had significantly higher mean importance ratings than private consulting engineers for the following factors: *innovative in performance*, i*nnovative in design*, *innovative in maintenance*, and *innovative in durability*. County/local officials had significantly higher mean factor importance ratings for *innovative in the environment* (4.64) than private consulting engineers (4.00) (Table 91).

Combined highway groups had the highest mean factor importance ratings for *innovative in durability* (5.07), *innovative in performance* (4.81), and *innovative in maintenance* (4.80). These importance ratings were significantly higher than *innovative in the environment* (4.32) and *innovative in design* (4.28). State DOT engineers had the highest mean factor importance ratings for *innovative in durability* (5.21), *innovative in performance* (4.91) and *innovative in maintenance* (4.88). Their mean importance ratings for *innovative in durability* and *innovative in performance* were significantly higher than ratings for *innovative in the environment* (4.40) and *innovative in design* (4.30). Although the ANOVA p-value indicates that private consulting engineers had significant differences among their mean importance ratings for innovation factors, no differences were located with Tukey's HSD. County/local officials had highest mean factor importance ratings for *innovative in durability* (5.43), *innovative in maintenance* (5.26) and *innovative in performance* (5.06). Their mean ratings for *innovative in durability* and *innovative in maintenance* were significantly higher than *innovative in the environment* (4.64) and *innovative in design* (4.54) (Table 91).

Discussion of Innovation Factors:

Innovation factors were least important overall to the highway groups. Manufacturers may want to consider changing their highway market strategy to include innovation factors, but they should place less importance in this than other material choice factors. Innovative products, as stated by the interview participants, increase risks with the structures. Highway officials innovative factor importance ratings reflected their importance for other factor groups. As with *durability* and *maintenance* factors, *innovative in durability* and *innovative in maintenance* received highest importance ratings. *Durability* and *maintenance* were very important to the highway groups, so new ideas or products that improve in these areas could be desirable to the highway marketing strategies. *Innovative in design* and *the environment* were the least important factors and manufacturers should emphasize them less frequently to compete effectively in the highway market.

Different highway groups had different importance for innovation factors, and this may need to be accounted for if a manufacturer is marketing wood products to more than one group. It appeared that county/local officials had the highest perceptions of innovations among the four groups. This could be because they were dealing with lower traffic counts and lower truck loads than State DOT engineers or private consulting engineers. Because of the lower traffic counts and lower truck weights, lower risks were involved on secondary roads. County/local officials may be more willing to use innovations and have a higher importance for innovation factors than State DOT engineers and private consulting engineers. Therefore, manufacturers may wish to use innovations in their marketing strategies primarily when marketing to county/local officials.

Perceptional Ratings of Innovation Attributes:

Highway groups rated the following materials for possession of innovation factors as perceived attributes: reinforced concrete, prestressed concrete, steel, aluminum, wood and plastic. The hypothesis that different highway groups would have different perceptions of wood as a construction material were tested using mean innovation attribute ratings for materials. Based on the *innovative in performance*, *innovative in design*, *innovative in maintenance* and *innovative in the environment* ratings for wood, we failed to reject the hypothesis. It could be concluded than different highway groups would have different perceptions of wood being an innovative material.

Significant differences were found among the highway groups' mean i*nnovative in performance* ratings. County/local officials and State DOT engineers had significantly higher mean perceived *innovative in performance* ratings for reinforced concrete, prestressed concrete, steel, and wood than private consulting engineers (Table 92). State DOT officials had the highest mean perceived *innovative in performance* ratings for plastic (4.99), which was significantly higher than other material ratings except prestressed concrete (4.66). Private consulting engineers' mean perceived *innovative in performance* rating for plastic (4.73) was significantly higher than all other material ratings. No significant differences were found within county/local officials group for mean perceived *innovative of performance* ratings for materials, including wood. The mean perceived *innovative in performance* rating for wood was the lowest for State DOT engineers (4.31) and second lowest for private consulting engineers (3.82) (Table 92).

Significant differences were found among the highway groups mean perceived i*nnovative in design* ratings. County/local officials and State DOT engineers had significantly higher mean perceived *innovative in design* ratings for reinforced concrete, prestressed concrete, steel, and wood than private consulting engineers (Table 92). State DOT engineers had mean perceived innovative in design ratings for plastic (4.95) that were significantly higher than reinforced concrete (4.47) and wood (4.41). Private consulting engineers had significantly higher mean perceived innovative in design ratings for plastic (4.73) than steel (4.13), wood (4.00) and reinforced concrete (3.94). County/local officials had no significant differences in mean perceived *innovative in design* ratings among any materials. The mean perceived *innovative in design* rating for wood was the lowest for State DOT engineers and second lowest mean rating for private consulting engineers (Table 92).

Significant differences were found among highway groups' mean perceived *innovative in maintenance* ratings for materials. County/local officials had significantly higher mean ratings for wood (4.40) than private consulting engineers (3.79). Within the State DOT engineers group, the mean perceived *innovative in maintenance* ratings for plastic (4.57) were significantly higher than wood (4.07). Private highway consultants had a significantly higher mean perceived rating for plastic (4.42) than steel (3.90), prestressed concrete (3.81), wood, and reinforced concrete (3.78). No significant differences were present within the county/local officials group for mean perceived *innovative in maintenance* ratings for materials. Wood had the lowest mean *innovative in maintenance* rating by the State DOT engineers and second lowest mean perceived rating by private consulting engineers (Table 92).

Significant differences were located among the highway groups mean perceived *innovative in durability* ratings for materials, but no differences among the groups were found for wood. State DOT engineers (4.88) and private consulting engineers (5.56) had highest mean perceived *innovative in durability* ratings for prestressed concrete. State DOT engineers (4.84) and private consulting engineers (5.00) had high mean perceived *innovative in durability* ratings for reinforced concrete. Their mean ratings for prestressed concrete and reinforced concrete were not significantly different, and these mean perceived ratings were significantly higher than ratings for all other materials. County/local officials had the highest mean perceived *innovative in durability* rating for plastic (4.72), which was significantly higher than all other mean ratings for materials. Wood had the lowest mean perceived *innovative in durability* rating for each highway group [for State DOT engineers (4.15), private consulting engineers (3.92) and county/local officials (4.20)] (Table 92).

Significant differences were found among the highway groups mean perceived *innovative in the environment* ratings for materials. County/local officials (4.58) and State DOT engineers (4.25) had significantly higher mean perceived ratings for wood than private consulting engineers (3.66).   No significant differences were located within the State DOT engineers', private consulting engineers' and county/local officials' mean perceived *innovative in the environment* ratings for materials. Wood had the third highest *innovative in the environment* rating by the combined highway engineers (4.13) (Table 92).

Significant differences were found among the highway groups' weighted mean perceived innovative attribute ratings for wood. County/local officials had significantly higher weighted mean perceived *innovative in performance* ratings for wood (23.03) than State DOT engineers (21.14) and private consulting engineers (17.22). State DOT engineers had significantly higher weighted mean perceived *innovative in performance* ratings for wood than private consulting engineers. County/local officials (20.71) and State DOT engineers (18.98) had significantly higher weighted mean perceived *innovative in design* rating for wood than private consulting engineers (16.28). County/local officials had significantly higher weighted mean perceived *innovative in maintenance* ratings for wood (23.12) than State DOT engineers (19.87) and private consulting engineers (16.59). State DOT engineers had significantly higher weighted mean perceived *innovative in maintenance* ratings for wood than private consulting engineers. County/local officials (22.81) and State DOT engineers (21.65) had significantly higher weighted mean perceived *innovative in durability* ratings for than private consulting engineers (18.12). County/local officials (21.27) and State DOT engineers (18.71) had significantly higher weighted mean perceived *innovative in the environment* ratings for wood than private consulting engineers (14.63) (Table 93).

Within the State DOT engineers group, wood had the lowest weighted mean perceived ratings for the attributes *innovative in performance* (21.14), *innovative in design* (18.98), *innovative in maintenance* (19.85), and *innovative in durability* (21.65). These weighted mean ratings for wood were significantly lower than the highest rated materials, which were plastic, prestressed concrete and reinforced concrete. No significant differences were found between State DOT engineers' weighted mean perceived ratings for wood and any other materials for the attribute *innovative in the environment* (Table 93).

Private consulting engineers had weighted mean perceived ratings for wood not significantly different from other lowest rated materials for the following attributes: *innovative in performance*, *innovative in design*, *innovative in maintenance* and *innovative in durability*. Their weighted mean rating for wood was significantly lower than the highest rated material, plastic, for all these attributes.

No significant differences were located between private consulting engineers' weighted mean perceived *innovative in the environment* ratings for wood and any other materials. County/local officials had the lowest weighted mean perceived *innovative in durability* ratings for wood (22.81). This weighted mean rating was significantly lower than the highest materials tested, reinforced concrete (27.46) and prestressed concrete (27.15). No significant differences were found among county/local officials' weighted mean perceived ratings for wood and other materials for the attributes *innovative in performance*, *innovative in design*, *innovative in maintenance* and *innovative in the environment*.

Discussion of Innovation Attributes:

It was determined that innovation factors were least important to the highway officials in their material choice decision. This indicates that it is least important for manufacturers to include changes in their marketing plans to make wood appear to be more innovative. If the manufacturers want to include innovation of wood in their marketing strategies, they will need to know what the highway groups' perceptions of wood products are in terms of innovation. The highway groups each had the lowest perceptions of wood possessing all innovative attributes, which indicated that they did not perceive wood to be an innovation. It is suggested that manufacturers improve the innovativeness of wood in durability, maintenance and performance to compete more effectively in the highway market.

In order to compete in more than one area of the highway market, manufacturers need to know if perceptions of wood possessing innovation factors differs among the groups. The county/local officials and State DOT engineers perceived wood to be more *innovative in performance, design maintenance, and the environment* than did private consulting engineers. This suggests that county/local officials and State DOT engineers consider wood more of a change or improvement in these areas than private consulting engineers. It is suggested that manufacturers consider ways to improve the perception of wood's innovativeness when marketing to the private consulting engineers.

Case Study Interviews:

Interviews were conducted in four states, including Georgia, Indiana, Maine and Montana. The interview participants included State DOT engineers, county highway officials and private consulting engineers. In Georgia and Maine, there were no county highway engineers or superintendents. Six State DOT engineers and six private consulting engineers were interviewed in Georgia. Eight State DOT engineers and four private consulting engineers were interviewed in Maine. Six State DOT engineers, nine private consulting engineers and four county highway engineers/superintendents were interviewed in Indiana. Montana's interviews included four State DOT engineers, five private consulting engineers and five county highway officials. The results from these interviews were composed and presented as case studies for each state.

Case Study 1: Georgia

Highway structures designed, constructed and maintained by Georgia interview participants include: highway bridges, box culverts, retaining walls, sound barriers, miscellaneous drainage structures, sign systems, and light systems. Georgia has guidelines for the use of wood products in these highway structures, but primarily the participants said they use regulations set by the Association of American State Highway Transportation Officials (AASHTO).

In the past three years, Georgia interview participants have used wood in the following highway structures: guardrail posts, piling, sign posts, formwork/falsework, box culverts, bulkheads, secondary road bridges and structures built with combinations of materials (for instance, bridges with wood decks on steel sub/superstructures). Some participants stated that little or no wood was currently being used within highway systems except in formwork/falsework and structures such as temporary bridges or shoring. Others said wood had the highest current use in piling, retaining walls, noise barriers and county bridges.

Some interview participants said wood had no future use in Georgia highway structures. Reasons they gave for wood having little future were lack of strength, increasing cost, and corrosion of metal parts when in contact with treated wood. Other participants said wood has potential use in short-span bridges in rural settings. Also, wood has potential use in low technology structures such as retaining walls, timber piles, sound walls, retaining walls, and sign posts. Other participants said wood use would be controlled by maintenance, historical or aesthetic needs. They would utilize concrete most in highway construction over the next three years because it was easy to construct and had good service life. Private consulting engineers participating in the study stated that their material use was dictated by the client, usually the Georgia DOT. Therefore, the private consulting engineers would use wood when the State DOT wanted a wood structure.

Problems with durability of wood in Georgia highway structures were discussed in the interviews. Participants said they have seen wood decay long before the expected life of the structure had passed. Highway structures were in high moisture areas or in intermittent contact with water. Therefore, decay causing bacteria or fungus have grown in the wood highway structures and shortened their life-spans. Also, participants had wood highway structures deteriorate early because of wood borers and insects. Durability problems with wood bridge decks in Georgia were caused by weathering. Finally, participants said that fast grown wood may cause durability problems. The fast grown wood was said to rot more quickly and was not as hard or strong as slow grown wood. The only durability benefit of wood stated by the participants was that wood did not corrode like steel. Therefore, maintenance costs were reduced because painting was not needed with wood highway construction products to protect it from corrosion. Some participants felt wood was applicable for temporary structures since it was not considered durable. Participants in Georgia stated that it was easier to reuse wood than other construction materials.

Georgia interview participants were asked if they had maintenance benefits or problems with wood in highway construction. The participants said wood was less expensive to replace in highway construction. Both material cost and labor costs were lower for wood than concrete. This made maintenance and construction costs lower for wood than for concrete. Participants said wood was easy to modify in the field and the replacement of wood parts with current construction equipment was less work than other materials.

Problems were cited by the interview participants in Georgia with using wood for infrastructure applications. The cost per unit strength for wood was high. Wood was considered expensive when compared to concrete or steel of the same size and strength, especially in the larger sizes. Participants said that corrosion problems occurred between treated wood and steel connectors. They experienced problems with wood connections when wood shrinks and swells with changes in moisture. Problems occurred in transferring loads to connectors because of the natural structure of wood. Participants said there was a tendency for wood to split and pull out at connections when under extreme loads. Other connection problems with wood concerned construction of combination wood and other material structures. When constructing with a combination of wood and other materials, the fittings between the wood products and alternate materials (such as concrete) did not match. These fitting problems could be caused by wood warpage due to its shrinking and swelling. The warpage would cause field adjustments to be made, increasing construction costs. Next, participants stated that there may be strength problems with wood products used in highway applications. New timber was grown at a faster rate with less dense, wider growth rings than old timber (pre-1950). This caused today's wood harvested to be weaker in bending strength than that harvested before 1950. Load capacity of wood was said to be smaller than steel or concrete. Wood constructed bridges were often restricted to shorter spans because of strength problems. Often, participants stated that wood structures had to be over-designed to attain the needed strength and safety factors. This makes the structures bulky and increases the cost of wood in highway construction. Large wood materials required participants to use heavy equipment and expensive labor which increased construction costs even more. Participants said there had been problems with chemical wood preservatives. Wood preservatives were expensive and not environmentally friendly. The participants often saw problems with chemical wood treatments leaching from the structures. Participants said there were wood material availability problems in Georgia, especially with large wood products such as wood piles. Therefore, concrete and steel was used in construction of highway structures, which could have been constructed of wood.

Georgia interview participants described benefits of wood products in the highway system. Wood was often more economical or cheaper than other materials. Initial costs for timber and the cost for equipment needed to construct with timber were usually less expensive than for concrete. Wood was aesthetically pleasing and in smaller sizes was readily available in Georgia. Depending on the labor source, they said construction with wood could be beneficial. Carpenters may be available, while stone masons or more highly trained people may not be available. Therefore, construction labor costs could be lower with wood products in highway structures relative to construction with other materials. Participants said wood structures could be constructed more rapidly than alternate materials such as concrete. This was important in many temporary structures such as bridge detours, but the overall importance of rapid construction to the participants was small. Georgia participants frequently stated that wood was best when used in temporary structures because it was lighter, often cheaper, easier to remove and easier to reuse than many other materials.

Participants were asked what needs to occur to increase wood product use in highway construction. There was a need for the cost of large wood products to be decreased. Participants said that durability of wood used in highway construction needs to be improved. Participants stated that perhaps these durability improvements could be made through improvement of wood treatment chemicals. The wood products industry needs to increase Georgia highway decision-makers confidence level for predictability of wood deterioration. There is a need for established designs and a textbook of wood design in highway applications. Design procedures and values for wood needed to be simplified. Current National Forest Products Association (NFPA) designs are too complicated and the NFPA design values needed to be updated. Also, participants stated that valid, objective information about correct applications for wood should be available to highway decision-makers. Participants in Georgia felt that for wood to become more widely used in highway structures, the wood products industry needed to direct more promotional efforts at the DOT and other highway decision-makers. Wood products manufacturers could improve their promotions in two main areas: wood products industry should push wood use wood in aesthetic settings and for more temporary use (in formwork, falsework and temporary bridges) where long term durability was not an issue.

Case Study 2: Indiana

The highway structures that Indiana interview participants have designed, constructed and maintained included: bridges, deflective structures under bridges, sound barriers, culverts, guardrails, median barriers, retaining walls, and sign systems. Indiana does not have guidelines at the state or county level for wood use in permanent structures, however, there are design standards for wood products in temporary highway structures.

In the past three years, Indiana interview participants have used wood in the following structures types: decorative railings and wood decks for pedestrian/bicycle trail bridges, lower volume, county road bridges, and temporary work such as formwork/falsework or shoring vehicle bridges and retaining walls. Participants said wood has potential in the following highway applications: bridges, guardrail and sign posts, temporary use such as falsework or formwork, and aesthetic or parks/recreation areas. In the next three years, some Indiana interview participants said they have plans to use wood products in pedestrian and highway bridges.

Problems with wood durability in Indiana highway structures were discussed in the interviews. Participants often saw premature decay and weathering of wood in highway structures. One example of early decay was caused by shrinking and swelling of wood decks with variations in moisture content. Shrinking and swelling caused cracks to form in bridge asphalt wearing surfaces, which shortened the wearing surface life and may have shortened the life of the bridges. Participants said the life expectancy for wood in highway structures was only 20 years, while concrete had a 50 year life. No durability benefits were cited with wood products in highway construction in Indiana.

Participants were asked if they had maintenance benefits or problems with wood in highway structures. Maintenance of wood structures was considered easier because it was easier to replace wood pieces on a highway structure as long as they were not a major structural component. For instance, replacing a wood bridge rail would be easier than replacing a concrete bridge rail. The participants said no special equipment, less technology and less specialized labor was needed to construct highway structures with wood than with other materials.

Indiana participants said there were maintenance problems with wood in highway structures. The main maintenance problem with wood in highway structures was caused by connections loosening when wood shrank with moisture loss. Participants said vehicle damage was more difficult to repair in place with wood structures in highway applications. Often the whole piece of damaged wood must be replaced which could be difficult if the wood piece was a major structural component. The high maintenance frequency with wood highway structures was considered a problem. For example, the participants said one has to replace bridge decks often because of problems caused by higher volume traffic and decay. Also, the participants said more maintenance was caused by the shorter spans that wood bridges can cross. Only shorter spans could be used because with wooden bridges wood beams deflected too much under loads. This greater deflection of wood beams caused more piles to be placed in the stream. The greater number of piles could cause a large amount of stream debris to catch under the bridge, which could be a hazard to the structure by weakening the piles or by becoming a fire hazard. Finally, participants felt that wood structures may require periodic in-place chemical treatment. Treatments would increase maintenance costs for Indiana highway decision-makers using wood in structures.

Indiana interview participants identified several problem areas with wood in highways. There were not enough suppliers of wood products for highway use in Indiana. In fact, there was only one supplier of bridge materials in the Indiana area. This allowed this single manufacturer to set the price for timber bridges. Next, safety using wood products was an issue with participants. The participants said there was a lack of crash test information about economical sizes of wood constructed guardrails. Economical sizes means wood guardrails can be constructed in sizes that would withstand vehicle crashes, but the large wood products required may be too expensive to be implemented. An affordable size timber guardrail needed to be crash tested. Some participants had fire damage with wood highway structures. A large problem with wood products was consistent quality of material. Wood products often bend, crack and warp. Also, wood was not homogeneous in its structure. The lack of consistent quality with wood made some highway decision-makers unsure of its strengths, its weathering resistance and what connection problems may occur with wood highway structures. Also, there was concern that wood bridges could not handle loads very long and experience fatigue over time. For example, participants said the wood decks could flex too much causing cracks to occur.

Indiana interview participants experienced benefits using wood products in highways. First, wood was considered aesthetically pleasing. Wood was said to be corrosion resistant and unaffected by deicing salts. Participants stated that unskilled labor could often assemble wood structures with proper supervision. Wood products allowed for quick erection of some highway structures while concrete structures had a lengthy forming time. Also, wood could be used in construction at any time of the year unlike concrete as there were no temperature constraints with wood products in highway construction. Finally, the participants said wood was perceived to be cheaper than other materials in some highway construction. It was not cheaper in large timber needs such as bridge pilings, but wood could be cheaper in some construction such as signs and retaining walls.

Participants were asked what needed to occur to increase the use of wood in highway construction. Participants said highway decision-makers needed better education on uses of wood in highway structures. Wood products manufacturers need to increase promotion of wood products use in highways as well as educating the highway decision-makers. Participants said they needed more suppliers of wood products for highway use. The price of large wood products needed to be reduced so that wood can be competitive with concrete. Finally, the durability of wood in highway applications needed to be proven. This would allow the Indiana DOT and local government agencies see that wood could perform as well as concrete or steel in highway applications.

Case Study 3: Maine

The types of highway structures designed, constructed or maintained by the Maine interview participants included: bridges (highway and pedestrian), retaining walls, box culverts, and sign/light supports. Maine does have guidelines for the use of wood products in highway structures. The participants stated they have used wood products in design, construction and/or maintenance of the following highway structures in the past three years: formwork/falsework (one participant claimed this was 90% of everyday wood use), temporary wood bridges and permanent bridges (wood was mainly used in the superstructure of permanent bridges). The highest current use of wood in highway applications was: formwork/ falsework, temporary bridges, secondary road bridges, guard rail posts, retaining walls, and sign posts. Within highways, the participants said the following structures have construction potential with wood products: bridge decks, bridge superstructure, temporary bridges/structures, guardrail posts, sound barriers, retaining walls and sign posts. Participants said in the next three years they had plans to use wood products in the following highway structures: formwork/falsework, bridge decks and pedestrian bridges.

Maine participants were asked what durability problems and benefits they had with wood in highway structures. Wood decay caused by fungus, insects and marine borers was the primary durability problem in highway structures. Some participants said that newly treated wood products did not last as long as wood products treated with creosote. They stated that some Maine wood species (mainly hardwoods) could not be chemically treated easily and were decaying too soon. Participants said it was hard to inspect interior sections of wood in highway structures. Therefore, the wood could look sound from the exterior, but the interior could be completely decayed. Other durability problems were caused by mechanical wear/abrasion. Mechanical damage has occurred because: ice damage from stream melts has caused damage to bridge pilings; mechanical abrasion has occurred on wood bridge decks; wood bridge decks have delaminated when trucks cross bridges at high speeds. Durability benefits with wood used in highway structures were cited by Maine interview participants. Wood in bridges was fatigue resistant and could withstand short-term overloads. Also, participants said salt would not affect wood durability (i.e. corrosion) like it would affect concrete or steel durability.

Participants gave some maintenance benefits in using wood products in highway structures. They said unlike concrete, which requires warm weather for construction, wood can be used in construction anytime of the year. Wood was said to be quick in construction, could be shaped easily, and specialized equipment was not required to construct with wood. Also, participants said for the most part less skilled people could work with wood products in highway structures. There were instances when wood construction required specialized training, such as when working with truss system designs. Wood was relatively light weight, making it easier to handle and transport than other construction materials. Finally, maintenance costs were reduced for wood compared to steel because wood did not corrode and needed no painting unlike steel.

Maine participants described maintenance problems in using wood products in highway structures. Wood tended to be less durable, and wood structures required higher maintenance depending on the situation. The heavy loads carried by trucks today and high traffic count traffic caused high maintenance of wood bridges. Wood required a great deal of maintenance in tightening connections as wood shrinks, swells, and relaxes under constant wear of traffic. Inspection of wood was difficult, often causing the wood maintenance costs to be high. Wood may be considered difficult to repair in place, as it might require a whole wood part to be replaced with a new piece. Participants said large wood sizes required for highway construction was not readily available in Maine. Wood products could not be stored for maintenance needs as it would rot, check and age. Therefore, delays in maintenance with wood products could occur when one had to order the necessary materials. Even though salt did not corrode wood, the participants in Maine said salt would corrode steel joints used in wood construction. Finally, preservatives made handling treated wood dangerous for highway workers.

Problems using wood in highway structures were described by the Maine participants. Wood used in highways could burn. Wood did not provide the structural strength required with today's road weight limits. Participants said it was difficult to meet the required deflection criteria using wood, which limits the span length of wood bridges. To meet the required strength when using wood in bridges, the wood framing was too deep for longer spans and could block stream flow. Participants said specialized equipment was required to handle and maintain the stability of large, highly flexible wood products such as timber trusses. No native Maine wood species were available to meet highway strength specifications and native wood lacks size required for highway construction. Also, Maine lacked wood treatment facilities and wood products for highway use had to be shipped in from other US areas. Wood construction in Maine was expensive because they had to use costly southern yellow pine which was treated in New York (the closest treatment facility). Also, they said larger pieces of wood had to be used to meet today's strength loads, which increased the cost of wood in highway structures. Finally, they had concerns over the environmental effects of wood treatments. Chemical wood treatments were perceived to be environmentally unfriendly and treatments were not penetrating wood products deep enough to protect the wood.

Participants identified benefits in using wood in highway construction. First, wood was considered aesthetically pleasing. Participants said construction with wood was quick relative to concrete and steel construction. Wood can be used in construction in cold weather unlike concrete. Wood was a renewable and local resource which could benefit the local economy through use in highway structures. They said as long as wood product quality was uniform, then you would have reasonable uniformity in strength. For non-native wood species, the strength was perceived to be adequate, durability was getting better, and the required sizes were available. Finally, the public perception of wood was good in Maine.

Participants said to increase the use of wood products in highway structures the following. Wood must become more cost effective: the benefits received by using wood in highway structures must out-weigh the costs. Maine DOT engineers have to see the advantages of using wood products in highway construction. A life-cycle analysis must be done and the DOT would have to be convinced that wood was viable in highway construction. Also, there needed to be an awareness of timber benefits within the Maine DOT. Therefore, the wood products industry needed better promotional and educational efforts targeted at the DOT. Chemical treatments needed to be developed that were environmentally friendly and still lengthen wood's service life. Innovation in the wood products industry was needed to make the timber industry more competitive. Some examples of wood highway structure innovations were: bridge designs that were easier to construct and test; designs that were not sensitive to material fluctuations in size. The Federal Highway Administration (FHWA) needed to mandate funds for wood bridge construction or mandate a timber alternative for bridge designs. Along with changes at the federal level, the state would have to build more wood highway structures to become familiar in designing them, to increase contractors knowledge in building them and to establish a market for wood products manufacturers. Basically, this indicates that the state would have to invest more money now for wood products in highways to be competitive in the long run. Finally, there was a need for improved grading rules that could be easily used by engineers or non-wood products people.

Case Study 4: Montana

Montana participants said they had designed, maintained or constructed the following highway structure: bridges (pedestrian and vehicular), bridge rail, retaining walls, guardrail, and culverts. Montana did have guidelines for the use of wood products in highway construction, but most were obsolete. In the past three years, interview participants used wood products in design, construction and/or maintenance of the following highway structures: widening existing timber bridges to meet the newer road, guardrail, sign posts, fencing posts and retaining walls. Participants said within highways, the highest current use of wood products was: guardrail posts, sign posts, retaining walls, recreation areas where an aesthetic setting was desired and wood structure rehabilitation. The greatest potential or future use of wood products in highways structures was: county road bridges, pedestrian bridges, timber bridge improvements, box culverts, sign posts, guardrail posts and highway fencing. Participants said engineered wood was opening the way for longer spans in bridges. As longer spans were passed with less piles in the water, then less debris would be trapped under a bridge which would reduce maintenance costs. In the next three years, participants said they had plans to use wood products in the following highway structures: timber bridge rehabilitation, bridge decks, box culverts, bridge rails, guardrail posts, sign posts and fence posts.

Montana interview participants identified several problems with durability of wood used in highway structures. Many durability problems were with wood products used in timber bridges. High deck wear occurred when bridge decks did not have a wearing surface. The deck wear was accelerated by sand and gravel being pulled over the bridge deck and grinding into the deck. Participants said high bending stress caused cracks to form along the bottom of longer span, wood bridge stringers. Decay of wood highway structures caused by bacteria and fungus was a problem. The participants stated that preservatives used today such as CCA were not as good as creosote in extending wood life-span. Older bridge designs often had decayed and would not hold the vehicle loads present on today’s highways. Bridge caps would decay, especially if untreated wood was used. As well as decay damage, there also has been some crushing seen in timber bridge caps. Timber pilings often decayed too soon when used in areas where the water level fluctuates. Finally, the participants said there often were problems with connectors in wood structures loosening as the wood shrinks and swells. The causes of these durability problems were said to be a combination of the material (wood), design, and maintenance.

Interview participants cited several benefits with the durability of wood. Primarily, the participants had seen adequate life with timber construction, especially if the wood was treated and the structure maintained. They hoped the wood structures designed today would have at least 50 years service life with proper maintenance. Treated wood would not be corroded by deicing salts unlike steel or reinforced concrete. Many participants said wood structures have adequate durability in Montana because of low traffic, low salt use, dryer climate and low insect problems.

Participants said they had seen maintenance benefits in using wood in highway structures. Wood structures were easy to fix because wood was lighter and requires simpler tools relative to other materials. Montana DOT and county engineers/superintendents had few maintenance resources and manpower, so lighter wood products were a maintenance benefit. Wood was perceived as easy to modify so that it best fit the application requirements. Maintenance with wood was fairly common knowledge in Montana and often maintenance of wood structures was considered easy because the materials were stockpiled.

Montana participants identified several maintenance problems with wood products in highway structures. Keeping a wearing surface on wood bridge decking was considered difficult. The shrinking and swelling of wood caused problems keeping wearing surfaces in place. Participants said it was becoming increasingly difficult to dispose of treated wood in Montana when replacing structural members. Poorly detailed wood structures (mainly bridges) with low drainage needed maintenance often and would degrade faster than concrete/steel with the same detail. Montana interview participants said it was more difficult to inspect wood structures than concrete or steel structures. Inspectors did not know what was a crack or fracture and what was a check in wood products.

Other problems with wood in highway structures were identified by the Montana officials. Cost was seen to be a major problem with wood. The participants said that buying solid wood or engineered wood was just as expensive as pre-cast concrete. Wood was not available in large sizes needed for certain construction. One example was with wood piles for bridges. Wood piles did not come in sizes long enough to reach required adequate depth for proper bridge support in soft soils. It was difficult to acquire the large timbers and quality wood needed for timber highway construction. Currently, there are no wood treatment companies in Montana and all treated wood had to be ordered from out of state, which increased cost. Participants said there were problems associated with chemically treated wood used in highway structures. Douglas fir was a primary species used in wood construction in Montana, but it did not treat well and decayed too soon. There were environmental issues with treated wood and it could be considered a hazard to work with in construction. Design standards sometimes could not be met using wood for current construction in Montana. Participants said it was difficult to connect wood bridge decks to support beams and not leave space where water could cause decay problems. Montana interview participants said the grading systems for wood were not uniform. The subtle differences between different associations' grading systems caused problems for the highway decision-makers.

Montana interview participants described benefits of using wood in highway structures. As with the other case studies, wood was said to be aesthetically pleasing and best fit many local surroundings. Participants said it was easy to construct with wood using low technology equipment and highway workers had the knowledge required for wood construction. Often, it was easier to correct for mistakes in highway structures with wood construction. Wood generally was said to handle overloads and impact loads well. Although wood could burn, another benefit with wood was fire resistance. Participants said steel would fail if heated through, but wood could receive surface fire damage and still carry loads. Some participants felt wood was initially cheaper in Montana than other construction materials, although this view was not held by all participants. Finally, the participants said that wood could be just as durable as concrete or steel under harsh conditions. For instance, snow plows would chip concrete and break or bend steel just as well as wood.

Participants in Montana said the following needs to occur to increase the use of wood products in highway structures. There should be a greater market approach by the wood products industry. The Montana participants said wood products manufacturers need to direct promotional and educational efforts at highway decision-makers. The wood products associations should inform engineers/decision makers where more suppliers are located. Interview participants mentioned that the wood products industry should develop timber construction design details for highway applications that work and require little maintenance. The durability of wood in highway applications in Montana was not well documented. Highway decision-makers needed to know how long wood could last in different species and different applications. The last needs suggested by the Montana interview participants were to reduce the cost and increase the availability of wood products.

Conclusions

This study has determined that education level did not affect the highway officials' perceptions of wood's overall performance. It was determined that officials who had course-work in design of structures with wood did not have different perceptions of wood's overall performance in highway structures than those that had coursework in wood design. Having standards for wood design did not affect the highway officials' perceptions of wood's overall performance in highways. Finally, age of highway officials and their years of work experience did not affect their perceptions of wood's overall material performance in highway structures.

Highway officials had different importance for factors used when making a material choice decision. *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. This was mainly because *durability, maintenance* and *cost* affect the efficiency with which a material performs it required task, while *environmental impact*, *ease of design* and *innovativeness of material* had less of an affect on a material's performance. *Environmental impact* was still important because the highway officials were responsible for their effect on the environment when they construct with a material. *Ease of design* was important in lowering design costs and decreasing risks of failure in the structures caused by design errors. Highway officials, as stated in the interviews, were not concerned with innovative materials because of the risks involved with the new materials.

No differences were found among the highway groups' overall perceived performance of wood. The infrastructure groups combined perceived prestressed concrete to have the highest overall material performance, while wood and plastic were lowest in overall material performance. Wood still was above average in its overall performance ratings by the infrastructure groups, which indicated that infrastructure officials perceive wood to be adequate at its required tasks in structures.

It was hypothesized that different highway groups would have different perceptions of wood as a construction material. No differences were found among the highway groups' perceptions of wood possessing cost, durability, ease of design and environmental impact. Therefore, the highway groups were said to have the same perceptions of wood as a construction material on these attributes. Differences were perceived to be present among the highway groups perceptions of wood's maintenance and innovation attributes, and the hypothesis was rejected for these attribute groups. Therefore, the highway groups were said to have different perceptions of wood as a construction material for these attributes.

Benefits with wood in highway structures could be utilized by wood products manufacturers to compete effectively in the highway market. Wood was perceived to be low in initial cost in highway structures. Highway officials perceived wood to be highly corrosion resistant. In design attributes, design standards were perceived to be available for wood, but they could be obsolete. In design attribute ratings for wood, wood was considered easy in construction and construction equipment was available for wood. Highway officials perceived that wood performed well in environmental attributes, especially *aesthetically pleasing* and *disposable/biodegradable*. In maintenance attributes, officials perceived wood to be *easy in repair* and *easy in field modification.*

Wood products could be improved upon in several areas in order to compete more effectively in the highway market. In *cost* attributes, wood was perceived to be high in *maintenance* and *life-cycle costs* in highway structures. Officials perceived wood to need improvements in *durability* attributes, including *fatigue*, *mechanical wear/abrasion, fire*, *weathering* and *biological decay resistance*. In *design* attributes, wood was considered available in highway markets, but not as available as other materials. Wood products were perceived to need improvement in the environmental attributes *chemically safe* and *recyclability/reusability*. Officials perceived there not to be adequate *standard structure designs available* for wood in maintenance. The highway maintenance personnel were not perceived to have experience in maintenance with wood, and wood was considered difficult to inspect. Wood was perceived to be the least innovative material in *performance, maintenance, design* and *durability*. Highway officials perceived wood to not be highly *innovative in the environment*.

Wood products manufacturers planning to enter or currently in the highway market should make consider the following strategies to compete more effectively. These strategies were developed from trends seen in interview and survey discussions. There was a need for the cost of large wood products to be decreased. Also, the price of large wood products needs to be reduced so that wood can be competitive with concrete and steel. Participants said that durability of wood used in highway construction needs to be improved. Participants stated that perhaps these durability improvements could be made through improvement of wood treatment chemicals. There was a need for established designs and a textbook of wood design in highway applications. Design procedures and values for wood needed to be simplified. NFPA designs were too complicated and the NFPA design values needed to be updated. Also, participants stated that valid, objective information about correct applications for wood should be available to highway decision-makers. For wood to become more widely used in highway structures, the wood products industry needed to direct more promotional efforts at the DOT and other highway decision-makers. Highway decision-makers needed better education on uses of wood in highway structures. Wood products manufacturers should support a more unified wood industry technical group for wood products in transportation markets. This supports results found by the National Wood In Transportation Information Center. They said wood products manufacturers could improve their promotions in two main areas: wood products industry should push wood use wood in aesthetic settings and for more temporary use (in formwork, falsework and temporary bridges) where long term durability was not an issue. Highway officials said there is a need for more suppliers of wood products for highway use. Currently, there are too few suppliers in many states for wood highway structure materials. These suppliers are able to control the market and keep prices high which is causing highway officials to use other materials in highways.

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