A HIERARCHICAL MODEL AND ANALYSIS OF FACTORS AFFECTING THE ADOPTION OF TIMBER AS A BRIDGE MATERIAL

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(Received October 1994)

ABSTRACT

The Analytical Hierarchy Process was used to characterize the bridge material selection decisions of highway engineers and local highway officials across the United States. State Department of Transportation engineers, private consulting engineers, and local highway officials were personally interviewed in Mississippi, Virginia, Washington, and Wisconsin to identify how various factors determine their choice of a bridge material. The Analytical Hierarchy Process was used to quantify this subjective data and to model the selection decision for different groups of decision-makers. Prestressed concrete was the material of choice in the majority of cases. This was followed by reinforced concrete, steel, and timber. Local highway officials chose timber more often than did either group of engineers. These results indicate that timber will remain a niche market for bridge applications.

Keywords: Timber bridges, decision modeling, analytical hierarchy process, marketing.

INTRODUCTION

The disciplines of Management and Marketing have evolved into separate sciences over the years. Management is organization-driven, wherein the effective manager must determine the purpose and direction of the organization, foster and manage change, and conduct operations so that the organization and its people function efficiently and effectively (Levitt 1991). Levitt goes on to state that managers make decisions; decisions deal with choices and choices involve alternatives, which include prospects for making, avoiding, resisting, and creating change. Drucker (1983) states that effective management requires precise analysis, rigorous allocation of resources, and timely decision-making. Managers are accountable to stockholders, financial backers, employees, and customers, so choices must be not only the best, but also justifiable.

Marketing has been called a philosophy. It

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is a total system of business activities designed to determine customers' needs and desires, plan and develop products to meet these needs and desires, and determine the best way to price, promote, distribute, and service the customer (Stanton 1978). This is often referred to as the marketing concept. Sinclair (1992) states that a marketing-oriented firm designs its products and service offerings to meet customer needs at a profit. Marketing is the income-generating activity of the firm and the process by which the organization reaches out to its customers and by which customers reach in to the firm.

Managers often utilize decision analysis tools to run their organizations more effectively. Marketing departments rely upon research methods involving customer surveys, purchasing activities, and demographics to understand and meet customer needs. Yet, as Drucker (1984, p. 1) states, "Marketing is so basic it cannot be considered a separate function. . . . It is the whole business seen from the point of view of its final result, the customer." Following on this idea, this study crosses the boundary between modern management decision analysis and the marketing concept. This study examines how particular criteria affect material-selection decisions for rural bridges. Quantification of this decision process should allow manufacturers of timber bridge materials to improve their ability to meet the needs of design engineers and highway officials.

THE BRIDGE DECISION PROBLEM

The choice of a material is the most important decision bridge designers make, and it has long-term consequences for the owner of the structure (Johnson 1990). Bridge material selection is a complex decision, with many individuals involved, and many factors of bridge design, use, and maintenance to be considered. It is not uncommon to have state Department of Transportation (DOT) officials, private consultants, and local officials work together on a bridge replacement decision. Each of these groups may have its own preferences concerning bridge materials. Often a consensus is necessary to determine the best material to use at a given location.

Highway officials and engineers across the United States have been asked to reevaluate their position on the use of timber as a bridge material. Extensive promotion and training began in 1989 by the Timber Bridge Initiative Program (TBIP 1990) to inform and educate bridge engineers and highway officials concerning the benefits of the modern timber bridge. It is believed that with an increase in the use of timber, local economies can be stimulated and the rural infrastructure rebuilt.

Since its inception, the TBIP has sponsored the construction of over 270 modern timber bridges in 48 states and assisted in 17 million dollars of research, education, and bridge support activities (USDA 1993). However, the long-term viability of timber bridges will depend not only upon this technology push, but also on the competitiveness and acceptance of the concept in the marketplace, the market pull.

Unfortunately, highway officials across the United States often have negative perceptions of timber as a bridge material. Studies by Clapp (1990) and Luppold (1990) have confirmed that highway officials are not ready to place timber in the same bridge material classification as prestressed concrete, steel, or reinforced concrete. Highway officials have stated that timber is short-lived, difficult to inspect, expensive, high in maintenance, and low in strength.

Many factors are known to affect the choice of a bridge material. Physical characteristics or site specific factors include: roadway alignment, length of clear span, clearance above waterway, hydraulic capacity requirements, and required loading capabilities. Yet, there are numerous nonstructural characteristics of the material such as initial cost, maintenance requirements, and others (Table 1) that also may influence this decision. These are the areas that manufacturers can address in trying to influence the choice of bridge material by design engineers.

Scott and Keiser (1984) state that much of the research that is done in industrial markets to identify and evaluate new opportunities is

TABLE 1. *Criteria used to evaluate bridge materials.*

Government research efforts	Standards specified by AASHTO	Material preference of local officials
Life-cycle cost of material	Past performance of the material in bridges	Availability of design information
Resistance to natural deterioration	Contractor's familiarity with material	Resistance to de-icing chemicals
Expected life of material	Bridge ownership (state, county, town)	Regular inspection requirements
Length of traffic interruption	Designer's familiarity with material	Impact on local economy
Maintenance requirements	Industrial promotional efforts	Environmetnal considerations
Initial cost of material	Aesthetics	Ease of repair
Bridge loading variations	Daily traffic count	

qualitative and unstructured. We demonstrate in this study that quantitative and structured analysis of decision-makers can be a useful tool for understanding customers and their perceptions. We develop a behavioral model of bridge material selection for several states and for several levels of decision-makers. Important nonstructural factors (criteria) in the bridge material selection process are identified, based on data from highway officials in 28 states. We use the highest rated six factors in the Analytic Hierarchy Process (AHP) to model the bridge material decision. The AHP model helps us analyze how important decision criteria directly influence the overall bridge material decision. From this, we recommend marketing strategies that can be used to increase the knowledge and application of timber as a bridge material.

THE ANALYTICAL HIERARCHY PROCESS (AHP)

Although various techniques exist for modeling decision-making, the Analytical Hierarchy Process (AHP) was chosen for this study. The AHP can be used as a behavioral, as well as a normative model of decision-making. The Analytic Hierarchy Process, developed by Thomas Saaty in the early 1970s, allowed us to quantify and aggregate subjective opinions. Saaty (1980) states that the practice of decision-making is concerned with weighting alternatives that fulfill a set of desired objectives. This multicriterion, multiperson model structures the decision process into a hierarchy. Through a set of pairwise comparisons at each level of the hierarchy, a matrix can be developed, in which the entities indicate the strength with which one element dominates another with respect to a given criterion.

Harker and Vargas (1987) indicate that there are three principles used in the AHP for problem-solving: (1) decomposition– structuring the elements of the problem into a hierarchy; (2) comparative judgments–generating a matrix of pair-wise comparisons of all elements in a level with respect to each related element in the level immediately above it where the principal right eigenvector of the matrix provides ratio-scaled priority ratings for the set of elements compared; and (3) synthesis of priorities — calculating the global or composite priority of the elements at the lowest level of the hierarchy (i.e., the alternatives). The four basic axioms that the AHP is based upon are summarized by Harker (1989) as follows:

Axiom 1. Given any two alternatives (or sub-criteria) i and j out of the set of alternatives A, the decision-maker is able to provide a pairwise comparison a_{ij} of these alternatives under any criterion c from the set of criteria C on a ratio scale which is reciprocal; i.e., $a_{ji} = 1/a_{ij}$ for all i, j, & A.

Axiom 2. When comparing any two elements i, j &A, the decision-maker never judges one to be infinitely better than another under any criterion c & C; i.e., $a_{ij} \neq \infty$ for all i, j &A.

TABLE 2. *Importance of criteria in the bridge material decision process.*

Bridge material factor	Decision level (mean rating)			
	Overall	Local highway officials	State DOT	Private consulting engineers
Lifespan (1)	5.95	6.17	5.89	5.82
Past performance (2)	5.92	5.93	5.98	5.83
Maintenance (3)	5.84	5.98	5.85	5.67
Natural deterioration (4)	5.82	5.92	5.72	5.82
Initial cost (5)	5.54	5.60	5.48	5.49
Life-cycle cost (6)	5.51	5.62	5.45	5.51
Ease of repair (7)	5.25	5.41	5.19	5.16
Standards specified in AASHTO (8)	5.24	5.15	5.14	5.42
Time of traffic (9)	5.08	4.98	5.26	5.01
Designer's familiarity (10)	4.86	4.91	4.70	4.92
Design information (11)	4.85	4.92	4.69	4.92
De-icing chemicals (12)	4.84	4.38	5.03	5.05
Environmental concerns (13)	4.66	4.74	4.68	4.53
Inspection requirements (14)	4.65	4.68	4.66	4.62
Loading variations (15)	4.56	5.05	4.34	4.38
Contractors familiarity (16)	4.41	4.61	4.16	4.47
Daily traffic (16)	4.41	4.58	4.41	4.24
Aesthetics (18)	4.34	4.20	4.27	4.51
Local highway officials (19)	4.23	4.16	3.71	5.01
Local economy (20)	4.11	4.59	3.80	4.07
Bridge ownership (21)	3.98	4.07	3.72	4.24
Gov. research (22)	3.82	3.76	3.85	3.74
Promotional efforts (23)	2.81	2.88	2.76	2.76

Rating scale: 1 (below average) to 7 (above average), average = 4.

Axiom 3. One can formulate the decision process as a hierarchy.

Axiom 4. All criteria and alternatives which impact the given decision problem are represented by a hierarchy. That is, all the decision-maker's intuition must be represented, or excluded, in terms of criteria and alternatives in the structure and be assigned priorities which are compatible with the intuition.

METHODS

Data collection

Primary data. –A disguised mail questionnaire was sent to over thirteen hundred highway officials in twenty-eight states to collect primary data concerning important nonstructural factors (criteria) that influence the bridge material decision (Table 2). Participants were asked to assume that the bridge site allowed for equal choice of material. This was meant to eliminate physical or site-specific characteristics that may influence the material choice.

Highway officials were grouped based on geographic regions and decision-maker type (Table 3). The groups were state DOT engineers, private consulting engineers, and local highway officials. Survey respondents were asked to rate 23 nonstructural criteria in the selection of a bridge material (Table 2). These criteria were selected by an extensive secondary literature search, discussions with civil engineers across the United States, and interviews with university personnel.

A pretest was conducted with highway officials in various decision groups in Virginia, Wisconsin, and Minnesota. After minor clarification of question wording, the questionnaire was mailed in April of 1993. No correspondence stated that the study was being conducted by the Department of Wood Science and Forest Products at Virginia Tech as it was felt this might bias some results or have an undesirable effect on the response rate. After

TABLE 3. *States surveyed for important bridge factors.*

West	South	Mid-Atlantic	Northeast	Midwest
California	Alabama	Kentucky	Maine	Indiana
Idaho	Arkansas	North Carolina	Massachusetts	Illinois
Montana	Florida	Tennessee	New York	Iowa
Oregon	Louisiana	Virginia	Pennsylvania	Michigan
Washington	Mississippi	West Virginia	Vermont	Minnesota
	Texas			Ohio
				Wisconsin

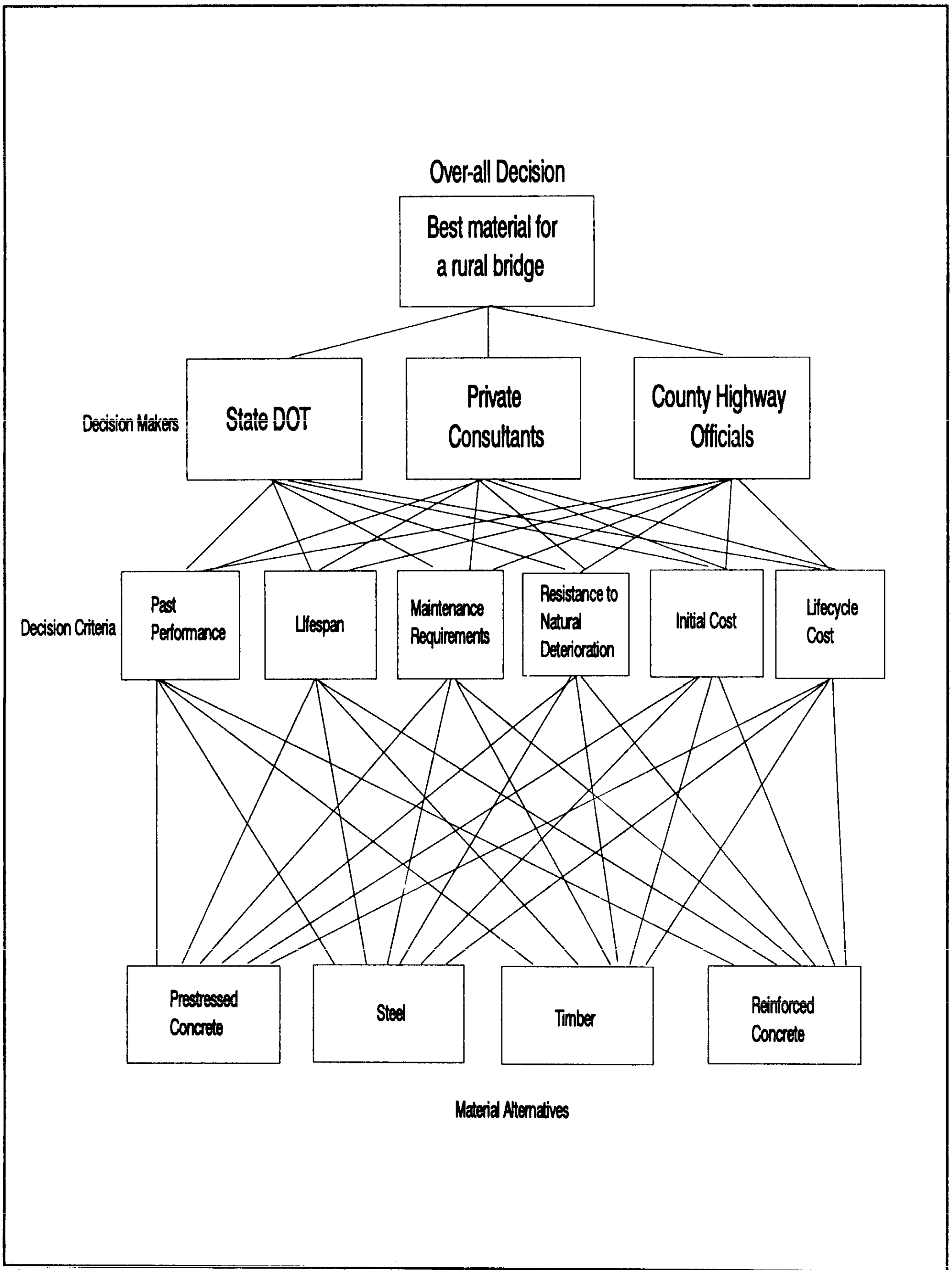

FIG. 1. Analytic hierarchy model for the choice of a bridge material.

two mailings, a total of 848 surveys were returned, 751 of which were usable. This resulted in an adjusted response rate of 61%.

Nonresponse. – In order to test for nonresponse bias, 50 individuals who did not respond to the mail survey were contacted by telephone and asked to answer selected questions (material preference, ratings of important bridge material factors, timber design education, and job duties). These individuals were randomly chosen from all nonrespondents. Multivariate Analysis of Variance (MANOVA) was utilized to determine if significant differences existed between respondents and nonrespondents on the selected parameters. In no case could the hypothesis of no difference between respondents and nonrespondents be rejected ($P = 0.11$).

Personal interviews. – During August, September, and October of 1993 semi structured interviews were conducted with 73 design engineers and highway officials in four states: Mississippi, Virginia, Washington, and Wisconsin. State Department of Transportation (DOT) engineers involved in preliminary design or local bridge maintenance/replacement decisions were interviewed. Private consulting engineers who were involved with local bridge design and county highway officials also participated in this portion of the study. Interviews with county officials and private consultants were limited to one per location. A questionnaire was designed for participants to use for completion of the AHP model. This questionnaire consisted of paired comparisons among the six highest ranked criteria involved in the decision process (Fig. 1) as determined by the initial survey. It also included comparisons among the different types of bridge material with respect to each criteria.

A rating scale from 1 to 9, as recommended by Saaty (1980), was used for the paired comparisons – the number 1 indicating that compared factors were equal in importance and 9 indicating that one factor was extremely more important than another. This questionnaire was reviewed by qualified personnel at Virginia Tech and pretested with private consultants and state DOT engineers in Virginia.

Each decision-maker made 51 paired comparisons to complete his or her individual AHP model. The computer program Expert Choice (1992) assisted in development and analysis of the models. A laptop computer was used to input the data to Expert Choice as each official filled in the questionnaire. This allowed immediate feedback to the decision-makers on their preferences and their overall choice of a bridge material. Individual results were then combined using the geometric mean to produce group decisions representing the separate decision-making groups in each state.

The balance of the interview was exploratory. Responses were recorded for interpretation and analysis. Specific areas of interest included: bridge costs, best locations for timber bridges, concerns with timber as a bridge material, guidelines on timber use, amount of bridge work in state, best material for short span bridges, reasons the state doesn't use more timber in bridges, bidding processes within the state, and factors that would allow the state to use more timber bridges.

States interviewed for AHP models

Four geographically dispersed states were selected for personal interviews to develop individual state AHP models. These states were selected based upon their resource base, geographic location, decision-making protocol, and past timber bridge usage. Characteristics of individual states are summarized below.

Mississippi – This state is located in the heart of the southern pine resource and has one of the largest number of timber bridges (over 3,500) of any state (FHWA 1993). Design decision-makers in Mississippi include state DOT and county engineers. The county engineer is a private consultant who is hired by the county board of supervisors for a 4-year term. This consultant may represent up to five different counties as the county engineer. All bridges utilizing Federal Highway Administration (FHWA) bridge replacement funds or state funds must be designed by the county engineer. The Mississippi Department of Transportation, which administers funding and reviews bridge plans, is divided into two sections: (1) the state Department of Transportation, which directs state and federal highway programs; and (2) the secondary roads division of the state Department of Transportation, which directs the local roads program. Both divisions are strong supporters of standardized bridge plans, which at the time of the interviews did not include plans for timber. Over 70% of the state's nearly 12,000 bridges fall under local/county responsibility (USDA 1989).

Virginia. – Virginia has a large eastern hardwood and southern pine timber resource base and one of the lowest numbers of timber bridges in the United States with fewer than 60 (FHWA 1993). The Virginia Department of Transportation (DOT) maintains over 97% of the bridges in the state. Virginia is divided into 9 highway districts, with a chief bridge engineer directing maintenance and replacement activities within his/her district. Private consultants are used occasionally when the work load is too great for the district engineers to handle. Virginia utilizes standard bridge plans that do not include complete plans for timber bridges. Temporary structures and timber plank on steel stringers are the only standard plans for timber available.

Washington. – Located in the Pacific Northwest, Washington has a large softwood timber resource. Yet, only 600 of the state's nearly 7,000 bridges are timber. Three decision-making groups are involved in bridge replacement in Washington. The Washington Department of Transportation (DOT) has a local programs engineer, who works with counties on bridge replacements, and a staff of engineers in the central office that design state and federal highway bridges. Private consulting engineers are often hired by counties to design their rural bridges. Each county in Washington is required to have a registered civil engineer on staff to oversee local highway maintenance. This engineer or his/her assistant will often design a rural bridge. Sixty-five percent of the state's bridges fall under local control. Washington utilizes standard plans; however, the only plans for timber are for temporary structures, such as detours.

Wisconsin. – Wisconsin is only 1 of 5 states that have shown an increase in the number of timber bridges from 1986 to 1992 (FHWA 1992). Over 500 of the state's nearly 12,000 bridges are classified as timber. Three groups of decision-makers are involved in design decisions in Wisconsin. The State Department of Transportation (DOT) is divided into 8 highway districts, each with a bridge engineer who works with counties on maintenance and replacement. Private consultants are hired by counties to design rural bridges. County highway commissioners are responsible for maintenance of local, state, and federal highways within their county boundaries. The county highway commissioner does not have to be an engineer, but the trend is to hire engineers in that position. The commissioner, inmost cases, is appointed by the board of supervisors for a 2- or 4-year term. Wisconsin has standard bridge plans that include plans for timber bridges.

The AHP for Wisconsin counties

To demonstrate how the AHP model was developed, an example based on county highway officials in Wisconsin is provided. In August of 1993 nine county highway commissioners/engineers agreed to participate in completing the paired comparison questionnaire. The counties were geographically dispersed across Wisconsin, and respondents were either county engineers or county highway commissioners. The purpose of the interview was explained; and as the official filled out the questionnaire, the responses were entered into a personal computer using the program Expert Choice. First, paired comparisons were made between the six important bridge criteria. Under each criteria, paired comparisons were made for preferences of bridge materials. Exploratory questions regarding bridge replacement decisions were discussed at this time. At the completion of the nine interviews, individual results were geometrically averaged and one composite matrix was developed (Table 4) representing county decision-makers in Wisconsin.

TABLE 4. *Geometric mean of paired comparisons of bridge factors as rated by 9 Wisconsin highway officials.*

	Pastperf	Lifespan	Maintenc	Resistac	Initial	Lifecycl
Pastperf	1.0	1.10	0.71	1.0	0.53	1.0
Lifespan	0.91	1.0	0.71	1.4	0.83	1.5
Maintenc	1.4	1.4	1.0	1.7	1.3	1.6
Resistac	1.0	0.71	0.59	1.0	0.67	0.40
Initial	1.9	1.2	0.77	1.3	1.0	1.2
Lifecycl	1.0	0.67	0.63	2.5	0.83	1.0
Total	7.21	6.08	4.41	8.90	5.16	6.70
Normalized matrix of paired comparisons for Wisconsin counties						
Pastperf	0.14	0.18	0.16	0.11	0.10	0.15
Lifespan	0.13	0.16	0.16	0.16	0.16	0.22
Maintenc	0.19	0.23	0.23	0.19	0.25	0.24
Resistac	0.14	0.12	0.13	0.11	0.13	0.06
Initial	0.26	0.20	0.18	0.15	0.19	0.18
Lifecycl	0.14	0.11	0.14	0.28	0.16	0.15

Calculation of a final priority vector for bridge material preference proceeds in the following way. First, the data in the bridge criteria matrix are normalized by column. Second, the values in each row are averaged to produce a vector of priorities for each bridge criterion (Table 5). Third, similar calculations are then repeated for each matrix of material preference under a given bridge criterion, e.g. past performance (Tables 6-7). Upon completion of these steps, the final composite preference vector for bridge material is the matrix product of (1) the matrix composed of bridge material preference vectors, and (2) the vector of bridge criteria (Fig. 2). This is the choice of bridge material for the decision-maker (in this case, county highway commissioners/engineers in Wisconsin) based upon the criteria measured (Fig. 3).

This process was repeated with engineers and highway officials in the four states selected. Composite models were developed for each group in each state. Overall material decisions were calculated for each decision-maker by state (Fig. 4). Expert Choice also calculates an inconsistency ratio, which is a measure of the transitivity of related, paired comparisons. That is, for comparisons among entities A, B, and C, the preference of A over C should equal the product of the preference of A over B and the preference of B over C, for the judgments to be consistent. Saaty (1980) states that an inconsistency ratio of less than 0.1 is excellent. Nevertheless, some inconsistency is inherent in most decision processes and should not necessarily be eliminated. The inconsistency ratios for aggregate responses of these decision-maker groups were all much less than 0.1. Table 8 summarizes the results of each state's models.

RESULTS

The most important nonstructural factors (criteria) as rated by all decision-making groups

TABLE 5. *Vector of priorities for Wisconsin counties.*

	Total of normalized row	Average of normalized row	Vector of priorities
Pastperf	0.84	0.84/6	0.14
Lifespan	0.99	0.99/6	0.17
Maintenc	1.33	1.33/6	0.22
Resistac	0.69	0.69/6	0.12
Initial	1.16	1.16/6	0.19
Lifecycl	0.98	0.98/6	0.16

TABLE 6. *Matrix of paired comparisons for preferences of bridge materials under the bridge factor (past performance) for Wisconsin counties.*

	Prestressed concrete	Steel	Timber	Reinforced concrete
Prestressed concrete	1.0	4.9	1.4	0.71
Steel	0.20	1.0	0.56	0.24
Timber	0.71	1.8	1.0	0.56
Reinforced concrete	1.4	4.1	1.8	1.0

TABLE 7. *Vector of priorities for bridge materials under past performance for Wisconsin counties.*

	Total of normalized row	Vector of priorities
Prestressed concrete	1.29	0.33
Steel	0.35	0.09
Timber	0.80	0.20
Reinforced concrete	1.55	0.38

across every region of the United States include: the expected life of a material, the past performance of a material, maintenance requirements, a materials resistance to natural deterioration, the initial cost of a bridge built with the material, and the lifecycle cost a bridge built with the material (Table 3). These six criteria were chosen because they were rated as more important in the bridge material decision than the remaining 17 criteria investigated and these differences were statistically significant *($P < 0.01$)*. In addition, six was considered to be the practical limit on the number of criteria included in the model because of the number of pairwise comparisons (51) required of respondents. These decision criteria are areas in which timber manufacturers need to address their efforts to promote timber bridges more successfully.

To determine if the four states selected (Mississippi, Virginia, Washington, and Wisconsin) were representative of their respective geographic regions, a Multivariate Analysis of Variance (MANOVA) was calculated for the selected criteria between the individual state and its region. No significant difference < 0.05) between each state and its region on these

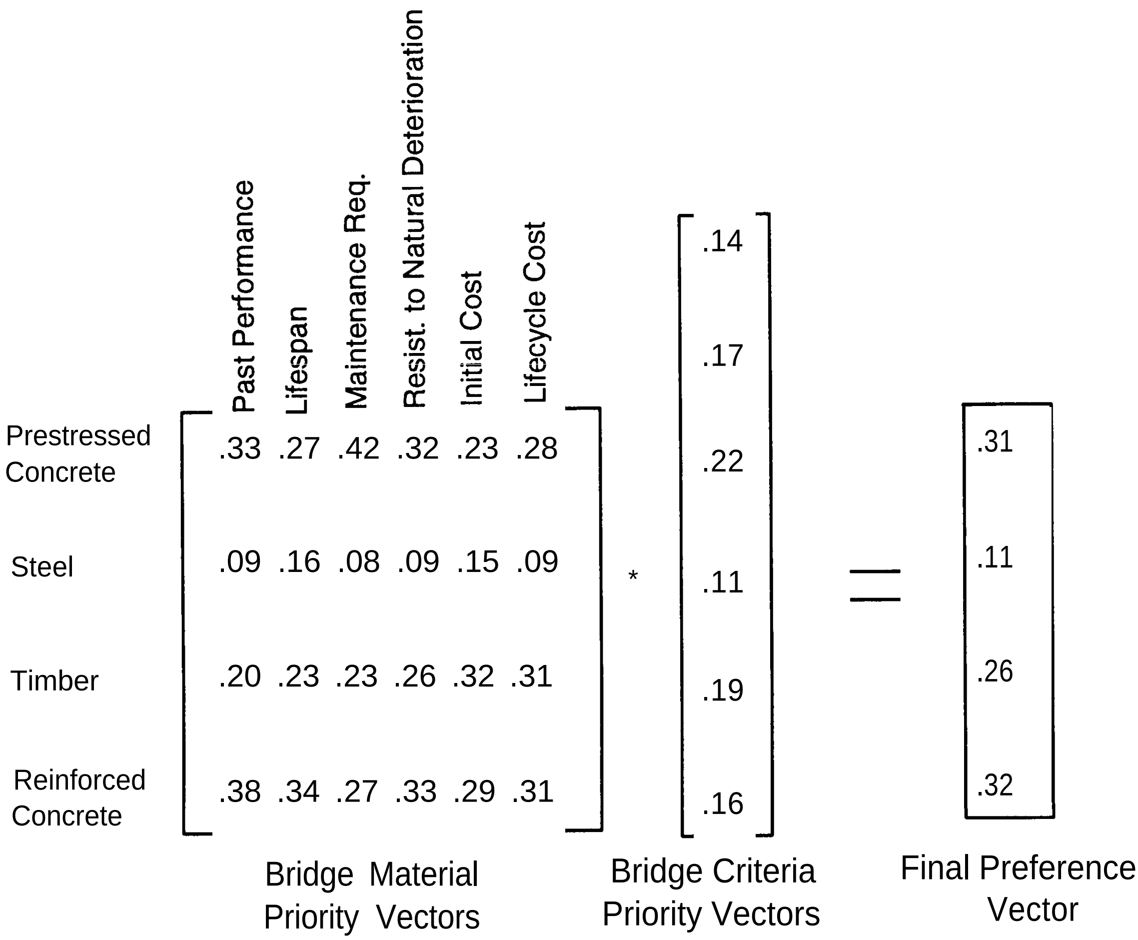

FIG. 2. AHP computation of the choice of a bridge material.

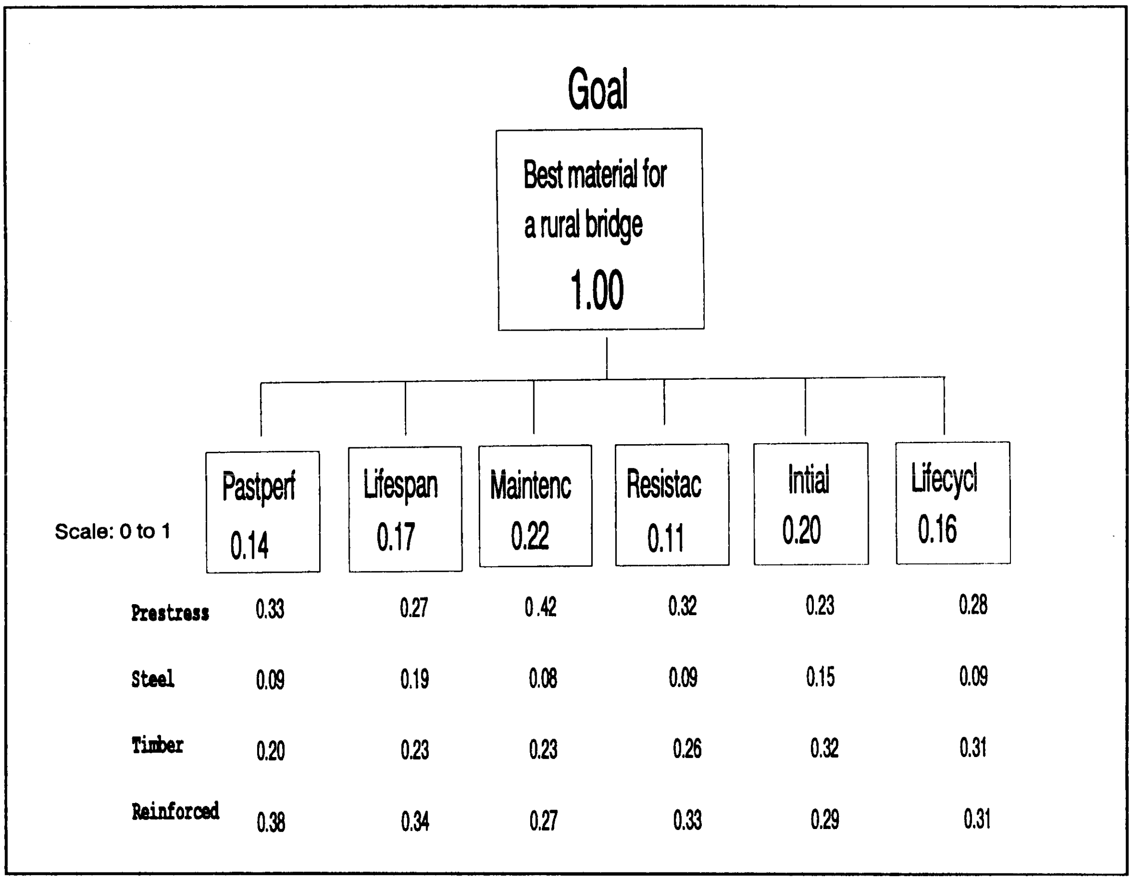

FIG. 3. Decision model for Wisconsin County decision-makers.

six factors could be shown. Analysis of Variance was used to determine if the states differed from others in the respective regions based on perceptions of timber as a bridge material. Again, no significant statistical differences could be shown. These results indicate that each state is representative of the region in which it is located and should provide a good indicator of bridge decision-making in that region.

Individual decision models can be combined arithmetically to perform statistical analyses (Saaty 1993). To determine if differences existed between states or decision-making groups, nonparametric statistical procedures were utilized. Nonparametric procedures are recommended when sample size is small or the distribution of the population from which the data are obtained is uncertain (Hollander and Wolfe 1973). The importance of the six major criteria in the bridge decision were quite uniform across decision-making groups and between states (Table 9). This agrees with earlier findings by the authors that major criteria are similar by groups and regions. Only for the criteria of maintenance did significant differences ($P = 0.05$) exist between the four states. This is to be expected because maintenance is strongly affected by climatic differences and local procedures.

Among the three major decision groups (DOT, private engineers, and local officials), aggregated across the four states, differences existed in the choices of steel and timber. Among the four states aggregated across the three decision groups, only reinforced concrete was not statistically different. In the states of Virginia and Wisconsin, differences existed be-

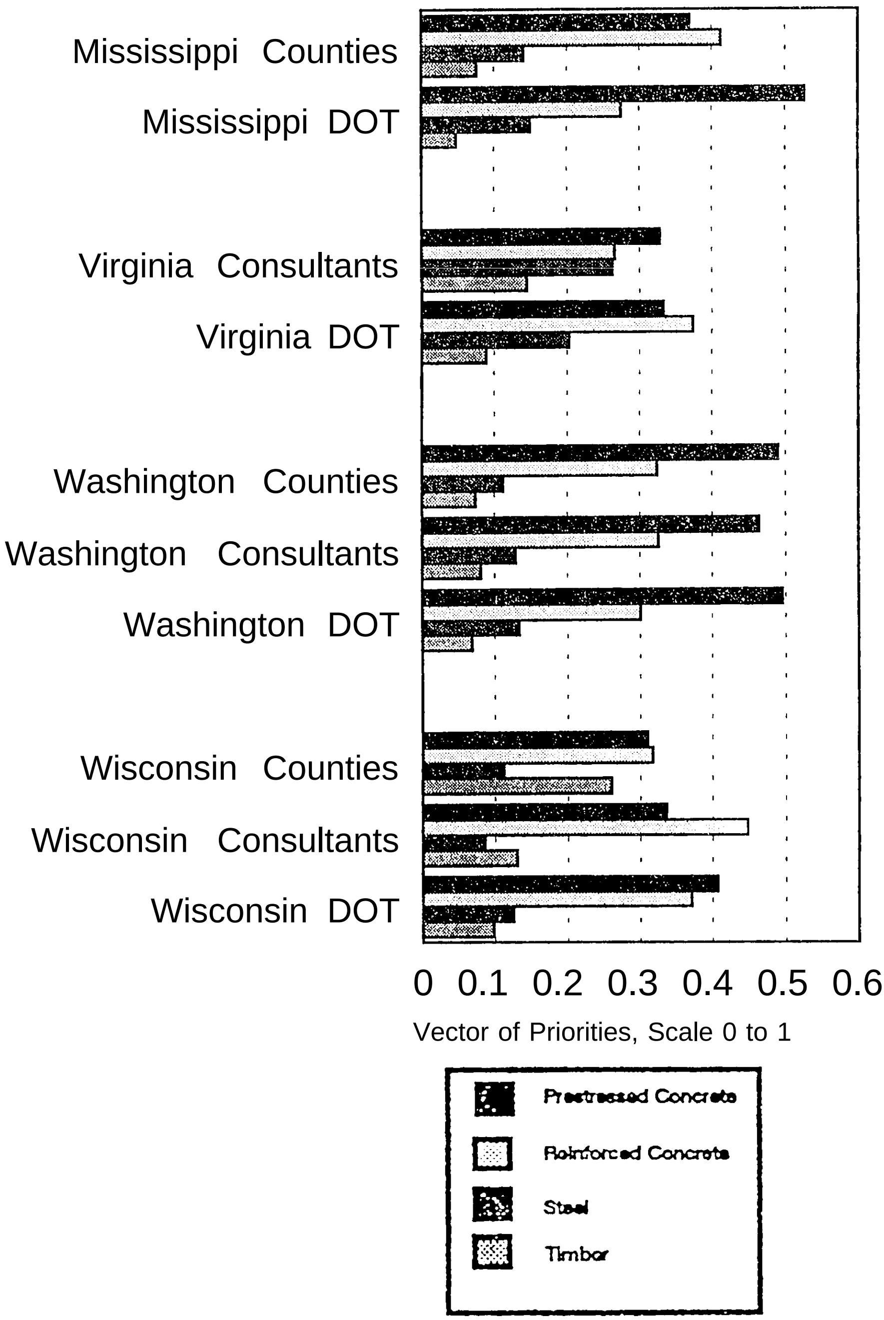

FIG. 4. Choice of a bridge material by state and decision level.

tween decision-makers' preferences for timber. Both prestressed concrete and reinforced concrete were deemed to have different preferences across decision groups in Mississippi. Only in Washington were the preferences for bridge materials not statistically different by decision group. These results indicate that even though decision criteria are viewed similarly, the extent to which various bridge materials are perceived as meeting those criteria varies

TABLE 8. *Summary of AHP models by state and decision-making level.*

State	Sample size	Incon. ratio	PRE	STL	TMB	REF	PP	LS	MN	RS	IC	LC
Priority ratings of material and decision criteria												
All states in study												
State DOT	29	0.01	0.44	0.15	0.07	0.33	0.16	0.17	0.20	0.16	0.13	0.17
Private engineers	20	0.01	0.38	0.15	0.12	0.34	0.19	0.13	0.22	0.15	0.14	0.17
County engineers	24	0.01	0.40	0.12	0.12	0.36	0.13	0.17	0.20	0.15	0.18	0.16
Mississippi												
State DOT	5	0.05	0.53	0.15	0.04	0.27	0.12	0.19	0.21	0.16	0.17	0.13
County engineers	8	0.04	0.37	0.14	0.08	0.41	0.14	0.11	0.17	0.19	0.19	0.12
Virginia												
State DOT	12	0.01	0.33	0.20	0.09	0.37	0.17	0.15	0.27	0.16	0.09	0.16
Private engineers	7	0.03	0.33	0.26	0.14	0.27	0.24	0.12	0.26	0.11	0.08	0.19
Washington												
State DOT	4	0.03	0.49	0.13	0.07	0.30	0.18	0.15	0.17	0.14	0.16	0.19
Private engineers	7	0.04	0.47	0.13	0.08	0.33	0.13	0.12	0.23	0.21	0.13	0.18
County engineers	7	0.05	0.49	0.11	0.07	0.32	0.09	0.16	0.21	0.16	0.14	0.23
Wisconsin												
State DOT	8	0.02	0.41	0.12	0.09	0.37	0.18	0.18	0.17	0.18	0.10	0.19
Private engineers	6	0.02	0.34	0.09	0.13	0.45	0.20	0.17	0.15	0.14	0.22	0.12
County Commissioners	9	0.02	0.31	0.11	0.26	0.32	0.14	0.17	0.22	0.11	0.20	0.16

Incon. ratio = inconsistency ratio, IC = initial cost, LS = lifespan, LC = lifecycle cost, MN = maintenance requirements, PP = past performance, PRE = prestressed concrete, REF = reinforced concrete, RS = resistance to natural deterioration, STL = steel, TMB = timber.

between states and between decision-making groups.

Sensitivity analysis was run on each model to determine if increasing the perceived performance on one or more criteria would affect the bridge decision. Prestressed and reinforced concrete were rated so much higher than steel and timber that changes in the criteria seldom resulted in changes in the decision. Only if initial cost became dominant in the decision would private consultants or local officials choose timber over steel. In no situation would Department of Transportation officials select timber based upon the six criteria measured. Department of Transportation engineers favored prestressed concrete. This may be attributed to their exposure to state and federal highway bridges and a lack of familiarity with timber design. Private consultants and county officials favored prestressed and reinforced concrete for rural bridges.

In Mississippi, only if initial cost became extremely important would county engineers consider using timber instead of steel. No changes would affect the Mississippi DOT engineers' decisions concerning timber. Private consultants in Virginia would choose timber above all other materials if initial cost became very important. No changes in criteria importance would affect the decision of DOT engineers in Virginia. In Washington, as initial cost became more important, local engineers and private consultants would favor timber over steel, but never over concrete. Again, no changes in criteria importance would affect the decision of Washington DOT engineers. Wisconsin highway officials would prefer timber as initial cost became very important and DOT engineers would favor timber over steel when maintenance became increasingly important. No changes in criteria importance would affect the bridge material decision of private consultants in Wisconsin.

CONCLUSIONS AND DISCUSSION

Decision-making applications of this research indicate that the Analytic Hierarchy Process can be utilized in a group situation to

TABLE 9. *Statistical comparisons between decision-making groups and states.*

Criteria	Comparison					
	Decision-groups [1]	States [2]	Decision-groups within Mississippi	Decision-groups within Virginia	Decision-groups within Washington	Decision-groups within Wisconsin
	Kruskal-Wallis Paired Sample or Oneway ANOVA *P* - Values					
Past performance	0.09	0.10	0.88	0.08	0.63	0.67
Lifespan	0.09	0.29	0.88	0.44	0.39	0.74
Maintenance	0.59	0.05	0.56	0.86	0.79	0.67
Resistance to natural deterioration	0.68	0.90	1.0	0.61	0.63	0.27
Initial cost	0.60	0.23	1.0	0.93	0.86	0.08
Lifecycle cost	0.56	0.08	0.66	0.55	0.69	0.42
Material preference						
Prestressed concrete	0.86	0.00	0.03	0.80	0.42	0.43
Reinforced concrete	0.88	0.47	0.03	0.18	0.74	0.06
Steel	0.01	0.00	0.24	0.20	0.80	0.08
Timber	0.07	0.00	0.38	0.04	0.92	0.00

[1]Comparison between 3 decision-maker groups: state DOT, private engineers, and local officials.
[2]Comparison between 4 states decision-makers Mississippi, Virginia, Washington, and Wisconsin.

assist highway officials in their choice of a bridge material. This model reflects the current bridge situation in the United States, with prestressed and reinforced concrete being the major bridge material chosen over 70% of the time by highway officials.

Decision-makers are in good agreement about the criteria that are important in the design decision. Across the United States, these individuals rated the most important criteria similarly by region and decision group. Maintenance requirements, initial cost, and past performance were the most influential criteria in choosing a bridge material. However, these criteria, when applied to the AHP decision models, influenced the choice of bridge material differently. Nevertheless, prestressed concrete and reinforced concrete were the materials of choice by every group in each state.

These results indicate that initial cost may be a competitive advantage for timber in bridge design. However, timber is rated so low based upon the other five criteria that it will very seldom be chosen as a rural bridge material. As little can be done with the criteria of past performance of a bridge material, educational efforts are needed emphasizing that timber bridges designed today are not the same as timber bridges built 40 to 50 years ago. Modern prestressed composites of steel and timber have the potential to perform as well, if not better, than other materials.

In addressing the criteria of maintenance, modern composites of steel and wood should reduce deflection and movement in timber bridges, which may have caused many of the past problems. Resistance to natural deterioration can be improved by building structures with water-shedding joints, good preservative treatments, waterproof surfaces, and stressed-type systems where the amount of water movement between wood members is reduced. Realistic comparisons of all bridge materials need to be made based on past design and construction practices. Concrete and steel structures may be performing better, because more of them have been built to modern standards than have timber bridges. Lifespan and lifecycle cost will both improve as timber lasts longer and becomes more competitive in the marketplace.

During interviews, questions were also asked about the problems with timber. In Mississippi, Virginia, and Washington a primary concern was lifespan. Engineers in each state indicated that treated timber is being replaced after 25 to 30 years in service. Initial cost of timber was a factor in most states, and timber is not perceived as cost-competitive. The cost of timber, therefore, cannot influence the decision over other bridge materials. Because timber often decays from the inside to the outside, inspection is more difficult for untrained engineers. The maintenance requirements of timber, compared to the other materials, were seen as deterrents to its use. Environmental concerns with wood preservatives and the timber resource supply were raised by Washington and Mississippi highway officials.

With state DOT engineers controlling the allocation of federal highway funds, efforts must be made to convince opinion leaders in this group about the viability of timber as a bridge material. Since this group chose timber the least, every effort is needed to demonstrate that timber is a viable material for rural bridges. To improve timber's perception by engineers, manufacturers need to address timber's short lifespan and maintenance requirements.

Marketing applications of this work indicate that timber manufacturers may need to address criteria other than those measured in this study to increase timber's market share. Other criteria on which timber may compete include: ease of repair, time of traffic interruption, resistance to de-icing chemicals, and aesthetics. Rural roads under county control offer the greatest opportunity for timber use, since these county individuals choose timber more often than DOT engineers. Manufacturers may want to look at other areas in which timber may be successful. Railroads, footbridges, light traffic bridges, and scenic covered bridges may offer further opportunities for timber in bridge applications.

ACKNOWLEDGMENTS

This research is based upon work supported, in part, by the National Timber Bridge Information Resource Center, USDA Forest Service, Northeastern Area State and Private Forestry, Morgantown, West Virginia, the Cooperative State Research Service, U.S. Department of Agriculture, under agreement No. 90-38420-5232 and The Center for Forest Products Marketing at Virginia Tech. The authors want to thank these agencies and all participants in the study for their generous contribution of time and information.

REFERENCES

CLAPP. V. 1990. Timber bridges in the real world. Wood Design Focus, Fall: 19–20.

DRUCKER, P. 1983. Managing for business effectiveness. Strategic management. John Wiley and Sons, Inc., New York, NY. Pp. 64-77.

—. 1984. Marketing management. 5th ed. Prentics Hall, Englewood Cliffs, NJ. P. 1.

EXPERT CHOICE. 1992. Decision support software. Version 8. Expert Choice, Pittsburgh, PA.

FEDERAL HIGHWAY ADMINISTRATION (FHWA). 1992. National bridge inventory data. U.S. Department of Transportation.

—. 1993. National bridge inventory data. U.S. Department of Transportation.

HARKER, P. 1989. The art and science of decision-making: The analytic hierarchy process. Pages 2-28 *in* The analytic hierarchy process: Applications and studies. Springer-Verlag, New York, NY.

—, AND L. VARGAS. 1987. The theory of ratio scaled estimation: Saaty's analytic hierarchy process. Mgmt. Sci. 33(11):1383-1403.

HOLLANDER, M., AND D. WOLFE. 1973. Nonparametric statistics. John Wiley and Sons, Inc., New York, NY.

JOHNSON, K. 1990. Timber bridge design, engineering and construction manual. 4th ed. Wheeler Consolidated, St. Louis Park, MN.

LEVITT, T. 1991. Thinking about management. The Free Press, New York, NY.

LUPPOLD, H. M. AND ASSOCIATES. 1990. Southern pine usage and timber bridge status often southeastern state highway departments. Holly Hill, SC. 89 pp.

NATIONAL INDUSTRIAL CONFERENCE BOARD (NCIB). 1964. Why new products fail. The National Industrial Conference Board Record, New York, NY.

SAATY, T. 1980. The analytic hierarchy process. McGraw Hill, New York, NY.

—. 1993. Expert choice: Decision support software user manual. Version 8. Expert Choice, Pittsburgh, PA. P. 90.

SCOTT, J., AND S. KEISER. 1984. Forecasting acceptance of new industrial products with judgment modeling. J. Marketing 48(Spring):54-67.

SINCLAIR, S. 1992. Forest products marketing. McGraw Hill, New York, NY. 403 pp.

STANTON, W. J. 1978. Fundamentals of marketing. McGraw Hill, New York, NY.

TIMBER BRIDGE INITIATIVE PROGRAM (TBIP). 1990. Crossings newsletter, sponsored by the Timber Bridge Information Resource Center, Morgantown, WV.

UNITED STATES DEPARTMENT OF AGRICULTURE (USDA). 1989. Rural bridges: An assessment based upon the national bridge inventory. Office of Transportation, Washington, DC.

—. 1993. The national timber bridge initiative–A status report. USDA Forest Service, Washington, DC.