National Cost Study of Timber Bridges

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Abstract

A study is underway to determine the initial cost of timber bridges compared to those of steel, concrete, and prestressed concrete bridges. This report discusses the early results of the timber bridge portion of the data set. To this end, timber bridge owners, as identified in the June 1994 National Bridge Inventory (NBI), were sent a specially designed questionnaire to survey cost information on timber bridges under their ownership. In order to establish a comparative basis, timber bridges were selected under the requirements that they be built no earlier than 1980 and be load rated according to American Association of State Highway and Transportation Officials (AASHTO) specifications. No private or government demonstration bridges were included in this study, Given these requirements, 1604 timber bridges were identified as survey bridges. This paper summarizes the analysis of data collected on the cost of timber bridge superstructures throughout the country. The results of such analysis suggest that unit costs were highest for both the longest and shortest bridges considered and tend to increase with higher load ratings. Additionally, it was noted that questionnaire responses were lower than expected for shorter, narrower bridges that were designed to carry lighter loads.

Keywords: Timberbridge(s) superstructure cost.

Purpose And Background

According to Smith and Bush (1994), there are approximately 200,000 deficient bridges throughout the country with a projected replacement cost of $84 billion. As Wolchuk (1988) indicates, concrete decks account "for about two-thirds of the deficiency cases." In the face of such staggering figures, there has been a renewed interest in the prospect of timber bridge utilization.

Throughout much of the 19th century, timber structures accounted for the majority of the bridges and railroad trestles in the United States. These were simple structures constructed of sawn lumber. Many timber bridges of the period even lacked preservative treatments that would allow them to withstand exposure to moisture and decay. Additionally, the older timber bridges were often crudely designed with little or no input by engineers. For example, it was not until 1840 that a complete stress analysis of a timber bridge design was included with the bridge designer's patent. In the 20th century, timber bridges were first replaced by steel. Steel competed with timber as a bridge construction material on a first-cost basis by 1910 and came to dominate the bridge market by 1930 (Ritter 1990).

The failure of older, primitive timber bridges and their eventual replacement by newer steel and, later, concrete designs is the likely source of a general perception held by some today that timber bridges are of inferior quality. Over time, however, the limitations of steel, concrete, and prestressed concrete have become apparent and range from susceptibility to corrosion to costly maintenance and replacement.

Beginning in the mid-1940s engineers began to reconsider timber for bridge construction. The development of such techniques as glue- and, later, stress- lamination demonstrated the strength of timber as a construction material and led to a renewed interest in timber bridge utilization (Ritter 1990). The rationale for this interest is three-fold. First, timber offers a potentially low-cost alternative to modern bridge construction materials such as steel, concrete, and prestressed concrete. Second, recent research indicates that timber bridges may be more durable than those constructed from other materials, particularly in cold climates where salts and other de-icing agents are frequently used. Third, it is hoped that the creation of a viable timber bridge market will encourage economic growth in rural areas with under-utilized timber resources.

The Timber Bridge Initiative program is a formal representation of the resurgent interest in timber bridges. Since its introduction, the program has resulted in over $17 million in congressional funding for bridge research, construction, and promotion (Smith and Bush 1994). As a result of such efforts, modern timber bridge designs, construction techniques, and preservative treatments have made it possible to better utilize local wood species that were previously viewed as undesirable.

Despite this interest, however, little is actually known regarding the initial and life-cycle costs of timber bridges relative to those of competing bridge construction materials. Data limitations have restricted the number and scope of studies in this area. Of the studies that have been conducted, most have been limited to a particular geographic region and a relatively small number of bridges. The latter shortcoming has made tests for statistical significance of cost comparison results virtually impossible. Accordingly, it is difficult to convince transportation agency officials that timber bridges are a viable alternative.

The main objective of this study is to determine the cost characteristics of timber bridges and to present them in an easily-comprehensible format to a wide-range of transportation officials. A secondary aim of this study is to identify and quantify the components of bridge superstructure costs.

Background Literature

Several studies have been conducted on the subject of timber bridge economics in recent years. The stated impetus for the bulk of these projects is the need for cost-effective alternatives to traditional infrastructure components of the national highway system.

In the majority of such work, five characteristics predominate. First, the studies tend to focus only on bridge superstructure, *i.e.* the deck, beams, girders, wearing surface, and periphery such as guard rails. Researchers have chosen this approach to avoid complications involved in attempting to identify and uniformly evaluate the cost components of bridge substructures. Specifically, they have found that substructure construction costs are more likely to vary with respect to site due to differences in geological formations, soil types, and other site-specific characteristics that are difficult to quantify. For example, Behr *et al.* (1990) consider superstructures only in their cost comparison of several bridge designs in the New England area. Similarly, Verna *et al.* (1984) limit their treatment of bridge replacement costs to major superstructure components, *e.g.* the deck and structural members.

Second, past research efforts tend to deal with initial as opposed to life-cycle costs. There is some question as to the need for initial cost information, since such costs only represent a portion of bridge costs over time. According to Wolchuk (1988), the immense task of rebuilding the nation’s bridges “should call for planning based on sound economic principles, with due consideration of the total cost of structures over their entire projected service lives.” Researchers cite difficulty in obtaining accurate, complete maintenance and replacement cost figures as the main reason for omitting life-cycle cost analyses.

A third characteristic of timber bridge cost research is that studies tend to be area-specific, *i.e.* they are limited to a particular state or geographical region. For example, the 1990 “Cost Comparison of Timber, Steel, and Prestressed Concrete Bridges” by Behr *et al.* applies only to potential bridge projects in New England and, thus, its results may not be wholly applicable in other regions. A study by Sarsley (1990) considers a single prototype stress-laminated timber bridge in the State of Connecticut. Studies by Verna *et al.* (1984) and Hill and Shirole (1984) deal with the similarly small geographic areas of the States of Pennsylvania and Minnesota, respectively. This limitation makes it difficult to apply the conclusions of past research to current bridge project proposals.

Fourth, some past research efforts rely on hypothetical as opposed to historical cost information. This is true of cost studies by both Behr *et al.* (1990) and Verna *et al.* (1984). In the former study, cost information was obtained by supplying participating contractors with a bridge design and asking each to provide an estimated bid. In the latter research effort, bids were supplied for competing deck replacement materials and designs. Despite its appeal from a data collection standpoint, this approach does not allow for the possibility of cost overruns and, thus, may serve to skew cost comparison results.

A final, critical characteristic of past research is a lack of statistical sophistication necessary to make valid comparisons between the costs of various bridge projects. As Behr *et al.* note in regard to their own study, this problem stems from the consideration of sample sizes that are too small for the application of any meaningful tests of statistical significance.

The results of past studies are varied and, at times, contradictory. Studies by Behr *et al.* (1990), Verna *et al.* (1984), and Hill and Shirole (1984) suggest that timber bridges are cost competitive with bridges composed of other materials for certain applications or within limited specifications, *e.g.* length, load-rating, *etc.* However, there appears to be no consistent pattern between studies as to the limits or characteristics of timber bridge feasibility. For example, Behr *et al.* (1990) find a positively-sloped relationship between unit cost and structure length, while Verna *et al.* (1984) find an inverse correlation between the two. A need exists for further clarification of timber bridge cost relationships.

Methods

It is the intent of this project to overcome some, but not all of the limitations of past research efforts. The study is unique in many regards, not the least of which is its sheer magnitude. The project covers bridges throughout the United States and from a variety of locations. This comprehensive approach should help to control for variable factors such as climate, labor, and transportation costs and will allow for the establishment of practical, generally-applicable results. Furthermore, the project utilized cost information from completed, non-demonstration bridge projects as opposed to cost estimates from hypothetical bridge sites. Finally, a detailed comprehensive data set was generated and statistical tests completed in order to assess the validity of study conclusions.

Some of the limitations of past research apply to the current study as well. Due to the potential variability of substructure costs with respect to site specific conditions, *e.g.* differences in soil composition and terrain between bridge sites, the study focuses primarily on superstructure costs. In addition, only initial costs are evaluated, since there are inadequate data for a meaningful comparison of life-cycle costs. This is probably due, in part, to the fact that modern-design bridges have needed little repair. Long-term cost data are often only available for bridges of antiquated design and construction.

Project methodology consists of two major tasks, data collection and compilation, and statistical analysis. The following two sections explain the project methodology in greater detail.

Data Collection and Compilation

Timber bridge selection was based on the U. S. Department of Transportation Federal Highway Administration National Bridge Inventory (NBI), a database that contains structural and inspection statistics for the nation's 668,433 bridges and other highway structures greater than 20 feet in length (FHWA 1988). The NBI includes such information as bridge identification or structure number, location, ownership, length, width in feet, the number of lanes, and the year built, as well as inspection information regarding each bridge's structural condition. The NBI database is updated continually and is available on magnetic computer tape.

For this project, a copy of the June 1994 NBI was obtained in magnetic tape form and downloaded onto a computer. Due to an error in storage or data entry, bridge information for the State of Texas was improperly aligned and had to be parsed into a usable format by software developed specifically for this task. Three bridge records were deemed beyond repair and lost during this procedure. At this point, unnecessary fields were removed from the database in an effort to reduce file size. Of 116 total NBI database items, only 36 were retained. Among these 36 were the state, owner, county, place, structure number, location, feature intersected, year constructed, number of lanes on, design load, deck width, and structure length. Some items, *e.g.* structure number, owner, county, *etc.*, were maintained to identify each bridge and assign it with its owner-agency. Others, such as structure length, deck width, year constructed, *etc.*, provide data on vital bridge characteristics and were selected for purposes of comparison and statistical analysis. The resulting database was then loaded into Microsoft Access version 2.0 to aid in data storage and management.

Once in this format, the database was again filtered to eliminate records, *i.e.* bridges, that fell outside the scope of the current project. Records were maintained only for load rated bridges constructed during or after 1980. This year was selected because many modern timber bridge innovations such as glue and stress lamination were unavailable or unknown in prior years. The database was also filtered to remove records representing pedestrian and railroad bridges. The resulting database contained 68,500 records.

At this point, a sub database was developed containing only timber bridges and meeting the above filtering requirements. The resulting database contained 1604 timber bridge records, each containing identification, design, and structure information as outlined above.

Here, efforts were directed towards obtaining cost, bid, and supplier information not found in the NBI. Using ownership information and state and county code numbers supplied in the NBI database, the *Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges* (FHWA 1988), and the *Codes for Named Populated Place, Primary County Divisions, and Other Locational Entities of the United States and Outlying Areas* (national Bureau of Standards 1987), an owner-agency was identified for each bridge record.

A form letter was sent to Department of Transportation or other central transportation office in each state that requested a list of names and addresses for county or transportation district officials and their agencies. The resulting lists were then merged to provide a contact person and an address for each timber bridge record in the project database. Similar lists were obtained for National Park Service and USDA Forest Service offices and the appropriate agency contacts were linked with each bridge.

Once a contact and address were established for each timber bridge record, a detailed two-page questionnaire was developed to obtain cost, bid, and contractor/supplier information from each respective bridge owner-agency. Additionally, owner-agency officials were asked to verify the accuracy of NBI identification information, location, length, and the year constructed for each bridge. These questionnaires were then mailed along with a return envelope to respective bridge owner-agencies across the country.

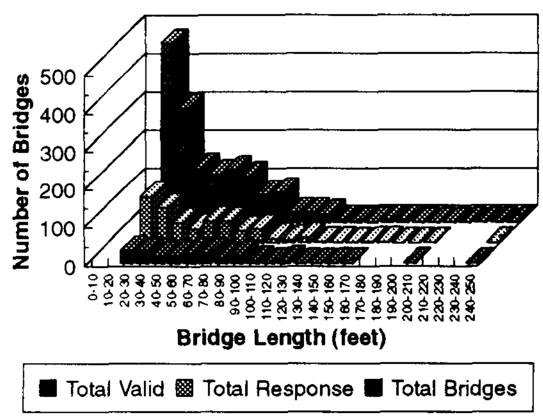
Upon receipt of completed timber bridge questionnaires, the new bridge data obtained from owner-agency officials were entered into the database by record. Those records containing superstructure cost information or a final contractor or bid worksheet were flagged for later identification as “valid’ or usable bridges. The newly obtained information was then used for a preliminary timber bridge cost analysis. Questionnaire response information was compared to that of the total number of timber bridges to ascertain whether the chosen sample exhibited the same characteristics as the population as a whole.

Data Analysis

Upon receipt of questionnaires from transportation owner-agencies, the characteristics of the bridges for which responses had been returned were compared with those of the entire population of timber bridges. The former group of bridges is referred to here as the *response* set, while the latter, the *total* population. Here, it was assumed that the return of bridge questionnaires is random if the number of bridges from the response set with a given characteristic, for example an HS 20 load rating, is proportional to the total population of bridges possessing that same trait. This analysis was completed for bridge structure length, deck width, number of lanes, load rating, and year constructed. Similarly, data from bridges for which usable superstructure cost information had been returned was compared to those of the total population. This smaller subset of bridges from the response set with complete cost information is referred to here as the *valid* set. The results of these comparisons are summarized graphically below. A chi-square test was also performed to determine whether the observed number of bridges for each characteristic differed significantly from the expected number for that characteristic. The expected number for a given category was based on the proportion of the number of bridges from that category to the total population. The resulting chi-square value is then compared to an accumulative distribution table to assess whether noted differences are statistically significant.

Structure Length - Of the 1604 timber bridges considered, 1591 possessed complete structure length information, and 553 of the 556 response set had usable length data. Of the response set, 223 were considered valid, since they included both

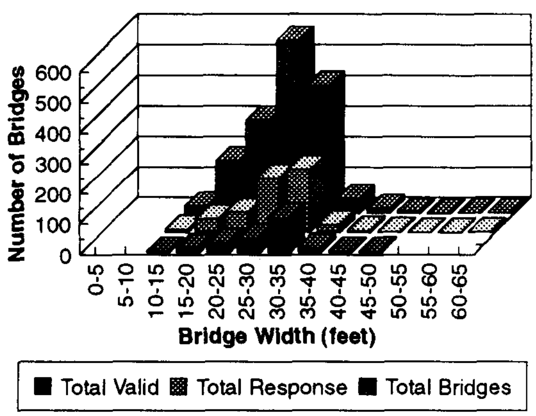
Figure 1 - Number of Timber Bridges versus Bridge Length.



complete structure length and superstructure cost information. As seen in Figure 1, the number of bridges from the response and valid sets appear to be roughly proportional to the total number of timber bridges from the original database for each ten-foot interval of length. Perhaps the single largest discrepancy is the lower ratio of response and valid set bridges between twenty to thirty feet in length to the total number of bridges in that range. The results of chi-square analysis suggest, however, that differences between the response and valid set bridges and the total population are significant, with chi-square values of 39.34 (at just above the 2.5 percent level of significance) and 71.47(at the 0.5 level of significance), respectively with twenty-four degrees of freedom. This is probably due to an under representation of bridges in the twenty to thirty foot category and an overrepresentation of bridges in the ninety to one hundred foot category. Removing these categories reduces the chi-square values to 36.30 for response set bridges and 59.08 for valid set bridges, with 22 degrees of freedom. The under-representation of bridges shorter than thirty feet may stem from a lack of reliable record-keeping for short, relatively inexpensive timber bridges in transportation agency offices. This is supported by questionnaire comments and is supported below as other bridge characteristics are considered.

Width - Of the initial 1604 timber bridges, 1570 possessed complete width information, as did 556 of 556 response bridges. All 223 bridges of the valid set had usable width information.

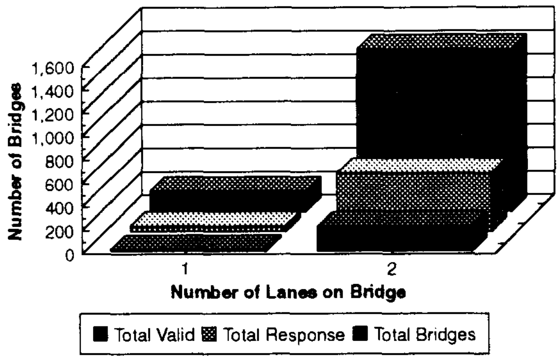
Figure 2 - Number of Timber Bridges versus Bridge Width.



While the response and valid set characteristics, as seen above in Figure 2, appear to match those of the total population, the results of a chi-square test suggest that the differences between observed and expected values are statistically significant at the 0.5 percent level of significance, with chi-square values of 77.03 and 56.61, respectively, and 12 degrees of freedom. Again, a large discrepancy exists for the range of values between twenty-five and thirty-five feet in width. When this range is removed, the values drop to 30.99 for the response set and 17.96 for the valid set, with ten degrees of freedom, making the difference between the valid set and the total population significant only at the ten percent level. Again, one finds that the smaller or, in this case, narrower bridges tend to be under-represented by the valid and response sets, with one exception noted in the latter. Likewise, wider bridges tend to be over-represented. As mentioned above, this may stem from a deficiency in record-keeping for smaller, less-sophisticated bridges.

Number of Lanes - Of the total data set, 1571 bridges had information regarding the number of lanes that cross each bridge. Of the 556 response bridges, 551 listed the number of lanes. 222 of these included complete cost data as well. Only one and two lane bridges are present in the population. At first glance, the lane characteristics from the response and valid sets appears to follow those of the total population, as seen below in Figure 3.

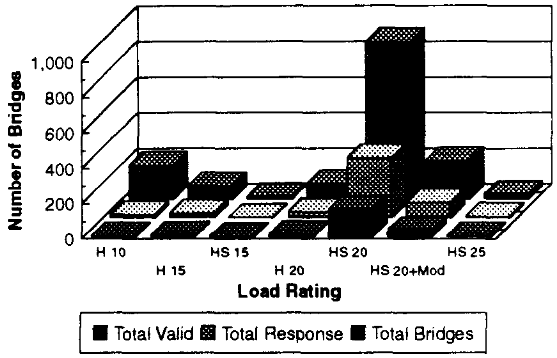
Figure 3 - Number of Timber Bridges versus the Number of Lanes on Bridge.



As experienced above, however, a chi-square test reveals that the differences between the population set and the response and valid sets are statistically significant at below the ten percent and 2.5 percent levels, respectively, with one degree of freedom. Again, most of the discrepancy appears to be the result of an under-representation of smaller, single-lane bridges.

Load Rating - Load ratings were absent for several bridges in the initial population. Only 1517 of 1604 bridges had complete data for this category. Similarly, only 527 of 556 response bridges listed a load rating, and 216 of these included complete cost information. Figure 4 illustrates that the above trend towards under-representation for smaller bridges was again apparent for load rating. This observation was supported by the results of a chi-square test which suggest that the differences between the total

Figure 4 - Number of Timber Bridges versus Load Rating.

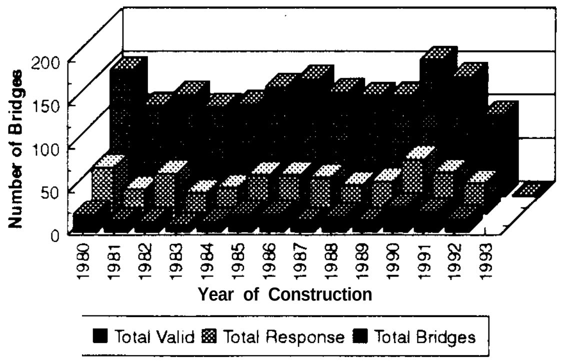


population and the response and valid sets are statistically significant at the 0.5 percent level, with chi-square values of 41.89 and 31.30, respectively (with seven degrees of freedom). Here, it was noted that H10 bridges, the lightest load classification in the total data set and probably that with the smallest bridges, were under-represented in the response and valid sets. When this category was removed, chi-square values improved to 6.50 for response bridges and 10.82 for valid bridges, with six degrees of freedom. Differences between the valid set and the total population were only statistically significant at the ten percent level. The response set was not significantly different from the population.

Location - The initial population of 1604 timber bridges was spread across the country among forty-seven of the fifty states. The response set demonstrated similar characteristics as the total population, as did the group of response bridges for which cost information was available. However, a chi-square test indicates that the differences between the total population and the response and valid sets were statistically significant at the 0.5 percent level. Based by comments provided on bridge questionnaires by owner-agency transportation officials, the reasons for failing to provide cost information for bridges ranged from inadequate record-keeping systems, to short-staffed or busy offices.

Year Constructed - Of the 1604 bridges in the initial data set, 1590 included information regarding the year each bridge was constructed, as did 555 of 556 response set bridges. Of the response set, 222 possessed complete cost information. As noted in Figure 5, no perceptible difference exists between the characteristics of the total population and those of the response and valid sets.

Figure 5 - Number of Timber Bridges versus Year Constructed.



A chi-square test supports this finding and suggests that differences between the population and the response and valid sets are not statistically significant, with chi-square values of 10.01 and 11.43, respectively (with thirteen degrees of freedom). It is interesting here to note that a category that is not size-related turns up no significant difference between the population and the response and valid sets. This observation indirectly supports the assumption that questionnaire response is a random process, when smaller bridges are excluded.

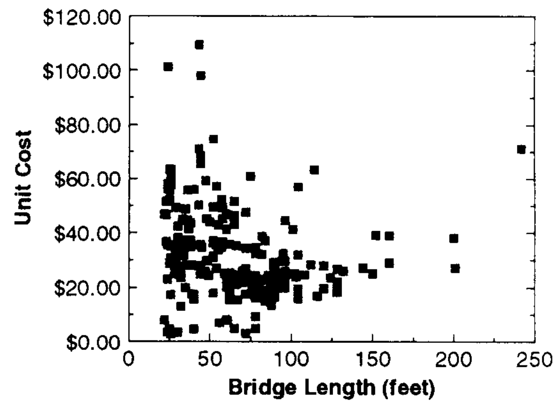
Results

Unit Cost versus Structure Length

Of the studies conducted on timber bridge costs, most focus on the relationship between bridge length and superstructure cost per square foot. It, thus, seems appropriate to address this factor first.

After indexing the unit cost figures to 1982 dollars using a construction sector producer price index (PPI) from the *Economic Report of the President* (Council of Economic Advisers 1996), the relationship between superstructure unit cost and structure length takes on a somewhat parabolic shape with high variability (see Figure 6). Thus it appears unit cost is at its highest at both short bridge lengths, roughly between 20 and 50 feet, and longer lengths above 150 feet.

Figure 6 - Unit Cost (indexed) versus Structure Length.



Higher costs at lower structure lengths may exist because of fixed costs, such as that for equipment rental, that are required regardless of length. These costs may only begin to be recovered on larger projects. In addition, there may be more variability of design at shorter lengths that leads to higher costs when untried bridges are constructed. At the other end of the spectrum, higher costs at relatively high structure length are probably associated with the increase in construction material volume necessary to maintain a given carrying load for longer bridges. In addition, a lack of standardization implicit in rare, longer lengths may serve to increase costs as untried designs and construction practices are advanced.

Unit Cost versus Load Rating

Because bridges built to carry higher loads may require more of the primary construction material per square foot of deck, it is likely that load rating is an important cost factor. There are seven different load ratings represented in the total data set: H10, H15, HS15, H20, HS20, HS20 + mod, and HS25. All of these load classifications were present in the valid data set, with the exception of HS15. In addition, there were few data points available for the H10, H15, and HS25 load ratings. This shortage follows the general trend in the population as a whole, with the majority of bridges falling in the H20, HS20, and H20 + mod classifications.

The number of observations available and mean unit cost for each load rating are listed below in

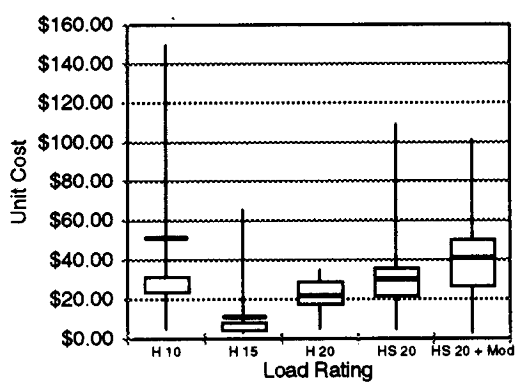
Table 1. Indexed unit costs for each load rating were sorted in ascending order and divided into

Table 1 - Number of Observations Available and Mean Unit Cost by Load Rating.

Load Rating	Number of Observations	Mean
H10	**4**	**52.41**
H15	**8**	**13.51**
HS15	**1**	**46.92**
H20	**9**	**21.67**
HS20	**154**	**30.34**
HS20 + Mod	**37**	**40.44**
HS25	**3**	**37.83**
Total:	**216**	**31.67**

quartiles. These quartiles were then used to develop the box plot shown in Figure 7. Because of the limited number of data points for the HS15 and HS25 load ratings, these categories were not included. The boxes in Figure 7 represent the

Figure 7 - Unit Cost (indexed) versus Load Rating.



middle 50 percent of the data for each load rating. The whiskers that extend from the boxes show the range of cost data for each category. The bold, horizontal lines show the mean for each load rating.

An initial look at the box plot suggests an upward trend in unit cost as load ratings increase. It should be noted, however, that load ratings H10, H15, and H20 are each based on between four and nine data points. In addition, an unusually high unit cost exists for one bridge in the H10 category, which dramatically alters the mean for that load rating. The elimination of this outlying observation lowers the mean unit cost for the H10 load rating to $20.05.

Unit Cost versus Region

Adopting regional boundaries used in a USDA Timber Bridge Information Resource Center (TBIRC) report (TBIRC 1993), superstructure unit cost was again evaluated, this time by region. One region, Northeast, was actually a hybrid of two TBIRC regions and includes states from along the Atlantic coast from Maryland north. The number of observations available and the mean unit cost for each region are shown in Table 2. Within the valid

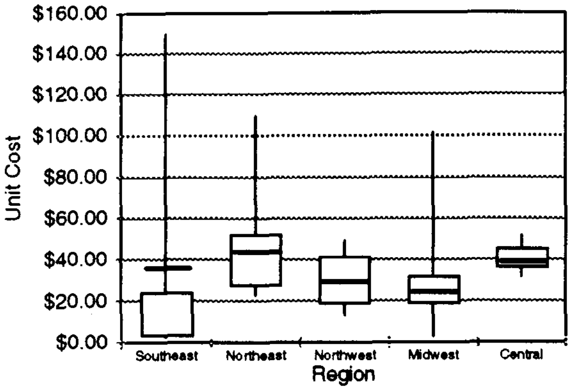
Table 2 - Number of Observations Available and Mean Unit Cost by Region.

Region	Number of Observations	Mean
Southeast	**5**	**$36.96**
Northeast	**54**	**$42.21**
Northern	**2**	**$28.79**
Northwest	**7**	**$30.06**
Midwest	**148**	**$27.81**
Central	**4**	**$41.40**
Intermountain	**2**	**$27.22**
Total:	**222**	**$31.84**

set, the two largest regions were the Northeast with 54 data points and the Midwest with 148 data points. The remaining regions all had between two and seven valid bridges each within their boundaries. The mean unit cost for the Northeast region was $42.21 while that for the Midwest was $27.81.

Like those for the load ratings above, unit costs for each region were sorted in ascending order and divided into quartiles. These quartiles were then incorporated in the box plot in Figure 8. The Northern and Intermountain regions were not included due to data limitations. The means for each region are again represented by the bold, horizontal lines, while the boxes include the middle 50 percent of the observations for each category. The whiskers represent the range for each region. The boxes in Figure 8 roughly follow the regional means reported above, with the exception of that

Figure 8 — Unit Cost (indexed) versus Region.



for the Southeast region. The mean for this region appears to have been skewed upward by the same unusually high unit cost noted earlier for the H10 load rating. Removing this outlying data point reduces the mean unit cost for the Southeast region from $36.96 to $8.82.

Concluding Remarks

The dual purposes of this paper were to describe the cost characteristics of timber bridge superstructures throughout the country and to identify the factors that comprise bridge costs. Based upon the above analyses, the following generalizations can be made. There appears to be a roughly parabolic relationship between the unit cost of timber bridge superstructures and structure length in feet, with higher costs at both the shortest and longest lengths. Additionally, there is a somewhat positive relationship between indexed unit cost and load rating, Finally, despite differences in mean unit costs among regions, there is no identifiable trend associated with this geographical breakdown. These findings are limited, however, due to the wide variability in the available data and, in the case of load rating and region, by the limited number of data points for some categories. This circumstance may relate to one of three causes: unspecified cost factors, a lack of standardization in timber bridge construction, or a realization of the market niche for timber bridges.

First, it is likely that still other cost components play an important role in determining bridge costs. For example, such factors may be site-specific cost determinants relating to site preparation and material and equipment transportation. If this is indeed the case, a similar characteristic of an unexplained variation in bridge cost for a given length should be observable for bridges constructed of other materials. Future research efforts will focus on this possibility and will also include a cost comparison between material types. The acquisition of cost data for bridges of other material types will enable the use of a paired *t* test to analyze variability in bridge cost by type of construction material, even if both sets of data have high variability in unit cost versus other factors.

An additional explanation for cost variability may relate a lack of standardization in timber bridge design and construction resulting in ad hoc assembly practices by various transportation agencies. If so, the implementation of standardization efforts by Lee, Ritter, and Triche (1995) and others will likely lead to a reduction in timber bridge costs. Again, future research efforts on other bridge construction materials will help assess the validity of this assumption, since standards are already in place for other popular bridge materials.

Finally, there exists the possibility that timber bridges have found their market niche in the form of primarily small-crossing, rural, and, most importantly, non-traditional applications that lead to a wide-range of construction practices and design concepts unique to timber alone. The limited number of timber bridges above 100 feet in length and absolute lack of bridges of more than two lanes in width support this notion. Whatever the case, it seems that future research is necessary to help identify the observed variation in timber bridge costs.

Given the size and scope of this data set, it is easy to understand the limitations of past studies to explain the nature of timber bridge costs. While the cost components considered above appear relevant, there remains a largely unexplained variability in superstructure cost. This finding heightens the need for an examination of cost data for timber bridges versus those constructed of steel, concrete, and prestressed concrete. Only after a thorough comparison between material types will the large-scale feasibility of timber bridges be recognized.

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