SUSTAINABILITY ISSUES OF FUNCTIONALLY OBSOLETE BRIDGES

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ABSTRACT

Interest in long-term durability and sustainability of bridges has challenged the development of modern bridge management. The structural condition and performance of bridges have drawn much economic and engineering attention. In comparison, the effective functionality of bridges is another major sustainability concern, affecting their safety, mobility, and life span. To reach cost-effective planning and systematic management, consideration of functionally obsolete bridges is essential. This article discusses the critical aspects of evaluation, traffic mobility, and congestion cost of functionally obsolete bridges. A methodology was developed for bridge functional obsolescence evaluation. Actual bridge inventory and conditions databases were studied to compile practical data that generates focused insight for decision-making. A forecast was developed to predict the number of functionally obsolete bridges in the future. Practical cost components of traffic congestion were discussed to facilitate consideration of better original design and construction versus reassignment design and work. The resulting study is practical for transportation agencies, officials, and researchers to support sustainable bridges by planning financial resources, management policies and strategies, design methods, and implementation practices.

KEYWORDS

bridges, management, sustainability

1. INTRODUCTION

1.1 State of Bridges

The effective mobility and life span of bridges are continuously decreasing as a result of the changing transportation needs and load conditions. Thus, issues of structural aging are combined with the ever-increasing strength and serviceability demands due to continuously growing traffic volume and load limits, beyond the consideration of the initial planning and design. As a result, a continuously increasing number of bridges are classified as sub-standard.

From the total number of nearly 600,000 bridges in the U.S. National Bridge Inventory (FHWA 2005), over 13% are rated functionally obsolete. A bridge is functionally obsolete when it cannot safely accommodate the volume or type of traffic it is serving (FHWA 2000). These bridges have older design features, such as limited load-carrying ability and inadequate geometric dimensions, that prevent them from accommodating current traffic volumes and contemporary vehicle weights and sizes. Interestingly, many bridges become functionally obsolete due to inadequate width even before they become structurally deficient. Although these bridges are not unsafe for all vehicles, they do impact the safe traffic conditions of all vehicles and restrict commercial and passenger traffic. Thus, these bridges have significant traffic function problems requiring immediate intervention. Many of these bridges are in need of major traffic redesign, reassignment, and reconditioning work. This fact makes modern bridge management highly challenging.

1.2 Bridge Sustainability

Bridges occasionally outlive a number of different traffic assignments with revised designs. Adjustment to meet modified requirements and updated codes is a complex engineering problem with economic management implications. Updated codes may sometimes prove the deficiency of the original design of existing bridges, requiring their retrofit. Older codes required 100 years service life for public structures. Current codes are adjusted to reflect more objectively technical and technological limitations and increasingly demanding operating conditions. Accordingly, the official service life of a public facility, such as a

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bridge, is expected to attain 75 years with only routine maintenance. Unfortunately, some bridges that are only 10–20 years old require extensive and expensive renewal work (FHWA 2005). Currently, to sustain a safe and economical 75-year service life for a bridge system has become a challenging bridge management task requiring practical planning, effective organization, and cost-effective maintenance.

Various structural condition assessment and performance evaluation methods, detecting and quantifying deficiency through instrumented monitoring and system identification, have drawn much attention and become relatively acceptable diagnostic procedures for complementing visual inspection (AASHTO 1989, 1994). Consequently, structural instrumentation, testing, and monitoring have become more popular (AASHTO 2003, NCHRP 1998, FHWA 1998, Saito 1997, Chang 2001, Balageas 2002, Mufti 2002, Alampalli and Washer 2002). In addition to the structural condition, the effective functionality of bridges is another major sustainability concern for bridge officials. Functionally obsolete bridges have economic implications related to traffic safety, mobility, and life span. Therefore, to reach cost-effective planning and systematic management, consideration of functional obsolescence of bridges is essential.

2. OBJECTIVES AND SCOPE

The objective of this article is to examine sustainability issues of functionally obsolete bridges for more effective bridge management. A methodology was developed for bridge functional obsolescence evaluation. The study also analyzes the database of bridge inventory in the U.S. and their conditions record to compile practical data. Based on the history of the proportional number of functionally obsolete bridges and their age distribution, the increase rate and trend of their number were identified. Then, applying the anticipated trend and rate, a forecast was developed to predict their number in the future. Practical cost components of traffic congestion were also discussed to facilitate consideration of better original design and construction versus reassignment design and work. The provided data on current sustainability issues is helpful for focusing on the resources necessary to enable more sustainable bridge management practices in the future.

3. BRIDGE MANAGEMENT

3.1 State of Bridge Management

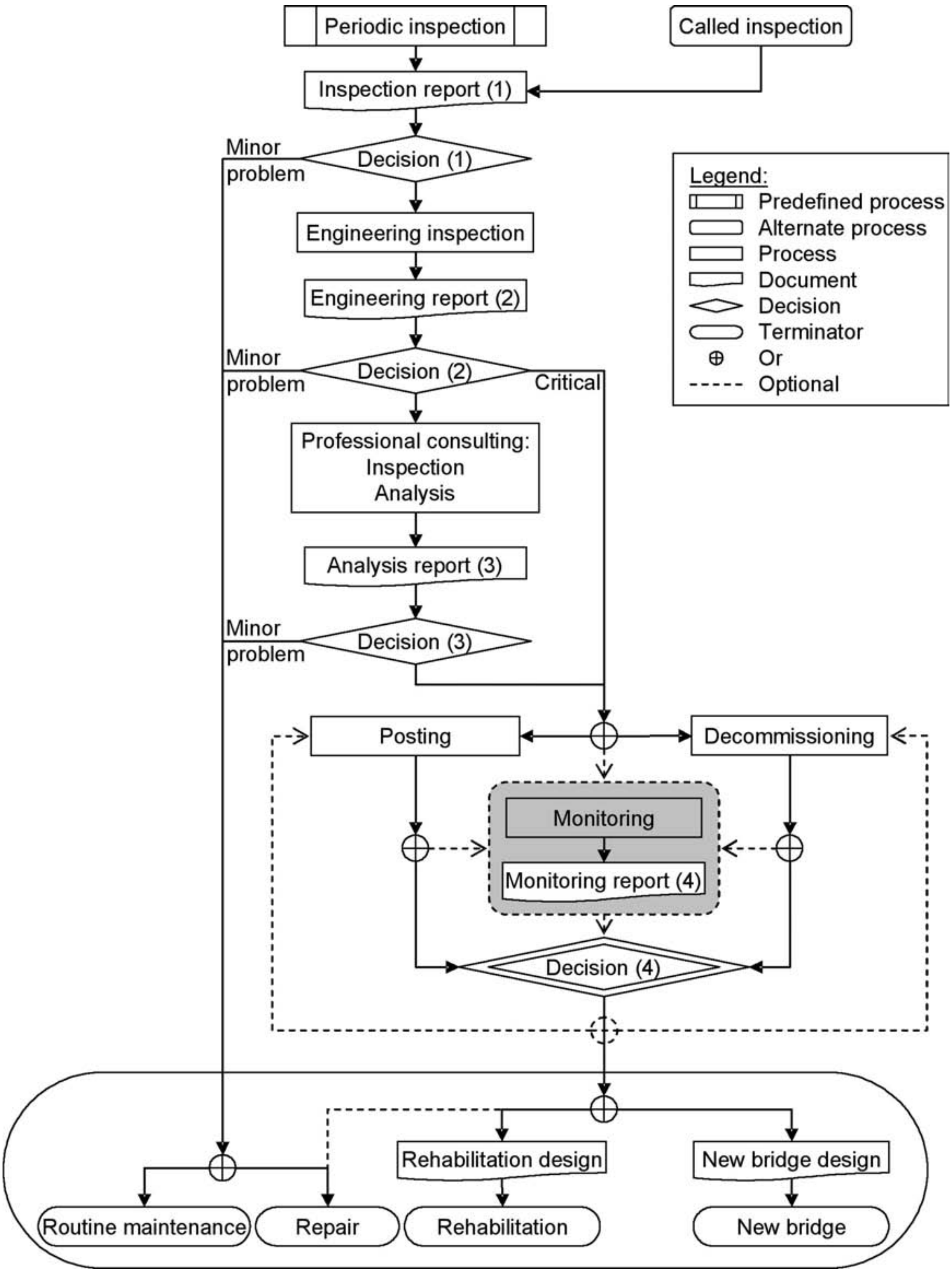
Transportation agencies are in a continuous struggle to preserve and improve the state of bridges and their mobility (IBMC 1999). Bridge management requires structural and functional evaluation of bridges, to help officials decide upon the necessary active measures for uninterrupted and safe service life. Typically, estimating the remaining strength, serviceability, durability, and functionality levels is the primary problem in bridge evaluation. However, data used to support bridge management vary from agency to agency, and under constrained resources, practice linking bridge management systems (BMS) with engineering analysis varies from state to state (Sanford et al. 1999). Also, bridge management system software are only administrative asset management tools to control the inventory, organize data, assume maintenance levels, simulate deterioration and performance models, analyze bridge service life-cycle, and optimize cost. These systems do not incorporate reliable quantitative information and condition prediction (Enright and Frangopol 1999) and do not provide the engineering evaluation required for bridge management.

3.2 Functional Evaluation

In case a bridge is identified as functionally obsolete, a thorough engineering evaluation is required. The decision whether to replace or preserve and how to preserve sub-standard bridges represents a common problem and poses difficult challenges for transportation agencies. In principle, the specific procedures how to evaluate a bridge before renewal, how to decide for renewal, and how exactly to renew require detailed analysis that is not usually performed since it is very time consuming and expensive. In the absence of standardized management procedures, there are virtually various paths to follow, depending on the gravity of the problem. Also, bridge management is a procedure that involves planning the appropriate integration of a range of engineering and management steps. The level of integration will depend on the initially perceived state of the bridge, its function, importance, and available funds.

Based on a typical management approach (Farhey 2005), a representative algorithm with conventional activities for evaluation of functional obsolescence of bridges is developed in Figure 1. In general, regularly

FIGURE 1. Typical bridge evaluation algorithm.



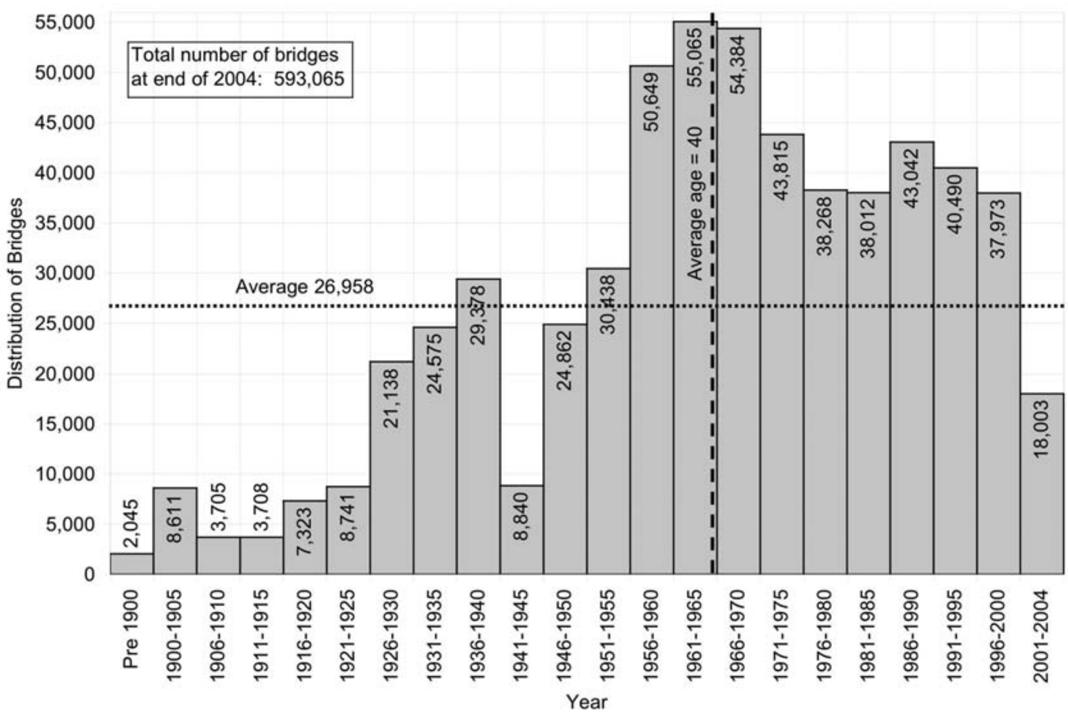
or periodically scheduled inspection (level 1 evaluation) may detect problems that are usually solved by typical maintenance procedures. However, plain visual detection is not always sufficient to categorize and quantify problems. In most cases, periodic inspections are not being performed by licensed engineers. Once a bridge is suspected of being functionally obsolete, a repeated and more elaborate inspection is required, preferably by a professional engineer that is proficient in evaluating the extent of the problem, probable adverse effects, and risks (level 2). This option is not always conclusive due to the obvious uncertainty of visual inspection that is not capable to cover comprehensively the complexity of many issues (Aktan et al. 1995, 1996). Therefore, this case may possibly require professional consulting (level 3) and review of original traffic design, if obtainable. Then, some extent of analysis with recalculation is required for comparison to the current state. The actual functionality level may be assessed based on current codes. If the reduction in the capacity is found to be beyond professionally acceptable limits, the bridge may be classified as functionally obsolete and consequently considered a candidate for posting or even decommissioning. Conventionally, evaluation based on instrumented traffic monitoring (level 4) is only an optional alternative path and provides possible back up for decision-making. The primary cost and time components of this level are invested in the logistics. Typically, analysis (level 3) and monitoring (level 4) are not necessarily integrated for evaluation. Next, various solution alternatives are considered, developed, and recommended for possible treatment. Eventually, a final decision is made for intervention, depending on public and financial capabilities. Establishment of an effective evaluation methodology integrated with bridge management system software is a primary concern for cost-effective management.

4. BRIDGE SUSTAINABILITY ISSUES

4.1 Bridge Mobility

Based on the database of the US National Bridge Inventory (NBI) for the end of the year 2004 (FHWA 2005), Figure 2 shows the distribution of all the bridges versus their time of construction using a scale

FIGURE 2. Distribution of bridges per year of construction.



of five-year intervals. The average age of the bridges is 40. The average number of bridges built during the five-year intervals is 26,958. A trend of decline can be noticed in the number of bridges built during recent decades, with a significant drop to below average during the last five years.

Based on the conditions record (FHWA 2005), Figure 3 shows the five-year history of the total number of bridges, the number of functionally obsolete bridges, and their percentage from the total (right axis). Figure 3 also shows the rate of change of the average age (right axis) of all bridges and functionally obsolete bridges. The increase in the total number of bridges is accompanied by an increase in the total age. The number of functionally obsolete bridges and their percentage from the total are quite steady. However, the average age of all bridges and of functionally obsolete bridges is increasing at the same time. From the total number of 593,065 bridges at the end of 2004, 13.55% are functionally obsolete. Figure 4 shows the distribution of the functionally obsolete bridges versus their time of construction. The average age of functionally obsolete bridges is 50. This is significantly below the officially expected 75-years service life of a bridge with only routine maintenance.

The percentage distribution of functionally obsolete bridges at end of 2004 is shown in Figure 5. The functionally obsolete bridge percentages were calculated from the number of bridges in the respective sub-group constructed within each of the five-year intervals. A third-degree polynomial trend line illustrates the rate of change of the percentage distribution versus time.

The history of percentage distributions of functionally obsolete bridges for the last five years is shown in Figure 6, considering that the NBI database (FHWA 2005) for the years 2000 through 2003 did not include data on the pre 1900's. Third-degree polynomial trend lines are also shown for each year,

FIGURE 3. Five-year history of functionally obsolete bridges.

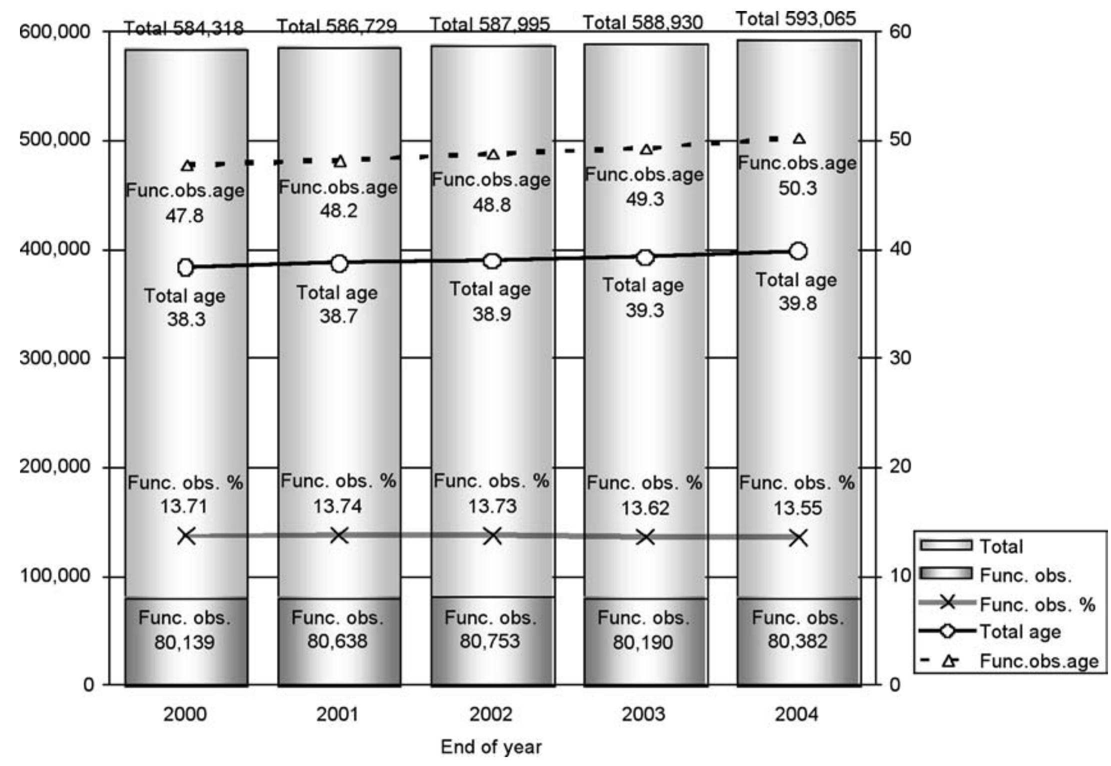


FIGURE 4. Distribution of functionally obsolete bridges per year of construction.

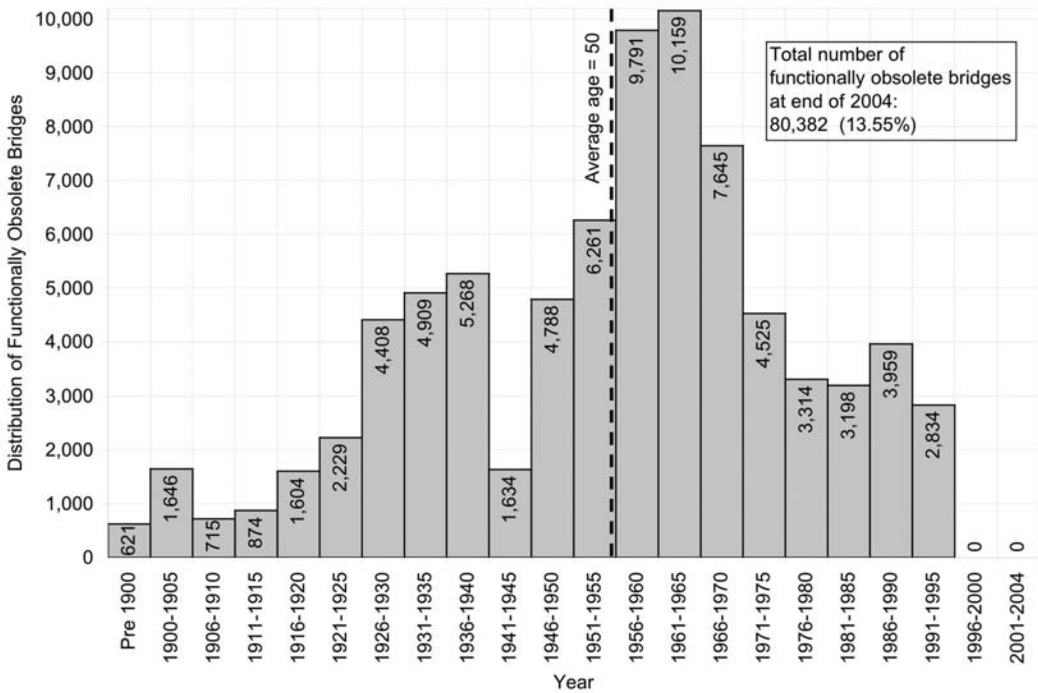


FIGURE 5. Percentage distribution of functionally obsolete bridges.

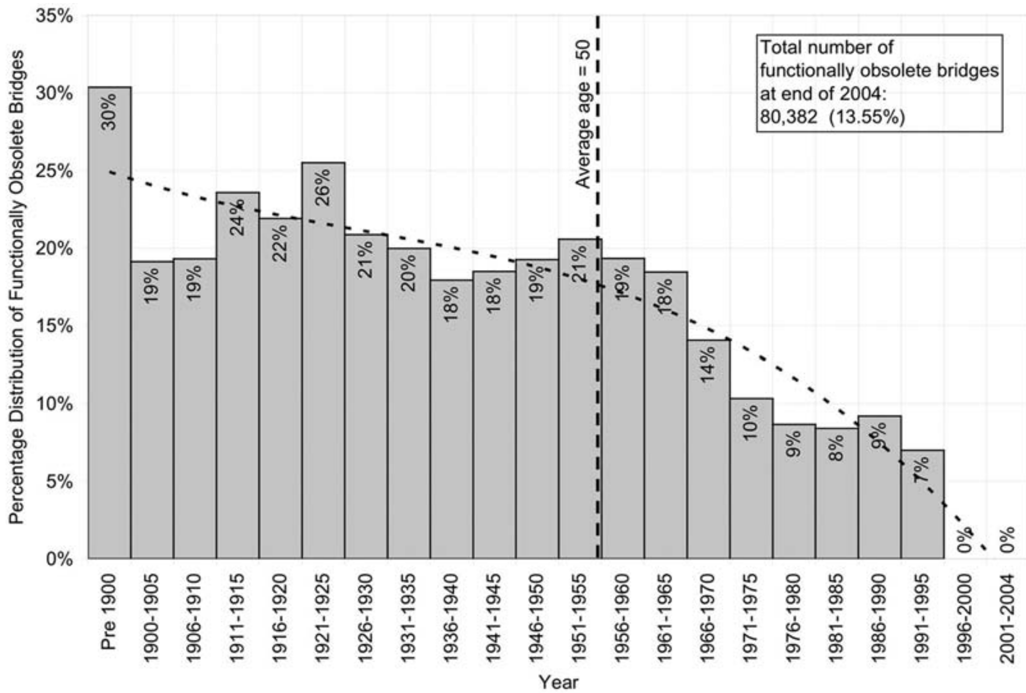
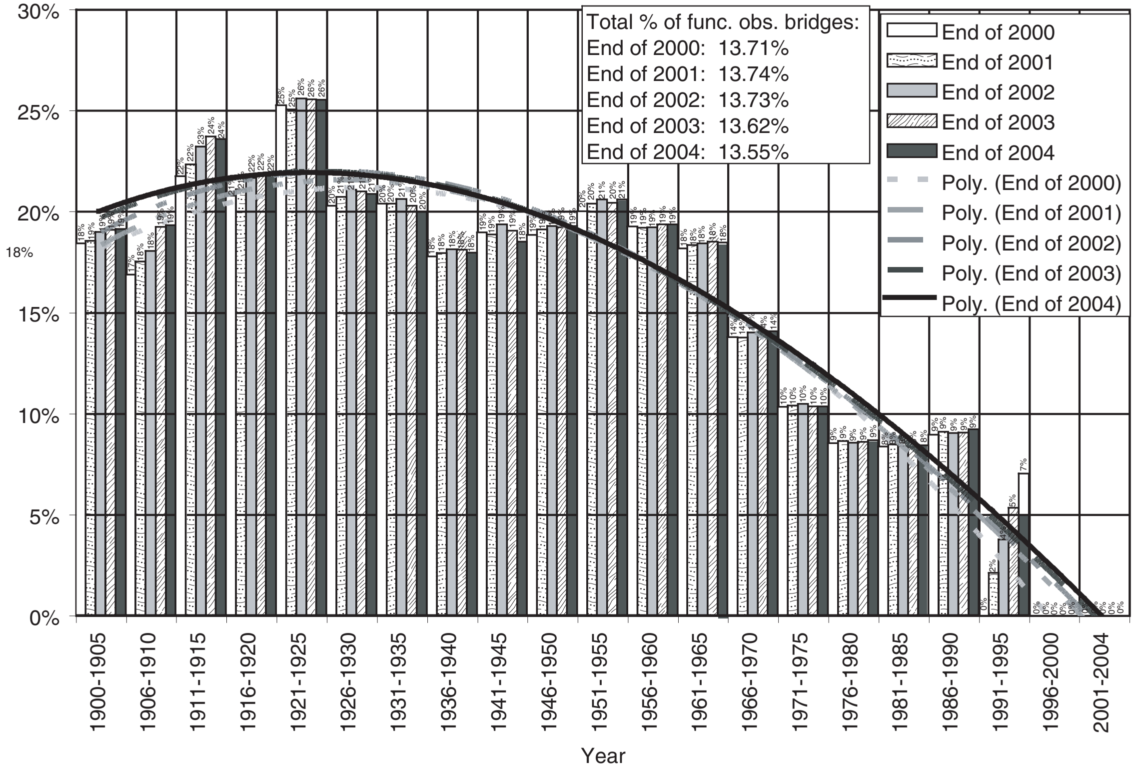


FIGURE 6. Percentage distribution history of functionally obsolete bridges



illustrating the rate of change of the percentage distributions versus time. Comparing the change between the trend lines of the years 2000 and 2004 for a five-year period, the highest difference is merely 2% for 100 years ago and for the last decade. Given the relationship between functional obsolescence and age is based on a maximum margin of error of 2% within five years, linear forecasting may be considered as a relatively valid approach to estimate the future increase of the number of functionally obsolete bridges.

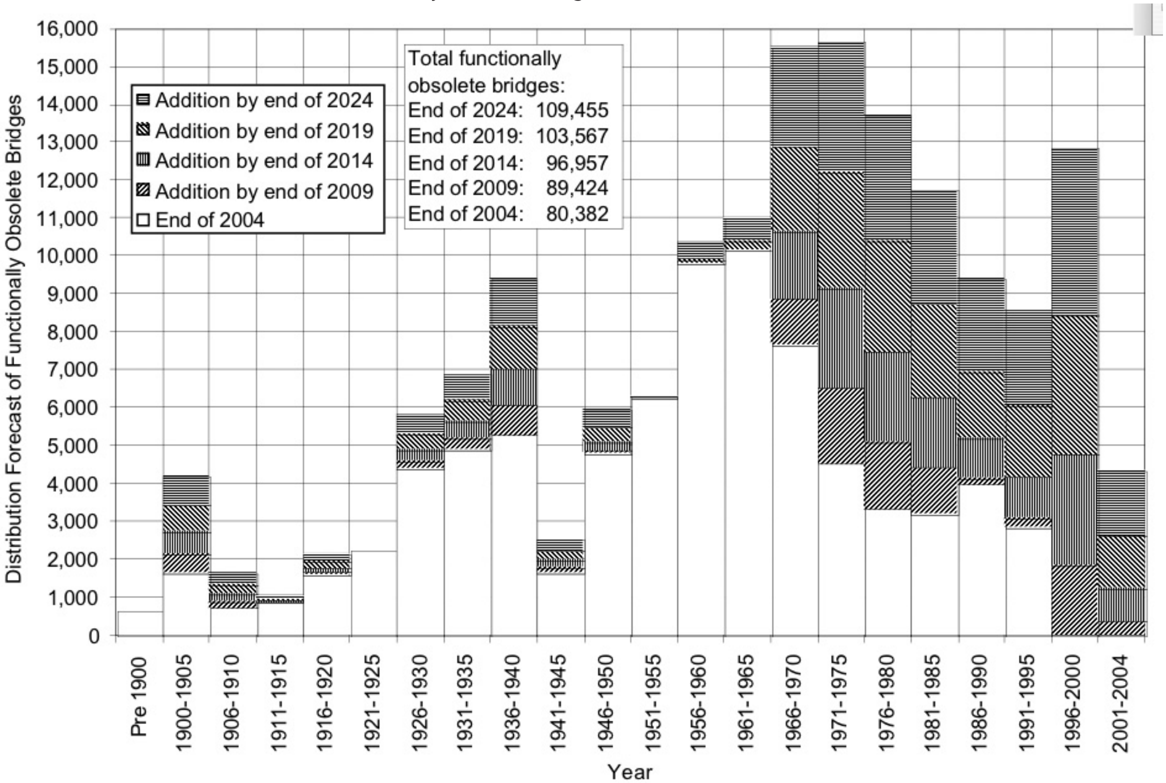
To determine the total number of bridges that will be functionally obsolete and thus will require resources and intervention, the numbers of all functionally obsolete bridges were accumulated. Accordingly, Figure 7 shows the forecast how the number of functionally obsolete bridges is expected to increase every five years for the next 20 years. The inset shows the total number of functionally obsolete bridges every five years. All these functionally obsolete bridges will require decision-making and some level of preventive action involving traffic redesign and renewal work. This record may be used for a strategic plan for the total need of intervention for a large and growing number of functionally obsolete bridges.

Using the above assumption, the relationship between functional obsolescence and age can be studied locally for states, counties, or cities, to forecast the local increase in the number of functionally obsolete bridges. Local rates of change of the percentage distribution versus time will naturally differ from the national trend (Figure 5), and thus will require a separate study.

4.2 Cost of Congestion

During the time a bridge is functionally obsolete, there will be some level of traffic congestion. Therefore, the total cost to the public, and thus the economy, should be considered. The cost components of congestion include the value of the extra travel time and excess fuel that is consumed during delayed travel. Thus, traffic congestion is waste of national

FIGURE 7. Distribution forecast of functionally obsolete bridges.



resources paid by the public. In the latest published data for the year 2002, the Texas Transportation Institute (TTI) (Schrank and Lomax 2004) provides annual congestion cost data for 85 selected very large, large, medium, and small urban areas in the US. To project a rough estimate in different locations and conditions, relative comparison of population, area size, and population density can be considered. For 2002, the value of travel time delay is estimated at $13.45 per hour of person travel for passenger traffic and $71.05 per hour of truck time for commercial traffic. The vehicle mix for calculation is 95% passenger and 5% commercial traffic. For 2002, excess fuel consumption is estimated using state average cost with an average of $1.42 per gallon. The average cost of congestion per hour is calculated assuming 250 working days per year.

To compare with the aforementioned functionally obsolete bridge mobility data for the end of 2004, the updated value of travel time delay is estimated at $14.30 per hour of person travel for passenger traffic and $75.55 per hour of truck time for commercial traffic, reflecting the consumer price index difference of +1.06337 (AIER 2005, BLS 2005). The respective fuel cost is $1.92 per gallon (36% increase) (EIA 2005) for excess fuel consumption. Latest fuel cost rises will increase the cost of congestion accordingly.

In the case that a bridge has to be closed for improvement or flagged for heavy vehicle passage, this data provides a realistic aspect for the cost components of congestion. This consideration is road and bridge-specific. Local and bridge specific estimates should account for the particular average daily traffic (ADT), passenger versus commercial vehicle mix, and local fuel cost. The accrued cost of traffic congestion that functionally obsolete bridges are causing during their sub-standard service may be significantly costly to the public. Unfortunately, the cost of congestion is not always considered in original designs or in the decision-making of functionally obsolete bridges.

4.3 Opportunity Cost

There is an opportunity cost associated with designing for functional requirements into the future. Also, there are uncertainties associated with the evolution of codes related to traffic functions and transportation needs over time. Taking these aspects into account, current codes explicitly define that bridge designs are expected to achieve 75-year service life with only routine maintenance. This definition implies functionality before obsolescence during the first 75 years.

5. CONCLUSIONS AND RECOMMENDATIONS

Bridges classified as functionally obsolete and destined for posting and decommissioning are a cause for reduced safety, limited mobility, traffic congestion, and unnecessary expense of public funds. Advanced bridge management requires a systematic functional evaluation methodology that is not only technically and financially feasible, but also practical and rapid.

The provided forecast for the number of functionally obsolete bridges may be used for strategic planning of the total need of resources for a large and growing number of functionally obsolete bridges. Advanced bridge management requires the development of integrated administrative and engineering solutions for increased sustainability, to enable more practical and cost-efficient decision-making, increase lifecycle, and decrease lifecycle cost of bridges.

The cost of traffic congestion of functionally obsolete bridges is significant. The high cost of better original design needs to be judged against the higher cost of intervention and replacement values of functionally obsolete bridges combined with traffic congestion. Transportation funding and bridge designs should consider the accrued cost of congestion to the public, which notably impacts the nation's economy.

Codes may need re-adjustment to reflect more objectively our incapability to control the uncertainties associated with the evolution of transportation function requirements over time in the future. To address sustainability issues, such a consideration needs to be specific to location and possible structural deficiency through the material and type of bridges.

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