Evolution of Bridge Performance Data and Assessments

John M. Hooks [1]

Abstract

How bridges perform is a critical factor in the optimal operation of highway systems. Bridge performance is not well understood and attempts at assessment still rely heavily on expert opinion or significant assumptions and generalizations. Starting with the original National Bridge Inventory, data on bridges has been collected in consistent, systematic and computerized formats since 1971. These databases have improved significantly over time, but they still are not a complete basis for realistic assessment of bridge performance. These databases will continue to provide value, will support long term assessment efforts and will themselves be furthered enhanced by feedback from the results of the upcoming Long Term Bridge Performance LTBP) program in the United States.

Introduction

The safe, efficient and economical operation of public highway systems is dependent on many factors. As a critical part of the physical highway infrastructure, any highway bridge has the potential to become an impediment to the optimal operating condition of transportation network it serves. This is most often evident when work is necessary to properly maintain, rehabilitate or replace an existing structure or series of structures. Bridge work sites usually involve one or more conditions that result in disruptions to safe, efficient and economical traffic flow. These include lanes that are narrowed or closed, live load restrictions, speed reductions, inefficient detours, safety hazards, etc. It is also evident where structurally sound bridges restrict traffic flow or present safety concerns because of functional capacities. Negative impacts on local and regional economies and environments often result from loss of productive time because of traffic delays and detours, from increased consumption of fuel, from increased engine emissions, etc. Optimal performance of bridges is of paramount importance to transportation agencies. This is true in regards to their fundamental mission of providing the best service to the traveling public and commercial interests. It is also true for the purposes of minimizing the overall (life cycle) costs of keeping bridges in service. Understanding bridge performance is a key factor in a transportation agency's ability to address current bridge deficiencies and to design and build higher performing bridges for the future. This issue is further complicated by the emergence of so-called high performance materials that are still unproven in long term service but that promise better performance even considering their higher initial cost. Understanding performance is also critical to the planning and engineering processes that lead to bridges that are easier, faster and less costly to build and maintain.

The performance of any single bridge is dependent on multiple and often interrelated factors which include: the original design parameters and specifications (bridge type, materials, geometries, load capacities); the initial quality of materials and of the as-built construction; varying environmental conditions of climate, air

[1] John M. Hooks, Bridge Technology Consultant, Warrenton, VA

quality, etc; corrosion and other deterioration processes; traffic volumes and percentage of truck traffic; and the type, timing and effectiveness of preventive maintenance, of minor and major rehabilitation actions and ultimately of replacement actions. All of these factors combine to impact the condition and operational capacities of the bridge and its various structural elements at any given point in the life of the bridge. Currently, bridge performance is not well understood and is not well documented. Most attempts at assessment of how bridges are performing rely heavily in some manner on expert opinion or on analyses that are dependent on significant assumptions or generalizations. For example, it is assumed that concrete decks are poured using concrete meeting or exceeding specifications, that the concrete is properly cured and that the deck concrete remains uncracked. On a given bridge, one or more of these assumptions may not be true and subsequent evaluation of the performance of reinforcement in the deck may not identify the true causes of any degradation in deck condition.

It is useful to segregate the primary issues in bridge performance in terms of structural condition and structural integrity, safety (of the users) and costs – user and agency. It is possible to identify most of important the factors that affect these three performance issues and these are delineated in Table 1.

Table 1 – Primary Issues in Bridge Performance & Relevant Factors

Structural Condition & Structural Integrity	• Structure type • Structural materials & material specifications • Vertical clearances – over & under • As-built material qualities & current conditions • As-built construction qualities & current conditions • Traffic loads – trucks • Environment – climate, air quality, marine atmosphere • Snow & ice removal operations • Type, timing & effectiveness of preventive maintenance • Type, timing & effectiveness of restorative maintenance, minor & major rehabilitation • Hydraulic design and scour mitigation measures • Soil characteristics - settlement
Safety (of Users)	• Structure geometry- clear deck width, skew, approach roadway alignment • Vertical clearances – over & under • Traffic volumes and percentage of trucks • Posted speed
Costs (User & Agency)	<u>Users</u> • Accident costs • Detour & delay costs <u>Agency</u> • Initial construction costs • Maintenance, repair & rehabilitation costs • Traffic maintenance costs

For over 30 years, the US has compiled a complete inventory of bridge information and condition data; and most states have at least several years experience compiling comprehensive bridge databases for use in their bridge management systems. Despite all these multi-year efforts, availability of high quality, useful data on many of the factors impacting bridge performance varies significantly. Much of the "static" data – structure type construction materials, dimensions, clearances, scour protection, functional classifications etc. – is, of course, well documented and easily accessible. Current and historical data on physical condition of bridge elements is readily accessible; but, some shortcomings of this data are discussed later in this paper. Beyond these two types of data, the availability and /or accessibility of high quality, useful data on factors impacting bride performance is generally poor to fair at best. Information on environmental factors is usually only available in generalized relationships between bridge location and regional characteristics of climate, annual snowfall, air quality, marine environment, etc. Useful data on the types, timing, costs and effectiveness of maintenance, repair and minor to major rehabilitation is very hard to assemble. Attempts to assemble useful data on these activities are hampered by the large variety materials and methodologies used for bridge work, inconsistent formats for establishing costs and lack of uniform and easily accessible descriptions and records of actions and costs. Furthermore, follow-up evaluations on effectiveness of various bridge activities are usually not conducted, or if conducted, the results are not documented in readily available, useful formats. Regarding the issue of user safety, currently it is all but impossible to correlate highway accidents with specific bridges, much less with specific bridge parameters – width, approach roadway alignment, etc. Accident costs cannot be addressed until accurate data, correlating accident rates as well as accident types and severity of losses can be assembled. Regarding the issue of cost as a measure of performance, user costs are separated from agency costs. Reliable models to assess loss of productive time, additional costs of transportation of commerce, increased fuel consumption and reductions in air quality are needed to assess bridge performance relative to total user costs. Regarding agency costs, initial construction costs are well documented and traffic maintenance costs could reasonably be assessed from bid prices for contract work on bridges. Here again though, the most critical gap involves the costs of maintenance, repair and rehabilitation.

In the U.S., it is in the area of measuring, recording, analyzing and using bridge condition data that most of the effort in bridge performance assessment has been concentrated. Collection of detailed information and condition data on bridges in the United States started with the requirement for a National Bridge Inventory (NBI) in 1971and has continued in the NBI and in other consistent, systematic and computerized formats for over three decades. There have been significant enhancements to these data collection efforts over time. Widely used databases such as the NBI and the AASHTOWare™ PONTIS bridge management database will be discussed below as part of the evolution of bridge performance data. The role of these databases vis-à-vis the upcoming LTBP program that is intended to monitor and assess bridge performance can and should be significant and examples will be discussed. It will be seen that these databases do not represent a complete basis for documenting and fully assessing long term bridge performance with proper consideration of all relevant factors. Furthermore, even the documentation of high quality data on a comprehensive set of bridge conditions, taken periodically over a long term, does not equate to assessment of bridge performance. A proper assessment of bridge performance requires systematic correlation of changes in bridge conditions and capacities with key factors that effect condition and capacities. These factors should include at least those listed above as prime factors impacting the key issues in bridge performance. Some further developments are necessary before there is a complete basis for realistic methods of assessing long term bridge performance resulting from a variety of factors and service conditions. Still, much of the basis for any long term assessment of bridge performance will be drawn from data, procedures and definitions already used in the NBI and bridge management databases. Equally important, there can be significant synergy between development of long term bridge performance knowledge from the LTBP and further enhancements to the established uses and products of the NBI and bridge management systems such as PONTIS.

Background – Bridge Population in the United States

In the United States, the Federal Highway Administration (FHWA) maintains an inventory of all bridges - structures with a total span length of 20 feet (6.1 meters) or longer - on all public highways. Data to support and continually update this inventory is submitted biennially by all the state departments of transportation (DOTs). This National Bridge Inventory (NBI) database currently contains records on approximately 478,000 bridges plus 114,000 tunnels and culverts. The mean ages of concrete and steel (superstructure material) bridges are virtually the same – 47 years old; prestressed bridges were not utilized until the 1950’s and the mean age of prestressed concrete bridges is 27 years old. The mean age of all bridges is 44 years.

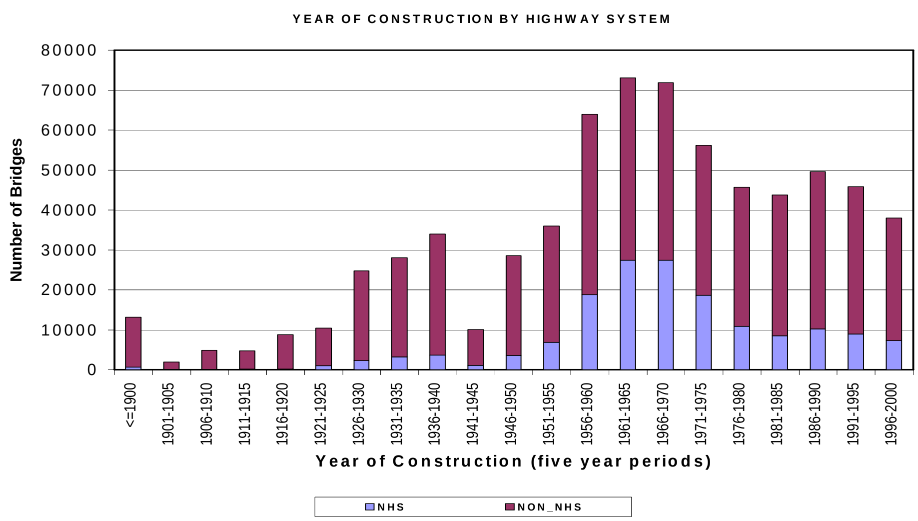

Figure 1 – Age Distribution of All Bridges in the United States - 2001

Figure 1 shows that even by the late 1960’s, the bridge population in the United States was large and already aging. This was at the time just prior to the first development of systematic approaches to record information and condition data on bridges. The collapse of the Silver Bridge at Point Pleasant, West Virginia in December 1967 was the seminal event in the development of bridge inspection programs, bridge data collection, formal bridge improvement programs and ultimately modern bridge management systems. Prior to this event, the state of the knowledge of bridges was very poor. Immediately after the collapse, crucial questions about the bridge population arose, particularly from the U.S. Congress: how many? what type? what materials? where? what condition? how vulnerable? what immediate improvement priorities? scale of effort and cost to address deficiencies, etc? There were virtually no useful answers immediately available. As a consequence there was no basis at all for assessing individual and overall condition of the bridge population and certainly no basis for assessing the performance of bridges over time.

The simple facts stated above, regarding differing mean ages of bridges, introduce an issue of enormous import in the assessment of bridge performance. Bridge engineering is not a static art or science. Significant new developments occur frequently and the assessment of bridge performance becomes a "moving target". Examples include:

- Bolting and welding replace riveting
- Epoxy coated rebars replace black bars in many states
- New alloys are developed to provide even further corrosion protection for rebars
- Design of concrete mixes evolves with significant improvements in strength and permeability characteristics
- High performance steels with greater strength, higher corrosion resistance, lighter weights become routinely used
- Applications of non-traditional materials such as fiber reinforced polymer composites are developed for both new bridges and in-service bridges

Each time such a new development becomes routine practice, the assessment of performance, particularly of structural condition and integrity is skewed. It is beyond the scope of this paper to address how to handle this "moving target".

The National Bridge Inventory

The National Bridge Inventory was created to fill the knowledge gap on bridge inventory information and bridge conditions, but not to support the ability to assess bridge performance over time. Guidance on meeting the requirements of the NBI was published in 1971 and by end of 1973, the states had inventoried most of the bridges on the Federal-Aid Highway systems. Over time, the NBI has become a current and historical database of a consistent set of data on almost every bridge in the US over 20 feet (6.1 meters) long. The NBI represents a database of bridge information that remains unique in the world. Inventory and condition data have been collected on a large population of individual bridges for over 30 years; the guidelines for collecting, reporting, checking, editing and storing this data have been very consistent over the life of the NBI; these guidelines are carefully written, accepted by all transportation agencies and have only been "tweaked" as necessary; in particular, the system of evaluating and recording the key appraisal and condition data on each bridge has remained virtually the same over the full life of the NBI. A full explanation of the data and the guidelines for collecting and recording the data can be found in the current issue of the *Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges* published by the FHWA. The data can be grouped into similar types of information which are identification (location, etc.), structure type and material, age and service, geometric data, navigation data, (highway) classification, condition ratings, load rating and posting, appraisal ratings (current ratings of adequacy of major features such as deck width), proposed improvements and inspection requirements.

With regards to supporting performance assessment, the key data fields of the NBI are the structure type and materials, the condition ratings and the appraisal ratings; fields that are less important, but still useful, are traffic volume data, location information (indicative of climate and environmental factors, potential for corrosion), load ratings, etc. However, the NBI data has some significant shortcomings:

- Condition ratings are limited to only a few, major structural elements of the bridge - deck, superstructure, substructure – plus channel and channel protection and culverts; the NBI does not record current nor does it store historical data on condition of individual sub-elements of a bridge such as beams, pier columns, abutment stems, etc.

- Appraisal ratings are limited to only a few key features of the bridge - structural evaluation, deck geometry, scour criticality, etc.

- The rating methodology relies on subjective, qualitative language. There is no requirement to record quantitative measurements of differing conditions or to locate areas of differing conditions with respect to the geometry of the element being inspected. For example, on bridges in poor to moderately good condition, the rating scores and language for decks, superstructures and substructures are:

Code	Description
5	FAIR CONDITION - all primary structural elements are sound but may have minor section loss, cracking, spalling or scour.
4	POOR CONDITION - advanced section loss, deterioration, spalling or scour.

- Since the most of the ratings are assigned based solely on visual inspections, hidden, underlying causes of damage such as rebar corrosion are not identified until surface damage appears. Therefore in the early stages, NBI ratings will not illuminate incipient degradation and as a result will misrepresent or skew many performance assessments based on NBI data...

- Again due to the subjective nature of the rating language, the reliance on visual inspection and a multitude of human factors varying from one inspection team to another, there is an inherent lack of uniformity in the ratings that also can significantly skew performance assessments based on NBI data. Further details may be obtained from the FHWA's 2001 report, *Reliability of Visual Inspection for Highway Bridges.*

- The full range of codes (from *9 for EXCELLENT CONDITION to 0 for FAILED CONDITION – out of service – beyond corrective action)* consists of unique integers corresponding to the guiding language. This type of data is not readily amenable to rigorous mathematical analysis with the purpose of charting continuous change or for predicting future changes.

The NBI does not, and cannot in its current form, provide the basis for an effective assessment of bridge performance from which critical decisions on bridge design, construction, maintenance and rehabilitation can be based. Nor would it be practical to try to reformat the NBI in order to make it an acceptable platform for performance assessment.

Even considering all the above, the NBI remains the most comprehensive source of information on bridges that is accessible in any one database. Both current and multi-year historical data are available for examination. The NBI can and has been used to make assessments that are useful, if only on somewhat of a superficial level and if the necessity of some significant assumptions is allowed. In the mid-1990s, FHWA established the Bridge Management Information Systems Laboratory (BMISL) at the Turner-Fairbank Highway Research Center in McLean, Virginia. This unit has been aggressively researching, augmenting, analyzing and mining the data in the NBI and other databases that provide data relevant to bridges and bridge performance. Over time, the BMISL has:

- Searched and identified relevant external data sources
- Reviewed the collected data sources for potential value and significance
- Processed each dataset for GIS integration with the NBI data
- Addressed potential issues with regards to location and location accuracy for existing external data layers

Relevant external datasets on environmental and natural hazard data previously collected for the lab are shown in Table 2.

Table 2 – Examples of External Data Available to Support Bridge Performance Assessments

Class of Data Representation	**Type of Data**
Climate	Precipitation-rain
	Precipitation-snow
	Temperature-freeze/thaw
Water	Hydrologic unit codes
	Flood data
Seismic	Spectral acceleration
	Peak ground acceleration
	Earthquake magnitude and depth

Regarding the last issue, location, the BMISL has been able to establish spatial coordinates for a significant percentage on the bridges in the NBI in order to improve the ability to conduct spatial analysis on NBI data with the different datasets.

Overtime, FHWA and the BMISL have been able to use the NBI to produce many results and products that have implicit or explicit implications for the assessment of bridge performance. While the validity of many of results are diminished somewhat by reliance on superficial data and significant assumptions and generalizations, they are none the less useful and indicative of results that could assist in the pending future development of the FHWA Long-Term Bridge Performance (LTBP) program.

Modern Bridge Management Systems

Beginning in the 1980's, several state highway agencies (Indiana, North Carolina, Wisconsin, Pennsylvania, et al) began to conduct studies with the multiple purposes of: developing a clear picture of the status of their bridge populations, identifying bridge needs, prioritizing bridge actions and projects and predicting future status of bridge populations in what if scenarios. The objectives of the Indiana studies were somewhat typical:

- Development of a method to better use the existing NBI condition data for selection of bridges for maintenance, rehabilitation and replacement
- Development of a method to provide consistent and statewide uniform measurements for rating bridges
- Analysis of bridge maintenance, rehabilitation and replacement costs and analysis of relationships between bridge attributes and costs
- Development of a method to estimate remaining service life of bridges and the effects of bridge activities on condition rating and service life
- Development of a bridge traffic evaluation scheme that relates physical characteristics of a bridge structure to accident potential
- Development of a project selection procedure using life-cycle cost analysis, ranking and optimization

The research studies and the subsequent developments produced by these studies were innovative but ultimately hampered by significant shortcomings. The reliance on NBI condition data represented a significant flaw, but the decision was reached based on practical considerations. It was deemed to be not practical and not economically feasible to develop requirements for collecting more in depth data on bridge conditions beyond what was required by for the NBI. Many states did expand on the data required for NBI, but the format of the additional condition data did not deviate significantly from the NBI format and retained the same high degree of subjectivity in the rating language. Several of these early efforts became the precursor of comprehensive bridge managements systems. However, most states remained skeptical of these approaches because of the reliance on NBI data with the attendant shortcomings as described earlier in this paper.

The recognition of the shortcomings in these early approaches at bridge management was a major reason that the FHWA and six state DOTs (California, Minnesota, North Carolina, Tennessee, Washington & Vermont) cooperated in the development of an innovative approach to bridge management systems. The resulting product of those efforts was the system currently known as the AASHTOWare™ PONTIS. In developing PONTIS, the developers recognized that the existing NBI condition ratings for the superstructure, substructure and deck were not sufficient for making useful decisions on bridge activities and that a more detailed condition assessment would be necessary. The developers ignored the practical and fiscal difficulties in implementing an entirely new system of inspection reporting with the potential for added burdens on the inspection system in terms of time and cost. What resulted was an “element level” condition assessment, or inspection systems, which tracks not only the severity of different problems, but also the extent. The current version of Pontis has over 160 different elements. Each element has a specified unit of measure, up to five unique condition states described in engineering terms, three possible actions to address each condition state and four possible descriptions of the bridge environment.

In this latter regard, the elements are further classified in one of four environments – benign, low, moderate and severe – in order to define the elements with regards to their susceptibility to deterioration as a result of environmental factors or local agency operating procedures. During the biennial inspections, the inspector would visually estimate, measure or otherwise ascertain the amount of structural element (in this case in linear feet) that exists in each condition state. Table 3 represents an example of an element level description of a bridge feature.

Table 3 – CoRe Element and Associated Condition State Language

Element	Reinforced Concrete Girder
Condition State 1	Element shows little or no deterioration. There may be discoloration, efflorescence, and/or superficial cracking, but without effect on strength and/or serviceability.
Condition State 2	Minor cracks & spalls may be present, but there is no exposed reinforcing or surface evidence of rebar corrosion
Condition State 3	Some delaminations and/or spalls may be present, and some reinforcing may be exposed. Corrosion of rebar may be present, but loss of section is incidental and does not significantly affect the strength and/or the serviceability of either the element or the bridge.
Condition State 4	Deterioration is advanced. Corrosion of reinforcement and/or loss of section is sufficient to warrant analysis to ascertain the impact on the strength and/or serviceability of either the element or the bridge.

PONTIS views deterioration as probabilistic rather than as deterministic processes and is able to automatically update previous deterioration predictions as more cycles of historic inspection data are input. The initial probabilities of transition from one condition state to there next were essentially determined from consensus of expert opinion.

The element level inspection system has reduced, if not entirely eliminated, the significance of the shortcomings discussed earlier with the inspections conducted under the NBIS and the data stored in the NBI. Condition data is recorded on the individual elements of the bridge rather than on the generalized elements of deck, superstructure and substructure. This expands the data collected while at the same time allowing the use of more specific guidance in more precise engineering language for inspectors to rate the elements. Thus the severity of any deterioration is better defined and the extent is estimated and recorded. This approach provides a much clearer picture of the changing conditions of each element as reflected in the changes in the condition state measurements over several inspection cycles.

Synergy - NBI, Pontis & the LTBP

Perhaps in a more logical scenario, the development of tools to manage bridge data, assess needs, develop priorities, allocate funds, etc. in an informed and rational manner should have come later; e.g., after a concentrated long term effort such as the Long Term Bridge Performance program to collect high quality, reliable data on bridge performance. Unfortunately, the urgencies of developing some method to address bridge deficiencies after the Silver Bridge collapsed did not allow a long term, logical approach to the development process. Decades would go by: before the need for asset management would become clear and the theories and tools to support asset management would be developed; before the understanding of basic processes impacting bridge conditions would be well understood and amenable to reliable measurement; and before the political will to invest major funds in analyzing performance of pavements and bridges could be mustered.

This argument does not diminish the value of the NBI or of the AASHTOWARE PONTIS database or of any other similar system. These systems are well established, widely used and they fill the different needs for consistent, systematic approaches to bridge management at the federal level and at the state and local agency level. What this argument does is identify the need to carefully consider the knowledge, tools and products incorporated in the NBI and in bridge management systems while establishing the focus, objectives, methodologies and protocols of the LTBP; and in turn to use the data and knowledge learned from the LTBP studies to enhance the performance of the NBI and of PONTIS and other bridge management systems. At the federal level, it may be possible to create a radically different definition of deficiencies on bridges and thereby redirect the distribution of the limited federal funds for bridge conditions and/or characteristics that have the most impact on the three areas of bridge performance. Conversely, it may be possible to diminish the focus on conditions and/or characteristics that in actual experience do not significantly affect performance. It may be possible, if not necessarily feasible, to identify the key elements of bridges that really require biennial or more frequent inspections versus those that don’t and to ultimately refocus the available inspection resources on the truly critical issues.

An example of synergy between the NBI and the assessment of long term bridge performance relates to the question of deficiencies on bridges and how they are defined. Beginning with early federal assistance programs after the collapse of the Silver Bridge, it was necessary to establish priorities for the use of federal funds to address needs associated with public highway bridges. The FHWA, in consultation with the American Association of State Highway & Transportation Officials (AASHTO) agreed on definitions of deficient bridges and on criteria for eligibility for federal bridge improvement funds. The definitions of structurally deficient bridges and functionally obsolete bridges are based on data that is reported to the FHWA and stored in the NBI. The FHWA’s BMISL has studied bridge deficiencies to determine what are the most prevalent factors that result in a bridge being rated deficient. Figure

2 indicates one of the findings of these studies. The most prevalent reason for rating of structurally deficient is superstructure appraisal which is entirely independent of condition. The condition of the deck, the most visible element of the bridge is only the 4th leading cause of a rating of structurally deficient.

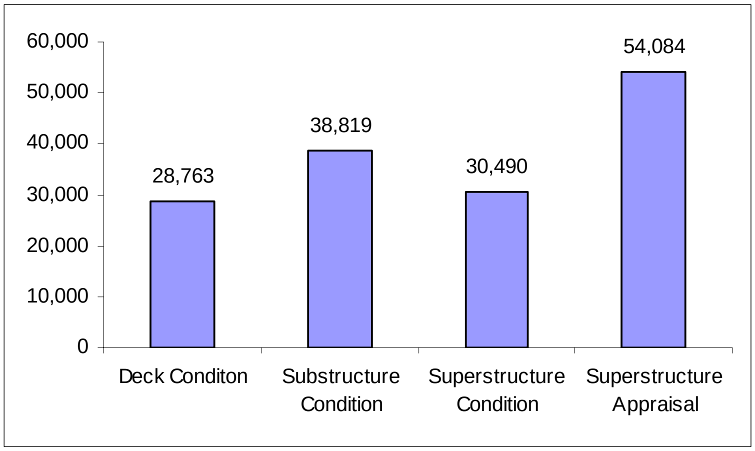

Figure 2 – Major Causes of Bridge Deficiencies

Based the same study, the number one cause of a deficient rating is related to deck geometry – a bridge that is functionally obsolete because the roadway width is considered too narrow for the traffic volumes currently using the bridge. Findings such as these have had and still have considerable impact on the allocation of billions of dollars of federal bridge funds.

Much of the pioneering work on defining bridge deficiencies is based on arbitrary definitions and significant assumptions and the reasoning behind many of these criteria is not well documented, not well understood and may in fact be misleading or fallacious. Traffic safety in the vicinity of bridges is an obvious parameter of bridge performance, yet there are no proven formulas to relate safety to bridge characteristics such as clear deck width, clearances, approach roadway alignment, etc. The *Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges* does present an arcane table for evaluating deck geometry considers traffic volumes, lane widths, direction of traffic and type of highway systems in order to rate the deck geometry. No apparent research supports these numbers and the method ignores possibly causative or complicating factors such as % of trucks in the traffic stream, approach roadway alignment and posted speed.

The synergy between the NBI and a future Long Term Bridge Performance program could work in this way: The data in the NBI is mined to identify the most prevalent deficiencies that impact bridge performance and affect the safe, efficient and economical operation of the public highway systems. Deck geometry is initially identified as one important factor affecting safety. The data in the NBI and other available databases can be mined to create a subset of bridges that reflects a range of the key variables including traffic volumes, truck traffic, deck widths and perhaps other causative factors such as climatic conditions, approach roadway alignment, posted speed, etc. The FHWA's Bridge Management Information Systems Laboratory was established to identify and analyze causes and trends of deficiencies within the

Nation's bridge inventory. The BMISL has developed and/or acquired the tools to support sophisticated analytical research on existing disparate data sources through a Geographical Information System (GIS) platform combined with Rational Database Management Systems (RDBMS) software and advanced mathematical and statistical software. Under a program such as the Long Term Bridge Performance program, data on types and frequencies of accidents can be monitored and analysis of long term accident experience can be used to correlate accident potential with the bridge parameters. Ultimately the findings can used to modify the calculations that determine bridge deficiencies and impact the distribution of federal funds for bridge improvements.

There is also some potential for synergy between the LTBP and databases for bridge management systems such as PONTIS. For example, the FHWA's BMISL has initiated an effort to create a database with multi-state and multi-year condition data on the commonly recognized bridge elements in the program PONTIS collected from a large number of states. This study, if continued, can provide useful data such as frequency of occurrence of each element nationwide plus variations in element definitions and condition state language from state to state. Analysis of this nationwide data can point to bridge elements to consider for long term monitoring based on: prevalence of the element in the bridge population; and high rates of deterioration (high transition probabilities) as projected in the bridge management system. The LTBP sample of instrumented bridges could focus on those elements in order to verify or help update the transition probabilities for more accurate prediction of future conditions. Furthermore, the possibility for correlation between data collected from a small sample of LTBP instrumented bridges with a large sample of similar brides evaluated in element level visual inspections should be an important factor. An example would be concrete decks instrumented under LTBP to record ongoing rebar corrosion activity, cored periodically to measure chloride contents and surveyed periodically with ground penetrating radar to map and measure delaminations. With this data correlated with element level inspection data, it might be feasible to modify the feasible actions as they relate to the various concrete deck condition states which would still remain described by surface characteristics of the deck.

Conclusions

This paper has provided some perspective on the evolution of bridge performance data and assessment in the US; evolution has proceeded from a state of virtual ignorance (pre 1970) to a state where sophisticated systems and tools for managing bridge data are in place, but also to a state where large gaps in the necessary data to make the most effective use of these systems and tools are easily identified. The paper has made some suggestions as to where the resources available for the LTBP should be concentrated; how the NBI and bridge management databases such as the AASHTOWARE PONTIS can be used to identify specific objectives for the LTBP; and how the data and knowledge learned from the LTBP lead to improvements in the effectiveness of the National Bridge Inventory and bridge management system database. These themes should be explored in depth as the objectives, methodologies and protocols of the LTBP are developed. It is clear that the NBI and modern BMS databases will play a significant role in future assessment of bridge performance and that a considerable amount of synergy can be expected as better bridge condition data and bridge performance knowledge is fed back from programs such as the FHWA's Long Term Bridge Performance Program into the NBI, PONTIS, etc.

References

- Federal Highway Administration Bridge Management Systems Information Laboratory (2002), Evaluation of the National Bridge Inventory: Composition and Condition of the Nations Bridges Based on Superstructure Materials & Designs
- Federal Highway Administration Office of Engineering (1995), Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges
- Federal Highway Administration Office of Research, Development & Technology (2001) Reliability of Visual Inspection for Highway Bridges,
- Volume I: Final Report (FHWA-RD-01-020) & Volume II: Appendices (FHWA-RD-1-021)
- Transportation Research Board (1994), Circular 423, Characteristics of Bridge Management Systems