Timber Bridges: Part of the Solution for Rural America

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A detailed inventory of the condition of highway bridges in the United States has been prepared in recent years. The study described in this paper indicates that an overwhelming proportion of rural highway bridges are on roads that serve low volumes of traffic. As a result of recent bridge failures and the vast number of bridges whose intended service lives have been exceeded, significant federal funding has been targeted for rehabilitation and replacement. The importance of directing an optimal proportion of funds to rural bridges is examined. The poor condition of bridges in rural regions and the impact of the problem on the the rural livelihood and economy is documented. The findings of a search of the National Bridge Inventory to assess the performance and current condition of timber bridges are reported. The function that the use of contemporary timber bridges can serve in addressing the severe rural bridge restoration needs has been identified. Descriptions are provided of favorable factors that were found to pertain to both existing and recently developed timber bridge technologies. These factors provide an incentive to the continued and increased use of timber bridges. A case study in Pennsylvania is documented to profile the nature of timber bridge use and the negative impact of unattended bridge repair needs in a state with a diverse rural economy. Constraints and reservations that have existed in regard to the recent use of timber bridges in rural regions are discussed. An exhaustive program of engineering development, research, and transfer of technology that is related to a plan to significantly increase the use of timber bridges in the rural highway environment is summarized.

RURAL AMERICA AND THE NATIONAL BRIDGE PROBLEM

The deterioration of the nation's bridges is a national problem that affects rural America. Transportation accessibility, which includes time, cost, convenience, dependability, and safety factors, influences rural America's economic activity and development potential.

The Rural Economy

The rural economy has currently diversified beyond its traditional agricultural base (*1*). These changes include a reversal during the 1970s of the decades-long trend of net outmigration; increasing employment from the trade, services, and manufacturing sectors; and less isolation, partly as a result of improved communications, transportation, and employment opportunities. Seven types of rural counties have been identified that characterize about 85 percent of the nation's 2,443 rural counties. The different types of rural activities and their general locations are shown in the map in Figure 1. The farming-dependent counties still compose the largest single group; they represent 29 percent of all nonmetropolitan counties, but only 13 percent of the nonmetropolitan population.

As the rural economy has become more diverse, the options for transporting people and goods have lessened. Rural regions have been especially affected by the abandonment of low-density railroad branch lines and the mergers of railroads. Combined with reductions in air service to rural regions, this has made much of the rural economy dependent on the availability of truck transportation.

In the farm sector, an increase in farm size, mechanization, and productivity has resulted from the use of larger trucks and farm implements, and heavy production inputs, such as feed, fertilizer, and fuel, which are supplied by the nonfarm sector. As the abandonment of railroad branch lines continues, the use of heavy trucks in rural regions can be expected to increase in order to carry production from the farms and other businesses to the distant elevators, ports, and markets. Farm families are also currently relying on the road system to travel to jobs off the farm. In fact, almost 54 percent of the total income of farm households in 1984 came from nonfarm sources (*2*).

In the face of this dependence on trucking, inadequate roads and bridges have resulted in detours and other travel inconveniences, slower delivery times, increased loss and damage of product, higher vehicle operating costs, and generally less efficient transport. Efficiency of transport is a key concern of businesses that serve farms and other centers of rural production because it affects the profitability of their operations and their willingness to serve rural regions.

Rural people and those serving rural regions need and expect the road system to meet their logistical needs. In a 1982 study of the economic and social impacts of deficient bridges, Wilbur Smith and Associates found that the use and delivery of seven vital community facilities and services (e.g., the use of schools and fire protection) were adversely affected by the existence of inadequate and collapsed or closed bridges (*3*).

National Bridge Problem

In its Seventh Annual Report to Congress on the status of the nation's bridges, the U.S. Department of Transportation (DOT) reported that 574,729 highway bridges were inventoried in the United States at the end of 1985 that were 20 ft or more in

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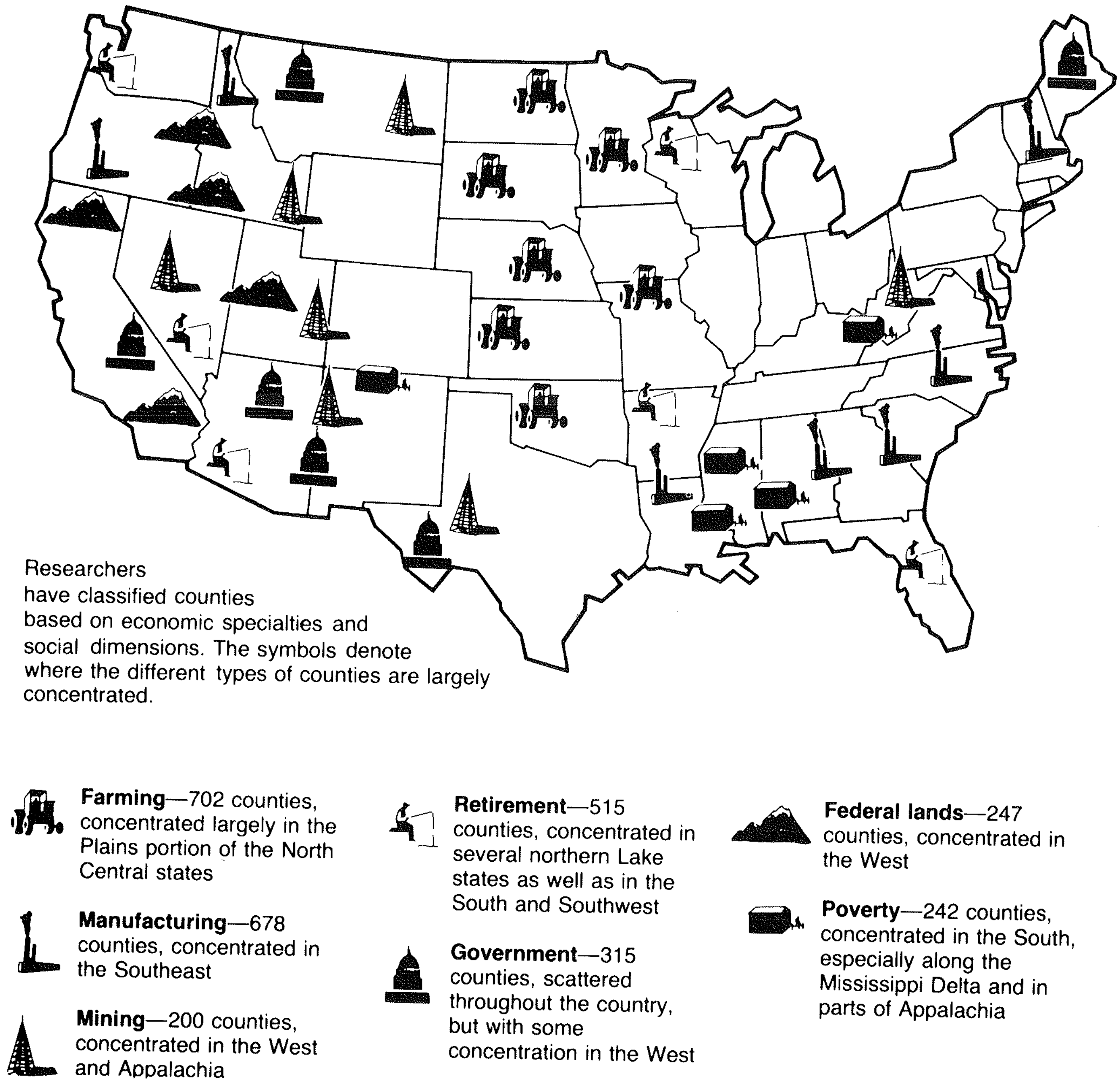

FIGURE 1 **Types of rural counties in the United States. Source: *Farmline,* U.S. Department of Agriculture, Sept.-Oct. 1985.**

length (*4*). Based on data furnished by the states, the FHWA estimates that about 42 percent of these bridges are deficient for either structural or functional reasons. The distribution of deficient bridges indicates that the bridge problem is national in scope.

Each inventoried bridge is assigned a sufficiency rating to be used to rank bridge reconstruction needs. The sufficiency rating reflects three considerations in the following relative percentages: structural adequacy and safety—55 percent, serviceability and functional obsolescence—30 percent, and essentiality for public use—15 percent.

Based on assigned sufficiency ratings, these bridges are designated as eligible for either replacement or rehabilitation under the Federal Highway Bridge Replacement and Rehabilitation Program (HBRRP). Higher priorities for federal replacement or rehabilitation funds are given to bridges that have lower sufficiency ratings. Bridges that are rated 50 to 80 are eligible for rehabilitation. Those rated below 50 are eligible for replacement. Bridges must be 20 ft or more in length to qualify for either category. Lists of eligible bridges are compiled by each state. Minimum and maximum limits exist for the percentage of annual federal funds any state may obtain. Legislation also directs that the states must use no less than 15 percent and no more than 35 percent of the HBRRP funds each year on bridges off the federal-aid systems. From fiscal years 1979 to 1985, the states obligated 19.7 percent of the total apportioned funds for the off-system (primarily rural) bridges (*4*).

Data published by the FHWA indicate that about 470,000 inventoried rural bridges existed in 1984, which included some bridges that did not receive federal aid (*5*). These rural bridges represent about 80 percent of the nation's total bridges. Almost half of the rural bridges are classified as local in function. A majority of the local rural bridges have relatively low traffic volumes of less than 100 vehicles per day (vpd) (*6*).

About half of the rural bridges also are considered to be deficient for either structural or functional reasons. Many were built in the late 1800s and early 1900s, when traffic volumes were less than they are today and the loads transported over the nation's highways were much lighter. Today's higher traffic volumes and heavier vehicles and loads require wider and stronger bridges. Some of the principal reasons for bridge deficiencies include a lack of proper maintenance that is partly a result of insufficient maintenance funds; hostile environmental conditions; wear from usage; inadequate initial design or construction; and exhaustion of the expected service life.

The classification of a bridge as deficient for functional reasons can often be remedied by upgrading it, but this is contingent on economic factors. A bridge that is classified as structurally deficient has the potential of being unsafe. Indeed, national accident statistics indicate there is a major fatality problem on rural roads (*7*). In 1984, about one-third of the total number of fatal and nonfatal traffic accidents occurred on rural roads. These accidents accounted for over half of all traffic fatalities. The FHWA reports that the most common locations for a fatal accident on a rural local road are at intersections, curves, or bridges, in that order (*8*).

The National Safety Council has explained that "motorist expectancy," based on driving experience and training, is a significant underlying reason for fatal accidents in rural regions, where traffic volumes tend to be low (*9*). The rural road system is traveled by motorists from all parts of the country. For economic and social purposes, it often functions as part of the larger national system. If the road system does not meet driver expectations, then accidents and fatalities are more likely to occur.

Because a deficient bridge is not necessarily unsafe, many of these bridges may be able to safely serve most traffic with proper posting, erection of signs or signals, installation of crash protection, and law enforcement. Unfortunately, such actions may inhibit the movement of heavy trucks and wide equipment, and result in costly detours for these vehicles.

In a study that investigated the economics of reducing the county road system in Iowa, the travel costs for different types of rural travel were estimated for three varying regions of the state (*10*). The majority of the travel in the study areas was made for household purposes. Farm travel, which ranked second, included all farm-related traffic by automobile, farm implements, farmer-owned trucks, and commercial vehicles. Although household travel was a very large percentage of the total miles traveled, it represented a relatively small percentage of the total vehicle travel costs. The cost of farm-related traffic was found to be high in relation to the total farm miles driven.

The rural road system is almost entirely the responsibility of the state and local levels of government. About 66 percent of the rural road mileage is currently under local control; 25 percent is under state control, but this varies considerably by state (*5*). For instance, nearly one-third of the rural mileage in the western states is under federal control because large tracts of land are in federal parks, forests, and reservations. In the South Atlantic region, several states have assumed the legal responsibility for all or nearly all of the local roads. Conversely, in many states of the North Central region, local governments have jurisdiction over most of the rural roadways.

Federal highway funding for rural regions is very limited in comparison to the dollar amount needed to make improvements; therefore, rural officials have relied heavily on other revenue sources. Depending on local and state government structures and laws, a combination of local real estate or property taxes, user fees, and direct federal and state grants, including revenue sharing, has been used (*11*). Rural governments are currently experiencing a high degree of fiscal stress, partly because they must provide costly services to lightly populated areas (*12*). They are also increasingly being asked to serve diversified needs that would further strain their limited resources.

Solutions to the rural bridge problem will vary by state and locality. One possible but previously overlooked solution is the timber bridge. Objective, recently garnered data on the timber bridges in the FHWA's inventory of bridges indicate that timber bridges are numerous, durable, and widespread. Modern advances in timber use have made the timber bridge an increasingly attractive option for small, local road crews.

STATUS OF THE NATION'S TIMBER BRIDGES

Timber Bridges on Public Highways

In 1985, the Technical Committee on Timber Bridges of the American Society of Civil Engineers (ASCE) sponsored a search of the FHWA's National Bridge Inventory (NBI), which includes data on the nation's inventoried public highway bridges that are 20 ft or more in length. The inventory was prepared "to provide Congress with an accurate report of the number and state of the Nation's bridges, in order to guide future legislation in the matter" (*13*). The ASCE Committee sought to produce objective, realistic information on the collective structural status of timber bridges in the United States; to make assessments of their longevity and durability; and to investigate their importance to secondary and rural networks.

The ASCE search was performed in two stages. The first stage was a simple, state-by-state, one-line listing of 11 details about each timber bridge in the bank. The second stage of the search was more exhaustive. Comprehensive matrices of data were produced for each state and then were compiled nationwide. These matrices were used to isolate the past and future performances, a profile of the timber bridge types and lengths, and their statuses. Age, jurisdiction, average daily traffic, and type were each compared with bridge length, estimated remaining life, and status.

In both stages of the search, all data items requested were not available for each bridge listed in the inventory. This resulted in some differences in the total numbers of bridges presented, but did not substantially alter the outcome.

Nearly 65,000 timber bridges in the NBI had main spans constructed of timber as of October 1985 (*14*). These bridges represent about 11 percent of all inventoried bridges on public roads in the United States. The vast majority (over 60,000) of the inventoried bridges can be characterized as longitudinal stringers covered with a deck. Two thousand are described as "deck bridges," which implies that no girders were used. Another 2,000 are called trusses or "frames." Only a mere handful (200) are classified as arches and "other." It is reasonable to assume, furthermore, that the majority of the older public bridges under 20 ft in length is constructed of timber.

Earlier and later inventory data obtained from the FHWA indicate that the number of timber bridges in the United States is declining. In 1983, the NBI included over 70,000 bridges with timber main spans; by September 1986, the number had dropped to just over 60,500 (*6, 15*). Other materials are evidently chosen for replacement and repair projects. Reasons offered for this include prior experience with old timber bridges and lack of knowledge about new timber bridge technologies and their construction advantages, durability, and economic competitiveness.

The ASCE search indicates that about 87 percent of the inventoried timber bridges are located in 19 states. Nearly two-thirds are located in the nine states of Alabama, Arkansas, Iowa, Kansas, Louisiana, Mississippi, Nebraska, Oklahoma, and Texas. In these nine states, timber bridges account for about 20 percent of the inventoried bridges. A high concentration of timber bridges is evident in the central and south central United States (see Table 1). Most of these bridges are located off the federal-aid systems of highways and are classified as deficient (*15*). Most are classified as deficient for structural reasons.

The timber bridges included in the NBI predominantly serve low-volume traffic. Seventy percent of the timber bridges are found on roads that have an average daily traffic (ADT) of less than 100. About one-third of these bridges carry fewer than 26 vpd, one-third carry between 26 and 50 vpd, and one-third carry 51 to 100 vpd (*6*). Of the low-volume groups, 59 percent are short bridges that are 20 to 40 ft long. Only 10 percent of all the timber bridges carry more than 500 vpd.

More than 46,000 of the timber bridges, or 83 percent of the total inventory, fall within the jurisdiction of county and city governments. These governments are primarily responsible for the shorter spans (88 percent of the 40 ft and under spans).

About half (55 percent) of the total of the inventoried timber bridges are open and unposted for any load limitations. However, 1,000 bridges are closed to traffic. Nearly all of the closed bridges are the responsibility of local governments. Forty percent, or nearly 25,000 of the timber bridges, are posted with a maximum legal load limit.

The year of construction of a given timber bridge in the inventory was cross-referenced with the estimated remaining life information to enable an appropriate design life to be approximated for the timber bridges currently in service. The sum of a bridge's age and estimated remaining life would be an indication of its design life. Weighting these discrete design lives by the number of spans falling in a given category yields the average design life of the entire inventory as follows.

$$\text{Average design life} = \frac{(\text{Average age} + \text{average remaining life})_{\text{group}} \times n_{\text{group}}}{\text{Sum of } n_{\text{group}}}$$

The calculated expected life of timber bridges currently in service is 47.4 yrs. This confirms the industry's belief that new timber highway bridges are expected to last 50 yrs (*16*). This is remarkable for older bridges, when one considers how many timber bridges are fairly far along in their life and were probably built with untreated wood. The expected design life results were grouped into design life categories, as can be seen in Table 2.

TABLE 1 NUMBER AND PERCENTAGE OF BRIDGES WITH MAIN SPANS OF TIMBER BY STATE IN 1985 (*4, 14*)

State	Number of Timber Bridges	Percent Timber	State	Number of Timber Bridges	Percent Timber
Alabama	3,171	20.6	Montana	1,829	37.3
Alaska	238	29.0	Nebraska	3,635	22.6
Arizona	109	2.0	Nevada	59	5.7
Arkansas	4,338	33.0	New Hampshire	157	6.2
California	1,276	5.7	New Jersey	289	4.9
Colorado	1,449	20.0	New Mexico	379	11.0
Connecticut	37	0.9	New York	246	1.4
Delaware	61	8.3	North Carolina	2,060	13.0
Florida	838	8.3	North Dakota	1,156	21.3
Georgia	1,196	8.4	Ohio	220	0.7
Hawaii	60	5.7	Oklahoma	3,880	17.0
Idaho	444	11.9	Oregon	1,282	19.5
Illinois	255	1.0	Pennsylvania	342	1.5
Indiana	291	1.3	Rhode Island	17	2.4
Iowa	4,812	18.4	South Carolina	769	8.6
Kansas	2,952	19.6	South Dakota	985	13.9
Kentucky	290	2.3	Tennessee	1,675	9.1
Louisiana	5,924	42.1	Texas	5,712	13.0
Maine	72	2.7	Utah	242	9.9
Maryland	237	5.4	Vermont	90	3.3
Massachusetts	159	3.2	Virginia	110	0.8
Michigan	421	4.0	Washington	1,098	16.1
Minnesota	1,994	15.4	West Virginia	86	1.3
Mississippi	5,920	35.3	Wisconsin	493	3.8
Missouri	712	3.0	Wyoming	449	15.8

TABLE 2 EXPECTED SERVICE LIFE OF EXISTING TIMBER BRIDGES

Expected Service Life	Number of Timber Bridges	Percent of Total
Less than 30 yrs	5,857	11
30-50 yrs	17,891	35
51-70 yrs	22,924	45
71-90 yrs	3,229	6
More than 90 yrs	1,389	3

Over 27,000 timber bridges have lasted longer than 50 yrs. Of these, over 4,500 have exceeded a 70-yr expected service life. About 100 of the bridges have an expected service life of at least 120 yrs. By contrast, almost 6,000 fell within the "under 30 yr" category. This group of spans certainly merits further investigation to determine if a common reason exists for these short design lives. This reason could be determined by tracing the individual bridges in the complete listing; site visits, however, might be the only way to isolate the real causes.

Timber Bridges in the National Forests

The NBI does not include the several thousand bridges that are located in the National Forests and other federal lands that also serve economically important rural traffic. Information about the timber bridges in the National Forests that are maintained by the USDA's Forest Service (FS) was reported in 1984 and 1985 (*17, 18*). Over 11,000 road bridges are maintained by the FS and 100 to 250 are added to the system each year. All-timber superstructures are present in about 55 percent of the FS bridges. Age data are not compiled. In six of the nine FS regions, contemporary glued-laminated (glulam) bridges comprise less than 5 percent of the FS inventory. The percentage is much higher in the other three regions, and ranges from 20 to 75 percent of the total.

The FS replaces or repairs about 270 bridges annually and is seeking methods to both maximize the service life of their existing and new bridges, and still rely on timber as a major material. Field inspection and evaluation of in-place bridges and examination of the FS's national maintenance, rehabilitation, and repair (MRR) needs are key directives in the process.

In 1983, the FS conducted a unique comparative study of 18 experimental timber bridges in the National Forests to assess the in-place performance of the bridges and the merits of dry-use versus wet-use design stresses (*19, 20*). The bridges, located in seven states, were constructed in the late 1960s and early 1970s. They varied in length from 20 to 168 ft, and had 20- to 73-ft span lengths. They were primarily constructed, or reconstructed, with newly developed (at that time) transverse glulam deck panels and a variety of interpanel connections. Some bridges had existing or newly installed nail-laminated decks for comparative purposes. Different types of members, construction, and materials were used in the remainder of the superstructures and substructures.

The inspected bridges were in excellent overall structural condition. Roadway conditions were typically excellent and provided for a smooth passage regardless of surfacing. Extensive asphalt cracking existed only where the surface was unusually thin. Evidence of deterioration as a result of either propagation of cracks or presence of potholes was rare. In addition, the moisture content data obtained from about 100 readings/bridge indicated that the components of the bridges being studied remained below the critical fiber saturation point.

During the summer of 1984, the feasibility of rehabilitating transverse nail-laminated timber decks also was investigated by interviewing FS bridge engineers in the nine FS regions and reviewing available technical literature. The survey revealed the extent of the bridges' needs and current practices and constraints (*17*). The FS bridge engineers generally consider the timber bridge service life to be fulfilled if 30 yrs of use are realized. Rotted deck laminations, excessive maintenance needs, loss of tightness, impaired load distribution, delamination, and asphalt deterioration are major reasons for electing to replace, the first two being the most compelling.

An important contributor to timber bridge deterioration in the National Forests is an inability to implement needed, regular, and thorough maintenance. A low priority is typically placed on maintenance in the FS as a result of limited budget funds. The bridges are seldom rehabilitated (*17*). Rural officials responsible for public bridges also face these decisions. Many of the timber bridges that serve rural regions consequently suffer avoidable degradation. This reality contributes a negative skew to inventory data on condition and estimated remaining life. Both of these facets would exhibit better outcomes with proper maintenance. Conversely, low traffic volumes are favorable to longevity but, in many cases, loads of a high magnitude or impact counter the gain.

The following four national MRR initiatives were recommended to the FS following the investigation; subsequent action has taken place (*18*).

- Computerization of the bridge inventory to put statistics on bridge condition in a common format, and identify and clarify needs;
- Workshops to disseminate information to administrators, engineers, and maintenance personnel;
- Demonstration projects to display and evaluate new methods and technologies; and
- Development of a long-term program to upgrade timber bridges.

INCENTIVES TO USE TIMBER BRIDGES

Advantages

The advantages of using timber for modern highway bridges have been well-documented by suppliers as well as buyers (*21, 22*). These advantages can be categorized into logistical, performance, and economic factors.

The logistics of installing timber bridges are simplified by the material properties of wood. The standard prefabricated glulam panels are lighter than precast concrete panels and steel beams, which enables the use of smaller, cheaper, and more common cranes. Wood can be installed under adverse weather conditions. Finally, the construction of timber bridges does not require sophistication; a typical local road crew can install a bridge with moderate supervision.

An attractive performance feature of timber for bridge use is its complete resistance to the deicing salts. Deicing salts have caused significant and surprisingly rapid deterioration of both steel and concrete bridges and components. Properly treated timber is stable and durable under the most severe environmental conditions. Because wood is salt-resistant, the integrity of toppings, coatings, and seals is not nearly as important as it is in concrete and steel spans. This is reflected in reduced maintenance costs. The resulting prolonged design life also decreases life-cycle costs.

The use of timber bridges can also save material costs. These costs are very site-specific and are a strong function of the relative distances to laminating plants, steel fabricators, and precast factories. The cost differential is rarely dramatic in this very competitive arena. However, savings can be reaped in substructure repair. Because timber's dead load is lighter and its connection requirements are simpler, an otherwise unusable pier or abutment is either adequate or economically reparable. Because its dead weight is light, a timber replacement for steel or concrete can support more live load on the same substructure. Lightweight timber deck replacements alone may obviate substructure or main member replacements. Local officials have often opted for complete replacement with culverts whenever major substructure work is involved.

A timber bridge can be less expensive than a steel or concrete span for several reasons. The greatest savings can be achieved when a small community is able to use its own road crews to install a bridge. In contrast to the heavy and sophisticated equipment requirements needed to install concrete and steel spans, a timber bridge can be installed with light cranes and hand tools. Semiskilled workers can accomplish the task, which means that savings can be derived by avoiding the use of independent contractors.

One of the primary reasons that timber bridges have not been used more often is that potential buyers have little exposure to them. Local officials have never considered the use of timber in their bridges, or their knowledge of its use is limited to old technology. The lack of a comprehensive, up-to-date design manual and general specifications for use by people interested in the timber alternative has widened the technology gap.

Fear of litigation, aggravated by the lack of specifications, has also caused hesitation to use timber. In a recent case in Connecticut, all parties involved, including the town engineer, a consulting engineer, and the town councilmen, were interested in installing a post-tensioned longitudinal deck timber bridge. The engineer eventually opted not to recommend the method because no technical documentation was available stating that such a bridge would meet AASHTO loading requirements for 20 yrs, which was the town's expectation.

The possibility of hydraulic restrictions is an important technical concern in regard to timber bridges. Widely spaced stringers can require a deeper cross-section than the equivalent framing would in concrete or steel. With a given deck elevation, this translates into a reduced hydraulic opening, which can be a problem during a flood. The construction of longitudinal deck bridges is an alternative that can sometimes be used to overcome the problem. The key to the efficiency of the longitudinal deck bridge systems is to distribute the load among the spanning deck pieces. Either transverse spreader beams under the deck or high-strength, post-tensioned steel rods through the deck can be used to distribute the load (*21, 23*).

Much has been written about the nation's infrastructure crisis. The gloomiest predictions would have us imagine a nearly bottomless potential market for replacement bridges. However, a perhaps more realistic approach to estimate the potential market for short-span, rural timber bridges is to speak with people who are currently marketing the product about their hopes and expectations for the future. One such conversation in 1986 yielded the following assessment.

A northwestern design and marketing company has actively pursued the low-volume, rural bridge market with timber bridges for 5 yrs (1981 to 1986). The company has not tried to go nationwide, other than in a few isolated cases, but has concentrated its efforts in Alaska, Washington, and California. This company now sells anywhere from 40 to 60 timber bridges a year. The president of the company forecasts that its volume of the market will rise to as many as 400 a year.

The use of timber has many interesting applications to the rehabilitation of existing spans. Steel girder bridges have been successfully redecked with glulam panels when the original concrete or steel deck was nearly removed by the action of road salts. Old concrete or masonry substructures require little modification to support new timber superstructures. Treated timber pile substructures can perform very well and can support superstructures of any material. Even existing timber bridges can be updated with new timber components. A long story made short on the use of transverse nail-laminated decks follows.

When glulam was first introduced, glulam stringers were placed at larger spacings than corresponding solid sawn stringers. Live load deflection caused the stringers to loosen and moisture to penetrate, and eventually the deck had to be replaced. Glulam deck panels were therefore developed as a replacement for nail-laminated decks.

Cost Aspects

The relative costs of timber, steel, and concrete bridges vary widely and are very site-specific. The following examples illustrate some of the cost considerations involved in making bridge replacements in cases in which the substructures were economically reparable. As with any economic decision made by engineers concerning engineering works, it is important to compare apples with apples and to ensure that all actual and eventual costs are considered.

The town of Canterbury, Connecticut, recently replaced a 27-ft span with a new timber bridge. The material costs alone were $28,000 for the timber, versus $31,000 for steel. These savings are clearly minimal, and not enough to compensate for any significant differences in expected aggravation. The savings available by use of town road crew labor, however, were more substantial. The installed costs of the timber bridge were $40,000, compared to an estimate of $60,000 for precast concrete when the required concrete contractor's costs were included. As a point of interest, had the town elected to qualify for federal funds by meeting AASHTO specifications for the span, the cost would have been nearly $400,000. The town's 20 percent share of that cost would have been $80,000, which means that more money would have been spent for a bridge that they judged to be far greater than the one they needed. This situation is not unlike situations that existed elsewhere in the country, as reported by the U.S. General Accounting Office in 1983 (*24*).

One carefully documented case of a bridge deck replacement in Allegheny County, Pennsylvania, indicates that some dramatic savings were derived by using timber for a new decking material, as shown in Table 3 (*22*).

The dramatic differences in initial costs were influenced by the required addition of a longitudinal steel beam and accompanying abutment widening for the heavier concrete and steel options. Engineers involved in this project foresaw that the

TABLE 3 COST COMPARISON IN 1979 DOLLARS (*22*)

Type of Bridge	Initial Cost ($)	Life Expectancy (Yrs)	50-Yr Replacement Reserve ($)
Glued-laminated timber	50,000	50	50,000
Reinforced concrete	95,000	15	316,700
Open steel grid	105,000	15	350,000
Concrete-filled steel grid	113,000	15	376,700

timber would withstand the action of the heavy salting program of the region for 50 yrs. The expected life for the concrete and steel alternatives was 15 yrs. This figure was based on actual experiences in the region. Significant, long-term cost savings were established for the timber alternative on the basis of this longer design life.

TIMBER BRIDGES AND RURAL ECONOMIC DEVELOPMENT

The FHWA recommends that when states evaluate bridges, set priorities, and select projects on rural roads with low traffic volumes, they should account for sufficiency ratings and other factors that reflect the state's needs, allow local input, and ensure a fair and equitable distribution of funds throughout the state (*25*). This, in part, recognizes that the lack of a complete, effective transportation network can be damaging to a state's economy.

Pennsylvania Case Study

Pennsylvania has a diverse rural economy. Agriculture, forestry, manufacturing, and mining are all important to its economic development. In recognition of the fact that adequate transportation is essential for its rural regions, the Pennsylvania Department of Transportation (PADOT) is examining the highway network in terms that are different than the traditional functional classifications of highways. Priority planning networks have been identified that highlight truck travel and the movement of goods that are important to the state's commerce and industry (*26, 27*). The roadways that do not appear on the networks serve more local purposes.

Four networks have been developed to target limited resources when highway and bridge improvements are considered. They are the Priority Commercial Network (PCN), the Agricultural Access Network (AAN), the Industrial-Commercial Access Network (ICAN), and the Coal Haul Network (CHN). Roadways on the PCN generally carry more than 500 trucks/day or are connector roads for regional industries. The AAN, ICAN, and CHN tend to be lower in traffic volume and consist of roadways that respectively support the state's agricultural and forestry, industrial and commercial, and coal development.

Data on the 1,713 inventoried timber bridges in Pennsylvania were provided by the PADOT's Bureau of Strategic Planning (*28*). Of these timber bridges, 370 are reported to be all-timber and 1,343 to be part-timber in construction. Most timber bridges in Pennsylvania are located in rural regions (91 percent), are 20 ft or more in length (94 percent), are the responsibility of local government (71 percent), and are traveled by fewer than 100 vpd (60 percent) (*14, 28*).

A total of 187 of the timber bridges in Pennsylvania (10.9 percent of the total) are located on a planning network. About 71 percent of all network timber bridges are located on the AAN, which provides access to the agricultural and forestry regions of the state.

A total of 5,237 bridges are on the AAN, 132 of which are timber; 128 of the timber bridges are located in rural regions (*28*). The majority of these bridges is under the control of the PADOT, but the responsibility is shared with the counties, cities, townships, boroughs, and railroads. The PADOT has responsibility for a relatively large share of the rural road mileage (about 30 percent). It is therefore not surprising that 89 of the network's 128 rural bridges are under its control.

The rural timber bridges in the network also tend to serve the higher volumes of traffic present in rural Pennsylvania. Almost 90 percent of these bridges carry over 100 vpd; over 40 percent carry more than 500 vpd. The bridges tend to be relatively long, with a median length of 48.5 ft, but they range in length from 11 to 2,010 ft. Fifty-four bridges are posted with weight restrictions, and another four are closed to traffic. The detour length for the posted and closed timber bridges ranges from 1 to over 99 mi. The median length of a detour around posted bridges is 5.5 mi, and 4 mi for the closed bridges. The detours translate into additional travel times that range in length from a couple of minutes to a couple of hours, depending on the speed of travel. In addition, many of the posted weight limits on bridges may in fact function as closures. The weight limits on the posted bridges range from 2 to 32 tons, with a median limit of 9 tons. Loaded school buses currently weigh between 8 and 10 tons, and commercial supply and agricultural trucks weigh anywhere between 15 and 40 tons, if not more.

The sufficiency ratings provide an insight into the deficiencies of the bridges on the network. Over 80 percent of the AAN bridges have ratings of less than 80 and are therefore eligible for federal rehabilitation funds; over half of these bridges are rated less than 50 and are eligible for replacement funds. The median rating is 72.5 for the open network bridges, 20.8 for posted bridges, and 4.0 for closed bridges.

Implications for Agriculture

As in Pennsylvania, the majority of the timber bridges in the United States is located in rural regions. In fact, the nine states that rank as the greatest users of timber bridges account for about 31 percent of the total cash receipts from agricultural production, 30 percent of the number of farms, and 34 percent of the farm land in the United States (Table 4) (*29*). It is therefore anticipated that the nation's timber bridges are especially important to agriculturally related travel and economic activity.

TECHNOLOGY TRANSFER NEEDS AND ACTIVITIES

It was concluded in discussions between the American Institute of Timber Construction (AITC) and the FS in April 1983 that the use of timber bridges to replace bridges on rural roads could be successfully encouraged with developed timber bridge technology. A fact-finding workshop was subsequently convened in Milwaukee, Wisconsin, in October 1983 to investigate the demand for timber bridges in rural regions and to identify the critical needs for implementing timber bridge technology (*30*). About 40 knowledgeable professionals representing segments of the wood products industry, bridge component manufacturers, the Federal Government, state transportation agencies, university researchers, and professional societies reviewed current capabilities, discussed the incentives and disincentives that exist for the use of timber in bridge construction, and provided advice on needs. The workshop concluded that existing and newly available timber bridge technology could play a vital role in addressing the nation's bridge needs.

Several of the following developments would be important to the optimization of a technology transfer effort:

- The development of a timber railing design that meets the vehicle impact requirements of AASHTO and local officials;
- The development of AASHTO bridge standards that specifically apply to bridges on low-volume roads;
- Synthesized information on the design, construction, rehabilitation, and economics of timber bridges;
- Increased education on wood as a structural material and experience with timber bridges on the part of bridge engineers;
- Documentation of the initial in-place cost and eventual life-cycle economy of timber bridges compared to bridges constructed of other materials;
- More flexible federal highway funding for bridge projects that satisfy AASHTO design requirements; and
- The development of comprehensive standard timber bridge plans to help reduce local engineering costs.

Subsequent to the workshop, the Forest Service, with the help of an implementation team, developed a Technology Transfer Plan for Timber Bridges targeted at state and local highway officials, federal agencies, and engineering and contracting firms involved in specifying, designing, or building highway bridges. The stated goal of the plan is to increase the use of timber bridges 10-fold in 5 yrs. Its objectives include informing the target audience about the advantages of using timber for new and replacement bridges on local and secondary roads, and federally owned property; providing guidance on the rehabilitation of existing timber bridges; and cooperating with mutually interested organizations and associations to improve the nation's road systems by providing safe, economical timber alternatives for bridge replacement needs.

The plan has the following six major components:

- The preparation of a timber bridge design and construction manual,
- The documentation of the cost-effectiveness of timber bridges,
- The development of bridge railing details that meet AASHTO requirements,
- The dissemination of information, particularly at the state and local levels,
- The execution of demonstration projects in the field, and
- The conduct of extensive national publicity activities.

Progress has been made in implementing the plan. The design and construction manual is currently being developed by the Forest Service (*30*). Its contents will include a compilation of existing timber bridge technology; design examples of timber bridges; comparative economics information; maintenance and inspection information; rehabilitation procedures; typical bridge plans; and a bibliography of related information sources. Several sites in the National Forests have been identified for the construction of demonstration bridges using new technologies; the construction costs and the labor and equipment requirements will be documented. A well-attended and highly successful

TABLE 4 TOP-RANKING TIMBER BRIDGE STATES IN 1985 AND THEIR AGRICULTURAL IMPORTANCE (*14, 29*)

State and Rank		Number of Timber Bridges	Farmland (1,000 Acres)	Farm Income ($1000)	Number of Farm-Dependent Counties
Alabama	(8)	3,171	11,500	2,262	6
Arkansas	(5)	4,338	16,000	3,562	29
Iowa	(4)	4,812	33,600	10,087	54
Kansas	(9)	2,952	48,000	6,547	40
Louisiana	(1)	5,924	10,100	1,661	6
Mississippi	(2)	5,920	14,200	2,351	19
Nebraska	(7)	3,635	47,200	7,636	64
Oklahoma	(6)	3,880	33,000	2,906	15
Texas	(3)	5,712	136,300	10,515	61
Total		39,944	349,900	47,527	294
U.S. Total		64,516	1,015,583	151,253	702
Percent of U.S. Total		62	34	31	42

technical workshop was held in Portland, Oregon, in March 1986 to present contemporary design and construction information on engineered timber bridges.

SUMMARY

The state-of-the-art of timber bridge technology in the United States was reported in 1983 (*31*). Since that time, the documentation of national bridge needs and concern about the adequacy of rural bridges to serve rural America have increased interest in the use of timber bridges. In particular, the provision of bridges adequate for the passage of heavy trucks is considered to be vitally important to agriculture and the rural economy.

Rural bridge needs are concentrated in the short- to intermediate-term range. Simple, lightweight, and quickly constructed bridges and bridge components are a priority need and a clear advantage in making needed improvements. The thrust of the renewed technology for timber bridges in recent years is focused on these aspects. Current actions by the timber bridge community are concentrated on establishing and promoting the proven durability and longevity of contemporary timber bridges to ensure their consideration as a viable alternative for making rural bridge improvements. Research and development are under way to provide improved components and novel bridge systems that are economical and simple enough to be used on rural roads.

Every indication is that state and local governments are going to assume a large part of the bridge improvement responsibility over the next few decades. A clear opportunity exists in rural regions for the pronounced use of contemporary timber bridges. The extensive use of all-timber bridges in the national forests has long underscored their capacity for low-volume, heavy-loaded traffic. Ongoing technology transfer efforts are intended to convey this capability to state and local bridge officials, and, by addressing development needs, enable timber bridge elements and structures to be incorporated into their improvement plans.

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