Chapter 2

Methods

Study Objectives

Specific objectives of this research 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 levels of infrastructure decision makers.

3) Develop strategies for increased wood use in infrastructure markets across the US

Methods

To meet the study's objectives, the following methodology was developed and used. A mail survey and personal interviews were used to collect primary data. Engineering professors, private consulting engineers, state department of transportation engineers and other professionals were contacted to identify the important criteria in the selection of materials for the infrastructure market. Once these criteria and factors were identified, a mail questionnaire was developed. This questionnaire identified the importance of material selection factors from the decision makers and it measured the perceptions of different construction materials in the nation's infrastructure. The final objective, strategy development was met by the interpretation of results from the mail survey, exploratory questions, and personal interviews.

Sample Development:

The sample frame consisted of decision makers from the public and private sectors of the highway infrastructure, the marine/inland waterway system, the railroad system, and the electricity distribution/ transmission system. The infrastructure systems have different people, goals and regulations followed when deciding on construction materials. Therefore, it was desirable to sample from each area so that the different groups' perceptions could be measured. The individuals responsible within each area for design, construction or maintenance of the transportation structures were sampled.

The highway transportation sample frame consists of three groups: state departments of transportation engineers (D.O.T.); engineers or highway officials from counties from each state; and private consulting engineers within each state. Since the highway groups were different in the areas they managed, highway officials were kept in the respective groupings in order to make comparisons among them. State D.O.T. engineers were located through phone calls to each state D.O.T. office. County engineers were found in the National Association of County Engineers (NACE) 1995-1996 Membership Directory (National Association of County Engineers, 1995) and through phone calls to state D.O.T. offices. The private highway consultants were located through phone calls to state D.O.T. offices and through the American Consulting Engineers Council (ACEC) 1995-1996 Directory (American Consulting Engineers Council 1995).

The U.S. marine/inland waterway infrastructure system's sample frame consisted of private consulting engineers, port engineers and engineers from the U.S. Army Corps of Engineers. The marine/inland waterway decision makers were considered homogeneous in the areas and structures they manage, and were not separated into different groups. The ACEC 1995-1996 Directory was used to find private consulting engineers that design waterway structures (American Consulting Engineers Council 1995). LLoyd's Ports of the World 1995 directory was used to locate port engineers (Pinchin 1995). Those port listings in the LLoyd's Ports of the World directory not showing a port engineer were sent a facsimile requesting the port engineers' names and addresses. The U.S. Army Corps of Engineers were found using the 1996 Department of Defense Telephone Directory (U.S. Department of Defense, Government Printing Office 1996) and the 1996 U.S. Army Corps of Engineers Directory (U.S. Department of Defense, Army Corps of Engineers 1996). The Department of Defense Directory contains up to date listings of engineers in Washington D.C. only, while the U.S. Army Corps of Engineers Directory contains office listings for the districts across the U.S. Phone calls were made to determine the key decision makers in each district for the U.S. Army Corps of Engineers.

The sample frame for the U.S. railroad infrastructure system consisted of civil/structural engineers and decision makers employed by railroads operating in the U.S. These individuals were located using the directory, The Official Railway Guide, 1996 (Schneider 1996). The railroad listing contains Class I, II, and III railroad civil/structural engineers. These railroad engineers were considered homogenous in the areas they manage, so these individuals were not separated into groups in the railroad system.

The electricity distribution and transmission infrastructure system's sample frame included distribution/ transmission engineers and decision makers employed by electric companies operating in the U.S. The engineers/decision makers from the electricity infrastructure group included those from the following company types: investor owned systems; municipal systems; rural electric cooperative systems; and government (Federal, state and local) systems. These individuals were found using the 1996 Electrical World's Directory of Electric Power Producers (Schwieger 1995). The engineers in these areas were considered homogenous in the management of distribution/transmission systems, and were kept in one large group.

The most important questions on the questionnaire were used to determine the sample size from each group. The most important questions were the factor importance rating questions and the material attribute rating questions. These questions had a one to seven rating scale and the total sample size for each area was based on the following equation given by Ballenger and McCune (1990):

$$n = [\ (Z_{/2})^2(\sigma)^2\ ]/h^2$$

where n = the required sample size,

$Z_{/2}$ = the reliability coefficient,

σ = the estimated population standard deviation,

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

In this study a 95% confidence interval was used. The calculation for the sample size, n, was as follows:

$Z_{/2} = 1.96$,

σ = (minimum value - maximum value)/6 = (7-1)/6 = 1,

h = +-0.2 on the 1 to 7 rating scale,

and $n = [\ (1.96)^2(1)^2\ ]/(0.2)^2 = 96$.

Therefore, a sample size of 96 was be needed for each rating scale question on the survey for infrastructure group.

Samples were randomly selected from each transportation system listing. The total number of questionnaires mailed to each transportation system were approximately 900 for the highway system, 500 for the marine system, 500 for the railroad system and 500 for the electricity distribution/transmission system. The highway system engineers were considered different in the areas they manage. Therefore, a larger mailing was conducted in the highway system to acquire a larger sample size and determine if there were differences in the perceptions of materials within the highway group. The expected response rate for the survey was 25 percent, so the needed viable samples should have been attained.

Questionnaire Development, Data Collection and Analysis:

The great number of factors and attributes to be measured made one questionnaire too long, and it was thought that this would cause the response rate to be unacceptably low. Two questionnaires were developed to measure the importance of material decision factors and perceptions of the various products from each transportation group. Both questionnaires contained similar questions measuring the certain factors and perceptions. Each questionnaire also had different questions measuring factors and perceptions. This allowed all the factors and perceptions covered in this study to be measured, while still maintaining an acceptable questionnaire length. The total number of surveys to be mailed were divided in half: 1200 surveys were identified as questionnaire A; 1200 surveys were identified as questionnaire B. This was to reduce questionnaire length and increase response rate.

The first sections of both questionnaires began with entry sections of the same dichotomous and multichotomous questions to determine the qualifications of the respondent (Appendix B). These questions included:

1) Does the respondent design, construct, and/or maintain transportation structures?
2) In what transportation system does the respondent work primarily?
3) What transportation structures has the respondent designed, constructed and/or maintained?

The second section of both questionnaires had similar rating questions to collect data about the importance of factors used in material choice decisions by the respondents. This section contained rating questions (1-low to 7-high) used to determine the respondents perceptions of different materials. This section of the questionnaire was used to meet the first two objectives which were to identify the factors important in the material choice decision and to determine the perceptions of wood in various infrastructure applications by different levels of decision makers.

Both questionnaires had factors grouped under the following section headings: *overall performance; cost; durability; design; environmental; maintenance; and innovation*. Under each factor heading, questions were asked to determine the different decision makers perceptions about materials according to different attributes. These perceptions were tested using attributes related directly to these factors. The respondents were asked to state the degree on a scale from one to seven on how each material possesses the stated attribute (one being not at all and seven being to a high degree). The attribute ratings for each material were weighted using the mean importance ratings found with the factors. The weighting was accomplished by multiplying the rating score for the factors by the rating scores for each factor's respective attribute. Those factors that were more important then showed a heavier rating for the attribute rating of the materials. These data assisted in identifying areas in which timber must improve its perceived performance characteristics. The rating sections and there respective factors are listed as follows:

1) *Overall Performance*.

2) *Cost*. Both questionnaires asked the respondents to rate the importance of initial cost, maintenance cost, repair cost, and lifetime costs.

3) *Durability*: Both questionnaires asked the respondents to rate the importance of fatigue and mechanical wear/abrasion. Questionnaire A asked the respondents to rate the importance of fire and corrosion in material choice decision. Questionnaire B asked the respondents to rate the importance of weathering and biological decay.

4) *Design*: Both questionnaires asked the respondents to rate the factors of design standards availability and material availability. Questionnaire A asked the respondents to rate the importance of ease of construction and design experience with material. Questionnaire B asked the respondents to rate the importance of past material performance and construction equipment availability.

5) *Environment*: Both questionnaires asked the respondents to rate the importance of chemical toxicity and aesthetics. Questionnaire A asked the respondents to rate the importance rating for the disposability/biodegradability factor and the environmental effects of material production factor. Questionnaire B asked the respondent to rate the importance of recyclability/reusability and percent recycled content.

6) *Maintenance*: Both the questionnaires asked the respondent to rate the importance of standard structure designs, ease of field modification and ease of repair. Questionnaire A asked the respondents to rate the importance of maintenance experience with the material while questionnaire B asked the respondent to rate the importance of inspection requirements.

7) *Innovation*: The questionnaires both asked the respondent to rate the importance of innovation in performance, design and maintenance. Questionnaire A asked the respondents to rate the importance of innovation in durability. Questionnaire B asked the respondents to rate the factor innovation in the environment.

Each factor is an attribute when possessed by a material. For example, *corrosion resistance* could be a factor used by a railroad decision-maker when deciding on materials for sign system construction. The factor, *corrosion resistance*, also could 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 railroad decision-maker, that person would mark a 7 on the importance rating scale. The mean of all ratings by railroad decision-makers for this factor was determined.

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 a material did not possess the attribute at all and a 7 rating indicated the material possessed the attribute to a high degree. For example, if the railroad decision-maker thought plastic highly possessed the attribute, *corrosion resistance*, then that person 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 provided 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 railroad 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 meant a material did not possess the attribute at all, to 49, which meant a material possessed the attribute to a high degree. For example, a railroad group's mean factor importance rating for *corrosion resistance* was 6.55, meaning this was a very important factor to the railroad group. One individual in that railroad 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 demonstrated that plastic highly possessed the attribute *corrosion resistance* and that the attribute was important to the railroad group.

The third section consisted of dichotomous and multicotomous questions designed obtain information about the respondents. The following information will be determined:

1) Whether or not the decision makers state had guidelines for the use of wood in design of transportation infrastructure in that person's transportation area?

2) How many of the respondents had formal courses on design with wood during their professional training?

3) Had the respondents used wood products in the design, construction and/or maintenance of transportation structures in the past three years?

The last section of the questionnaire contained exploratory questions. The first question asked the respondent for opinions on the best opportunities for wood products in transportation infrastructure. The second question asked if there is anything the respondent would like to share about their experience and use of materials in infrastructure. These exploratory questions helped to meet the last objective of this research: to develop strategies for increasing the use of wood in the transportation infrastructure of the U.S.

The questionnaires were reviewed by knowledgeable civil engineers and university personnel to test their face validity, clarity, and to ensure no important material selection factor was overlooked. A pretest was conducted with officials in various infrastructure groups. This pretest included mailing or faxing the questionnaires to twelve individuals from the population and personal interviews with three individuals from the population about the questionnaire. The individuals who were mailed or faxed the questionnaires were sent instructions with the questionnaire. These instructions were: first, complete the questionnaire as if they were a respondent for the study; second, make comments on the questionnaire where there are problems or difficulties in answering the questions; and third, to return the questionnaire. The personal interviews were sessions with individuals in the areas of design, maintenance/rehabilitation and construction. These individuals were asked to examine the questionnaire and identify any problems in the wording, to make sure the instructions were easy to follow and to make sure that any important factors or attributes which were not listed are included. The responses from the mail and personal interview pretests were used to clarify question wording and revise the set of material attributes and factors to be tested.

A disguised questionnaire with a cover letter explaining the purpose of the study was mailed in the summer of 1996. No correspondence stated that the study was conducted by the Department of Wood Science at Virginia Tech, as it was felt this would bias some respondents answers or have a negative affect on the response rate. In order to increase response rate, a reminder post card was mailed two weeks after the initial survey mailing. This was followed by a second questionnaire mailing to non-respondents approximately one month after the initial mailing and then another set of reminder cards two weeks after this second questionnaire mailing.

Data Analysis:

First, data entry errors were checked over the entire questionnaire using the following summary statistics: range; mean; total sample count. Next, section one of the questionnaires was analyzed using summary statistics. Examples of these summary statistics were to find: the mean and standard deviation of the number of usable respondents that work in marine/inland waterways transportation systems; the mean and standard deviation of usable respondents that work in design engineering; and to find the total numbers of respondents in different organization types (such as state departments of transportation or county engineers). Cross-tabulations were also conducted between this section and the other sections to see if there were any variables on the questionnaires that influenced one another.

The second section of the questionnaire, utilized rating questions for the factor importance and the perceptions of materials according to certain attributes. The decision making factor groups in each survey had some of the same questions (or dependent variables), but there were also different questions on each survey. This resulted in half of the sample to have different test questions from the other half. Summary statistics were used on section two of the questionnaire.

An example of the summary statistics obtained from section two would be to find the mean and the standard deviation of the factor importance ratings. Multivariate Analysis of Variance (MANOVA) was to simultaneously explore the relationship between several categorical independent variables (the infrastructure groups and two or more metric dependent variables (infrastructure 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 infrastructure group on factor importance or material perception ratings. Differences within the groups and between the groups were determined. For example, ANOVA would be used to test for differences of perception ratings for concrete's overall performance by all engineer types. An example of this would be to test the hypothesis that there were differences in perception ratings for the material's overall performance between all groups of engineers. Tukey's honestly significant difference (HSD) test was used to determine where differences were located between infrastructure groups and within each infrastructure group. A significance level of 0.05 was used throughout the study.

The third section of the questionnaire was analyzed using summary statistics and cross-tabulations. The fourth section of the questionnaire was different since it is used to measure qualitative data and not quantitative data. In this qualitative research, trends or relationships between the respondents were established. The analysis first identified trends from each respondent. These quotes were sorted on the basis of their similarity. The meanings of the groups of quotes were determined and then defined to a category of meanings. The results were a map of the different experiences that the questionnaire participants perceived as the best opportunities for wood products in transportation infrastructure. It was also used to map any other knowledge trends or aspects about materials used in transportation the respondents would like to discuss.

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