ASSESSMENT OF BRIDGE INSPECTION AND MAINTENANCE IN THE UNITED STATES

BY

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Submitted to the graduate degree program in Civil, Environmental and Architectural Engineering and the Graduate Faculty of the University of Kansas School of Engineering in partial fulfillment of the requirement for the degree of Master of Science

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Abstract

Bridge inspection and maintenance is extremely important to the country since it is the economic lifeblood of the United States business and people relying upon them to do business and get to work. Although bridge disasters are relatively rare, the consequence of a failure can be disastrous. Technical and management problems that under the identification of bridge deficiency and obsolesce need to be identified and solved in order to keep bridges from falling apart. The purpose of this paper is to understand the problem behind bridge inspection and maintenance system in the United States in order to develop potential solutions to solve the problems that the DOTs are facing on the aging bridges and limited budget. A cost management model and a maintenance spending model are analyzed from this research.

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Acknowledgements

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Chapter 1. Introduction

On August 1, 2007, an unexpected tragedy happened that took 13 lives and injured more than 100 people. The collapse bridge of the I-35W across the Mississippi River in Minneapolis awakened the nation about the safety of our highways (Figure 1.1). Commuters in the US spent most of their weekdays on the road. They hardly understand the danger they are facing everyday and any bridge deficiency and potential collapse may not seem apparent to them. Such a tragedy signaled the importance of bridge maintenance and inspection in this nation.

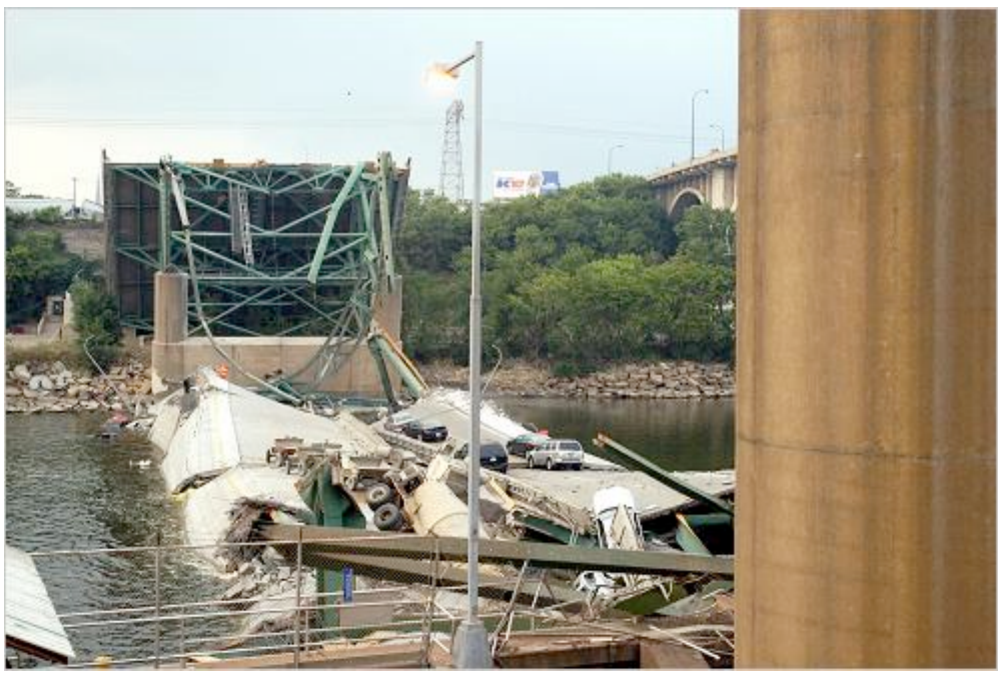

Figure 1.1 Official Minnesota Department of Transportation investigation photo of the I-35W bridge collapse in Minneapolis, taken Aug. 3, 2007 (Source: "NTSB Expected to Adopt Final Report on I-35W Bridge Collapse" by ASCE, 2008)

1.1 History of the bridges

With more than 230 years of history, most of the early population centers in the US concentrated in the Northeast and Midwest, as such, much of the country's infrastructure was built significantly long time ago (Eagleton Institute of Politics, 2004). The advancing technology of the 19^{th} and 20^{th} century accelerated the growth of the transportation network in the country (Eagleton Institute of Politics, 2004). The transportation growth was further pushed by the heavy infrastructure investment, initiated by Eisenhower and continued by other presidents, after the Second World War (Eisenhower Presidential Center, 2008). Many of the bridges built during the massive infrastructure development periods are still in place and used by the public. The 2007 statistics published by the Federal Highway Administration highlighted that 9,033 U.S. bridges are over 100 years old (Federal Highway Administration, 2007). The majority are located in states in the East and Midwest as shown in Table 1.1.

States	Number of 100-year-old Bridges
ILLINOIS	801
IOWA	1,117
KANSAS	501
MASSACHUSETTS	426
MISSOURI	900
NEW JERSEY	304
NEW YORK	366
OHIO	1,980
PENNSYLVANIA	912

Table 1.1 States with the most number of 100-year-old bridges (FHWA, 2007)

Modern bridges are made by steel and concrete. However, some older bridges in these states are made of stone, and wood (New York State Department of Transportation, 2008). The wide range of materials used to build bridges complicates the bridge maintenance and inspection. In addition, some materials are more vulnerable to the environment than steel, and may require more frequent inspection and maintenance than new steel bridges.

1.2 Bridges built in the Era of Interstate Construction and their conditions

2006 marked the 50^{th} anniversary of the federal law, which brought the current Interstate Highway System to the country. According to a report by Dr. Jeffery Memmott, in 2006, there were nearly 600,000 highway bridges in the US (Memmott, 2006). Among these bridges, 24 percent of them were built between the 50s and the 70s. In the interstate construction era, the traffic was not as busy as it is now and no one could have imagined that these highways have to accommodate more than 250 million passenger vehicles every day (Memmott, 2006). According to a study by the US DOT, the number of vehicles in the US rose steadily since the 1960s (Bureau of Transportation Statistics, 2006). In a 2004 survey, there was one passenger vehicle for every 1.2 persons (United States Census Bureau, 2004). The design of older bridges was not meant to handle the current traffic demands. Additionally, 25 percent of these bridges were on the list of deficient bridges according to US DOT NBI report in 2007 (Federal Highway Administration, 2007). Thirteen percent of these bridges were classified as structurally deficient. In other words, elements on them “need to be monitored and/or repaired” by the FHWA and the USDOT standard. This does not imply that the bridges are” likely to collapse or that is unsafe”. It simply meant that it must be “monitored, inspected, and maintained” (Federal Highway Administration, 2007) based on the USDOT definition.

Yet, the I-35 W Mississippi River Bridge, built in 1964, was inspected one year before the collapse (American Society of Civil Engineers, 2008). It was rated 4 out of 9 and it could be operated without load restrictions (American Society of Civil Engineers, 2008). Prior to the failure, MnDOT had concerns about the welding under the bridge, and they planned to continue the inspection until the Fall of 2007 (American Society of Civil Engineers, 2008). Such facts and data imply simply that the condition of such deficient bridges in the country may be worse than what officials have predicted (American Society of Civil Engineers, 2008).

1.3 Current Bridge Management System

Bridges in the US are monitored using a centralized system (American Association of State Highway and Transportation Officials, 2006). This system includes specifications, components, and conditions that are recorded in the National Bridge Inventory (NBI) (American Association of State Highway and Transportation Officials, 2008). All the inspection data from regulated chronological inspections must be reported to the NBI for data analysis and maintenance schedules. The means and methods of the inspection are carried out satisfying the requirements of the National Bridge Inspection Standard (23 CFR 650.3) (American Association of State Highway and Transportation Officials, 2008). The conditions of the bridges are gauged in a nine-point ranking system. Nine for being "superior" to present "desirable criteria", and zero for "requiring to be closed" (New York State Department of Transportation, 2008). The officials will use a computer program to rank the need of maintenance of the bridges and arrange the maintenance within the state and federal budget each year. The most common software that local DOTs and USDOT use is Pontis (American Association of State Highway and Transportation Officials, 2008).

Pontis, one of the "Bridgewares" developed by the American Association of State Highway and Transportation Officials (AASHTO), is a comprehensive Bridge Management System (BMS) software that organizes bridge maintenance and inspection. The purpose of this software is to improve the methods of administration, planning, research, design, construction, maintenance, and operation of transportation facilities (American Association of State Highway and Transportation Officials, 2006). The software has the ability to allow inspectors to report inspection data to the NBI and also to analyze the information for maintenance. In addition, it can plan and schedule repairs for bridges by the federal and local DOTs. In addition, Pontis can predict the condition of a bridge in the coming years with or without specific repairs and display the depreciation on graphs. It can rank the priority of maintenance of the bridges according to NBI code and financial situation as well. Even though it is a powerful tool with different function moduli on BMS, it is not used nationwide. Some states use it only in some counties or big cities. This issue raises question on the software’s functions and credentials. What kind of data needs to be input during inspection? In addition, how does the software predict the bridges future condition and come out with data for maintenance? The other question is the data output given to professionals. Can the engineers understand the data? Can they plan proper repair actions from the data given by the software? The aircraft industry has a similar system for maintenance data analysis. The system can predict if maintenance is structurally sound or specific maintenance is needed to be carried out. Their system is widely used and it evaluates all repairs for aircrafts meeting even higher requirements. Ideas may be brought to BMS and to improve the current system.

The use of BMS software implies that each state DOT has its own approach to manage the bridge inventory. Furthermore, city, county, and state agencies handle their bridges in different manners. They have separate responsibilities in different stages of the inspection and maintenance within the same inventory of bridges. Studies show there are conflicts across agencies that may affect the health of bridges (Dubin & Yanev, 2007). Is there a more preferable model on bridge inspection and maintenance that can better utilize financial resources and cooperation between different government agencies?

1.4 Finance for bridge inspection and maintenance

The American Society of Civil Engineers (ASCE) conducts its own infrastructure deficient investigation in the United States, and they conduct studies on the infrastructure and have released a report card each year since 1998 (American Society of Civil Engineers, 2009). The purpose of the report card is to raise the awareness among the government officials and the public on the quality of the infrastructure in the country. The investigation includes studies by the local chapter in different states annually on 15 infrastructure categories, such as bridges, aviation, rail…etc. The local ASCE chapter determines the state and federal budget and the number of infrastructure projects conducted in each category in their state every year. Then, the organizations determine the rate of increase on the number of infrastructures in each category. For example, the ASCE in Texas determined that the number of bridges in the state of Texas increase at an annual rate of 0.7%. The local chapter will then determine the desired budget for the improvements and the actual improvement work that has been completed that year. Finally, the department will give a grade for each category to the state and the national 28-engineer-council will release an overall national grade to the public (American Society of Civil Engineers, 2009). Since 1998, the first year of the report card, the cumulative grade of the infrastructure in the US is a D. The grade for bridges is a C, which barely meets standards. In 2009, The Report Card shows that the infrastructure is poorly maintained. ASCE announced that many infrastructures are unable to meet the current and future demands, and it is unsafe in some cases (American Society of Civil Engineers, 2009). In the same study in 2001, the projected budget needed was $1.3 trillion to restore the infrastructure to acceptable levels. The number continued to balloon to $1.6 trillion in 2005 and $2.2 trillion in 2009. The cost increased $0.6 trillion within 4 years (American Society of Civil Engineers, 2009). The increase is due to the rate of inflation and the worsening condition of the infrastructure. Therefore, the longer the maintenance is ignored, the higher the maintenance cost will be.

There are few causes to the current problems. For bridges, the first problem is due to the fact that bridge inspection and maintenance funding is very limited from the federal government under the federal regulations and budget shortfall (American Association of State Highway and Transportation Officials, 2008). The federal government is more willing to fund new construction projects (Dubin & Yanev, 2007). State government can only use emergency funding for bridge maintenance if an infrastructure fails or if there is a possible threat to the public safety. As such, the most common strategy is to rely among the local and state government local taxes such as sales tax, and state income tax for infrastructure maintenance money. However, money from the taxpayers is usually insufficient to support the massive cost of inspection and maintenance of bridges. Federal government should take a leadership role in funding and the state and local government should look for more alternatives for funding.

Chapter 2. Literature Review

When a transportation incident happens, the National Transportation Safety Board (NTSB) will investigate the cause of the event by site visits and debris testing. They will report to the public and suggest improvements on the structure involved in the accident (American Society of Civil Engineers, 2008). NTSB's initial finding for the I-35W Mississippi River Bridge collapse is that the collapse may have been due to a corroded gusset plate, and other components, which had not been inspected for some time (American Association of State Highway and Transportation Officials, 2008). The gusset plate was in bad condition and had only half of the thickness left during the inspection in 1993. Some of the structural components on the bridge were difficult for inspectors to reach (American Society of Civil Engineers, 2008). The findings raised public awareness and the current bridge condition highlights the management problems in the existing system (American Association of State Highway and Transportation Officials, 2008). Since the incident in 2007, the amount of researches and studies by government agencies such as USDOT and FHWA, and by academics has increased (American Association of State Highway and Transportation Officials, 2008). Valuable findings from either technical or management research on bridge inspection and maintenance will uncover the issues that government agencies are facing to keep up with bridge maintenance. Review of these results will help us to have a better understanding of the current condition and future improvements needed.

2.1 Awareness in the public on Bridges Maintenance

The Bridge Maintenance System in the US was not a popular topic due to local government strategies and the lack of funding. In 1967, the Silver Bridge connecting Point Pleasant, WV, and Kanauga, OH collapsed due to material fault and corrosion (The University of Maryland, 2009). In addition, the Mianus River Bridge collapsed in Greenwich, CT in 1983 due to metal corrosion and fatigue (The University of Maryland, 2009). This led the country to develop a modern Bridge Maintenance System for the aging bridges. Even though the failure of the I-35 W Bridge in Minnesota was not due to an insufficient repair, it has awakened the public to the aging highway network (American Society of Civil Engineers, 2008). Since that event, the data on the obsolete and deficient bridges has been uncovered and has raised questions concerning inspection and maintenance management. Without a doubt, the current supervision of bridges has flaws that need to be addressed. Studies in different states by government agencies and academics brought the problems to light (American Association of State Highway and Transportation Officials, 2008).

The I-35W Bridge in Minneapolis was not the only bridge collapse in the history of the US. A few bridges collapsed due to inappropriate maintenance management. For example, the Upper Steel Arch Bridge between Niagara Falls in the US and Canada collapsed due to the fact that the ice from an ice storm caused the deteriorated bridge railing to fail as shown in (Figure 2.1) (The University of Maryland, 2009). In

January 1938, a severe ice storm hit the Niagara Fall, and flooded the lower river with ice. The ice of the river pressed against the bridge and caused the collapse. Even though it was caused by natural forces, the bridge had serious structural problems, and the government and public ignored them. On June 8, 1925, new searchlights for the Niagara Falls were installed on the bridge causing it to sway wildly due to the added weight (Encyclopædia Britannica, Inc., 1911). Furthermore, the bridge railing was deteriorated concerning the public. Vehicles could easily crash through it (Encyclopædia Britannica, Inc., 1911).

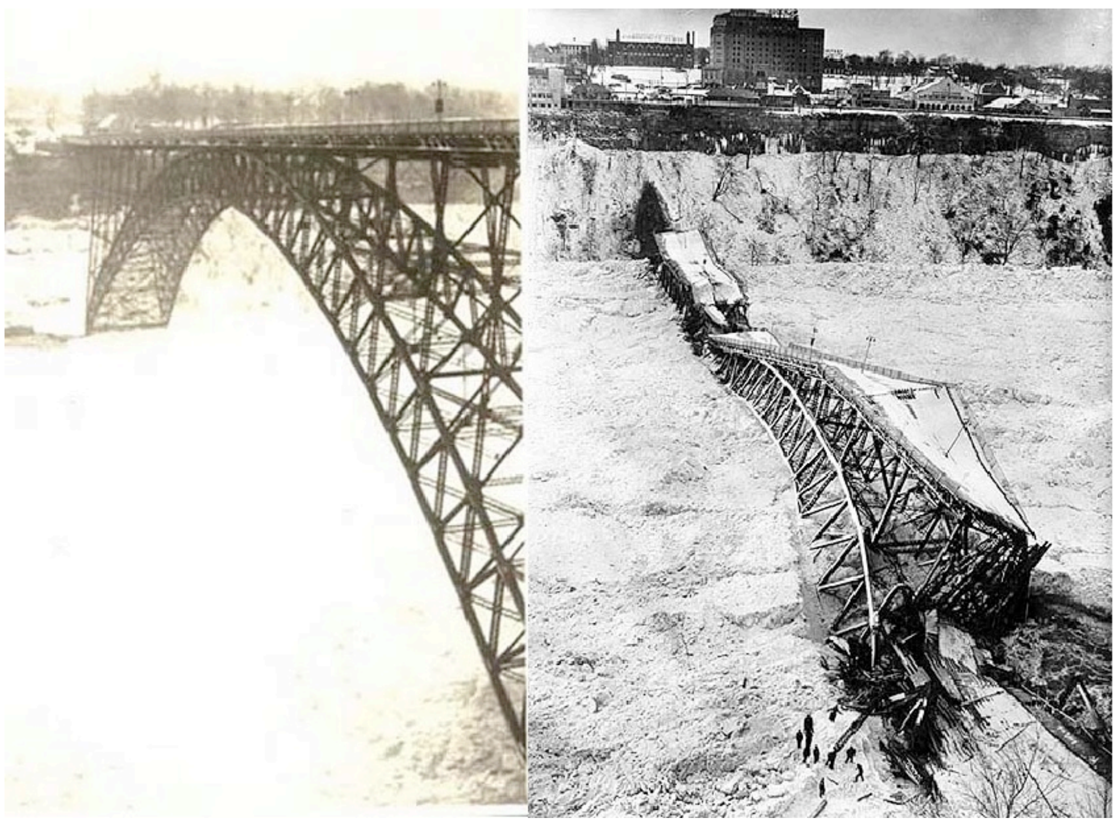

Figure 2.1 Upper Steel Arch Bridge near Niagara Falls Before and After the Collapse (Source: Department of Civil Engineering at the University of Maryland, 2009)

A later example was the Tennessee Hatchie River Bridge in 1989 as shown in Figure 2.2. The 50-year-old bridge collapsed on Saturday April 1, 1989. Before the accident, heavy rain and hail fell in the area flooding the Hatch River. The river was at 14.7 feet, 2.7 feet over the flood stage. It caused the river channel to shift. (Lawrence E. Jackson, 2008). The water washed away the deteriorated foundation of the timber piles causing the accident and taking eight lives. The National Transportation Safety Board (NTSB) determined that Tennessee State DOT noticed the deterioration of the bridge timber piles foundation before the incident (Turne- Fairbank Highway Research Center, 1995). Unfortunately, it was not fixed before it collapsed.

Figure 2.2 Hatchie River bridge (Source: Turne- Fairbank Highway Research Center, 1995)

Ever since the accidents happened in the 60s and 80s, the public was not aware of the failing infrastructures in the country until the bridge collapse in Minnesota in 2007.

The later incident marked the 50^{th} year anniversary of the Era of Interstate Construction. The bridge infrastructures built in this era reached their design service life (American Association of State Highway and Transportation Officials, 2008). Regular maintenance and rehabilitation will no longer work (Abudayyeh & Al-Battaineh, 2003). The public should be more aware of this issue. At the same time, the government should invest more resources on the transportation infrastructures.

2.2 Geographic Factors and Statistics Observation

Ever since the tragedy happened in Minnesota, the statistics on bridges in the US has caught more attention than when the bridges actually collapsed due to scarce repair. The bridge data made by the government agencies finally got the attention from the public. Each year, the USDOT and FHWA release new statistics on the bridges in the nation. From 2007 data, there are close to 600,000 bridges in the country. The number of bridges in each state is shown in Figure 2.3 (Federal Highway Administration, 2007). Out of all the states in the country, except Texas, the states in the Northeast and Midwest have the greatest number of bridges. The finding is reasonable since there are more rivers, lakes, and coastlines in these areas which require bridges for travel (United Nation, 2008). The state of Texas has a lot of construction companies and design firms specialized in bridges and flyover highways (United States Census Bureau, 1997). The state government supports the local companies and decided to build more flyovers and bridges. Therefore, the Texas state has a lot more bridges than other states in the country. A good example is the High Five Interchange in

Dallas, TX. It is a large five-level stack freeway interchange on Interstate 635 and US 75. On the west coast, only California has equal number of bridges per capita like the states in the Midwest.

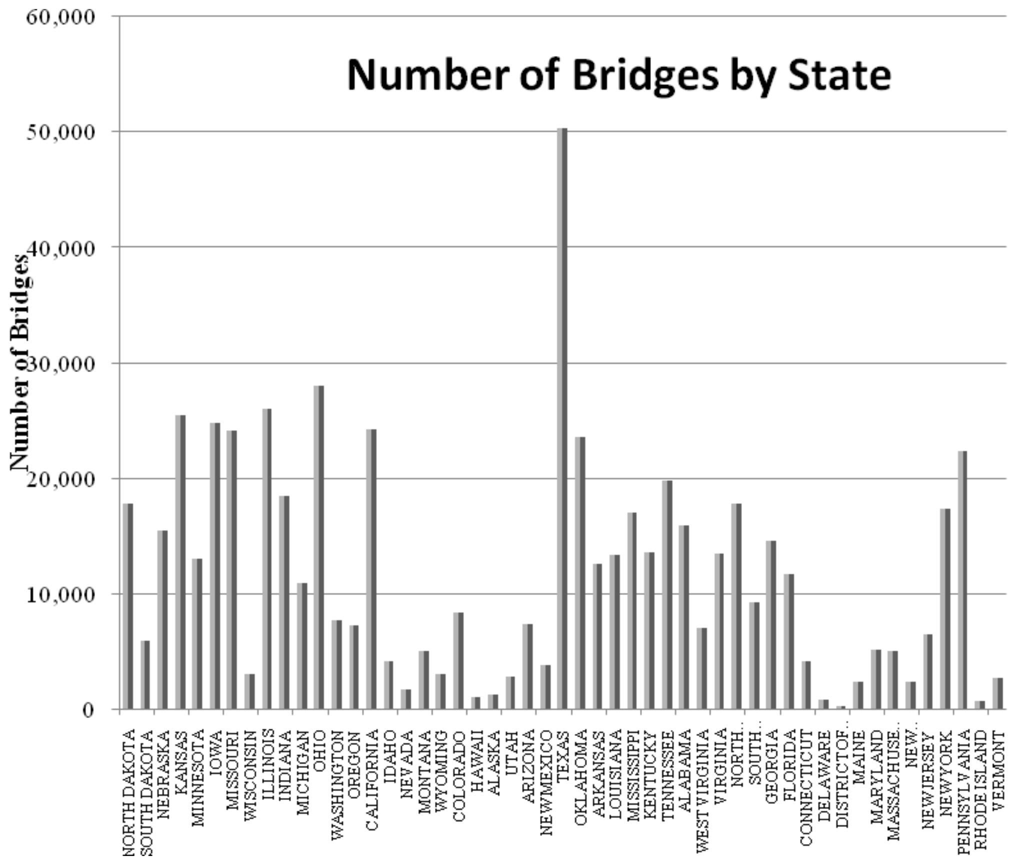

Figure 2.3 Total Number of Bridges in the US by State (FHWA, 2007)

Figure 2.4 shows that the total number of bridges in the Midwest is over 200,000 while the number of bridges in the Southeast is just over 150,000. However, due to the fact that Texas is included as part of the Southwest Region, the quantity of bridges in the Southwest is higher than expected. If Texas is excluded in the regional study of the data, the East region would have been the third highest quantity of bridges in the country. Relatively, the amount of bridges concurs with the number of deficient and obsolete bridges in the country. As expected, the states with the highest number of bridges have higher number of deficient and obsolete bridges as shown in **Error! Reference source not found.** and Figure 2.6. For example, in Pennsylvania, there are more than 20,000 bridges in the state. Out of the 20,000 bridge, close to 6000 of them are considered deficient and more than 4,500 of them are considered as obsolete under the National Bridge Inventory Rating Scale. The number of defective bridges is considered to be high. Similar conditions are observed in the Midwest and the Southeast Region of the country.

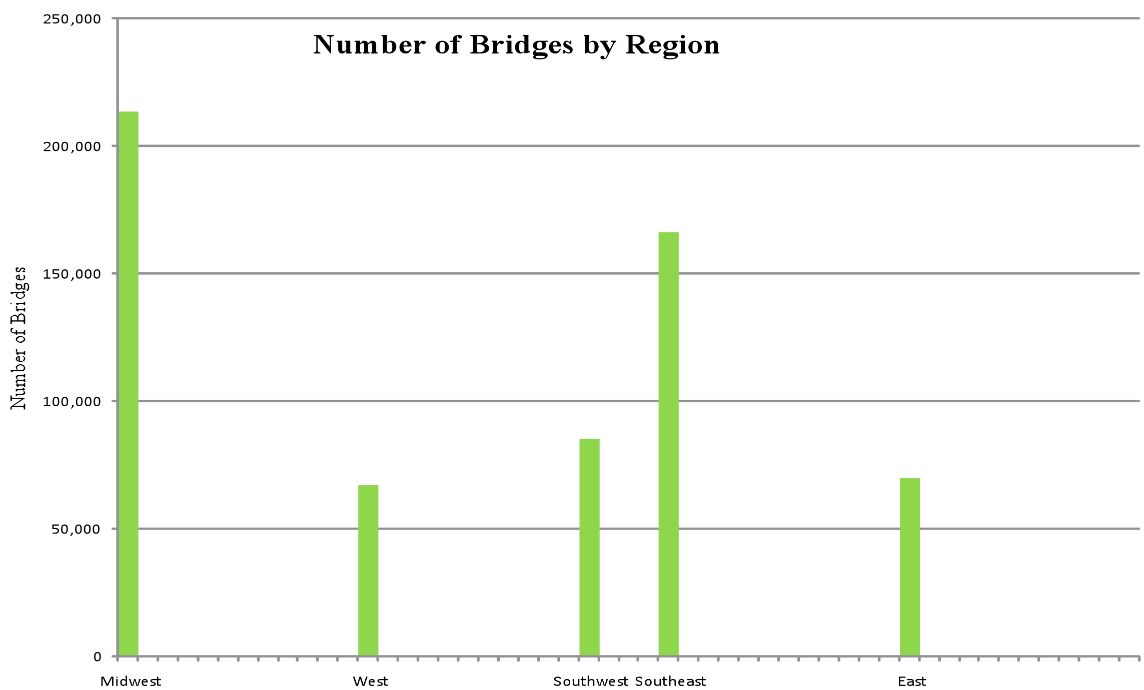

Figure 2.4 Number of Bridges in the US by Region (FHWA, 2007)

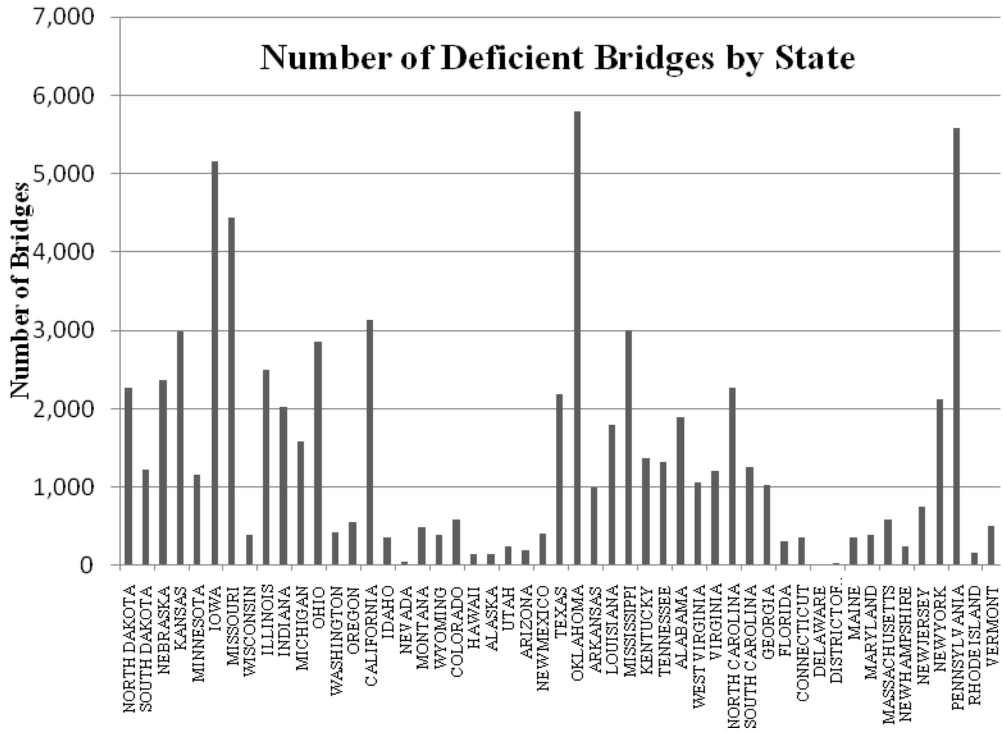

Figure 2.5 Number of deficient bridges in the US by State (FHWA, 2007)

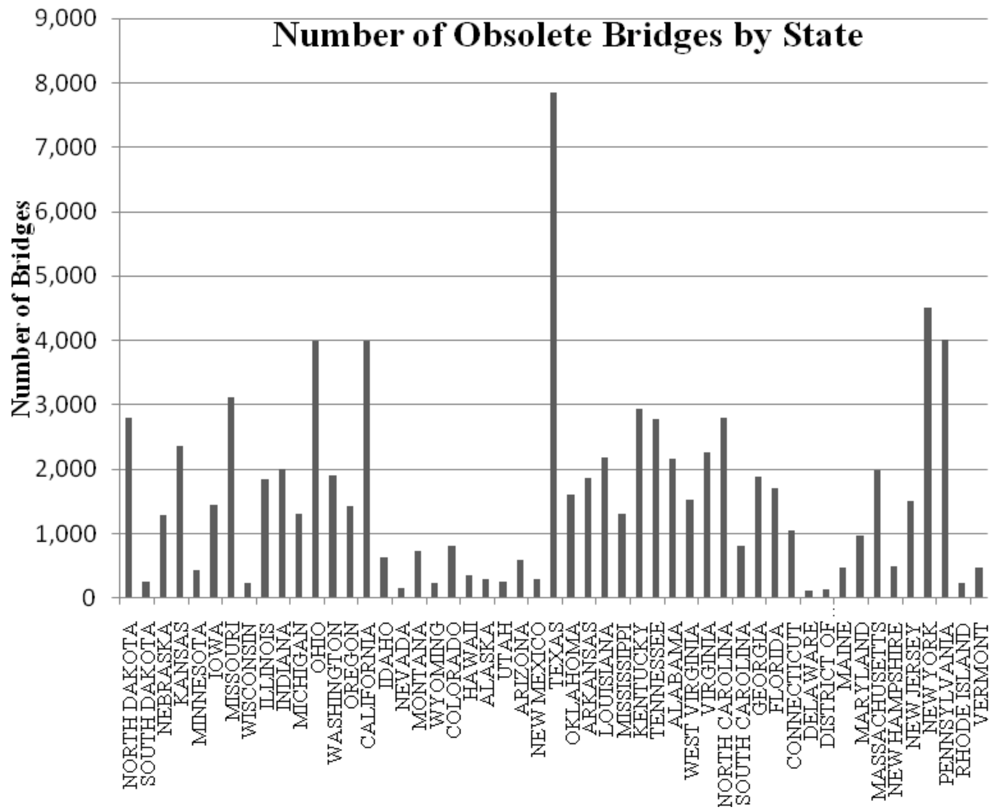

Figure 2.6 Number of obsolete bridges in the US by state (FHWA, 2007)

The National Bridge Inventory statistics shows that most states in the country have a lot of deficient or obsolete bridges. While some states may have serious defective bridges, these states such as Pennsylvania have more issues with bridge deficiency. Bridge arrangement may be the cause of the issue. Pennsylvania has 7.69% of its deficient bridges considered, and they represent 4.85% of all of the obsolete bridges in the US as shown in Figure 2.7 and Figure 2.8. The state has 5,100 miles of railroad and 120,000 miles of highway. The railroad and its subway and trolley system are part of the Southeastern Pennsylvania Transportation Authority (SEPTA), the 5th

largest in the nation (Pennsylvania Department of Transportation, 2008). With so many miles of road, railroad, and subway bridges, it may be difficult for a DOT to handle the maintenance and inspection well. In addition, the state has 124 historical stone arch bridges that require extra effort to maintain and preserve since they are considered as state historic structures (Pennsylvania Department of Transportation, 2008). Pennsylvania DOT has its own special bridge maintenance manual and special maintenance plan for stone arch bridges as shown in Figure 2.9 (Pennsylvania Department of Transportation, 2008).

Figure 2.8 shows that Texas has 9.52% of the nation obsolete bridges, which is the highest percentage in the country, though it has the largest number of bridges in the US. These data may imply that these states may not allocate sufficient resources to their state bridge maintenance program. With such limited funding, bridge repair budgets may need to be re-adjusted to support this extraordinary bridge deficiency.

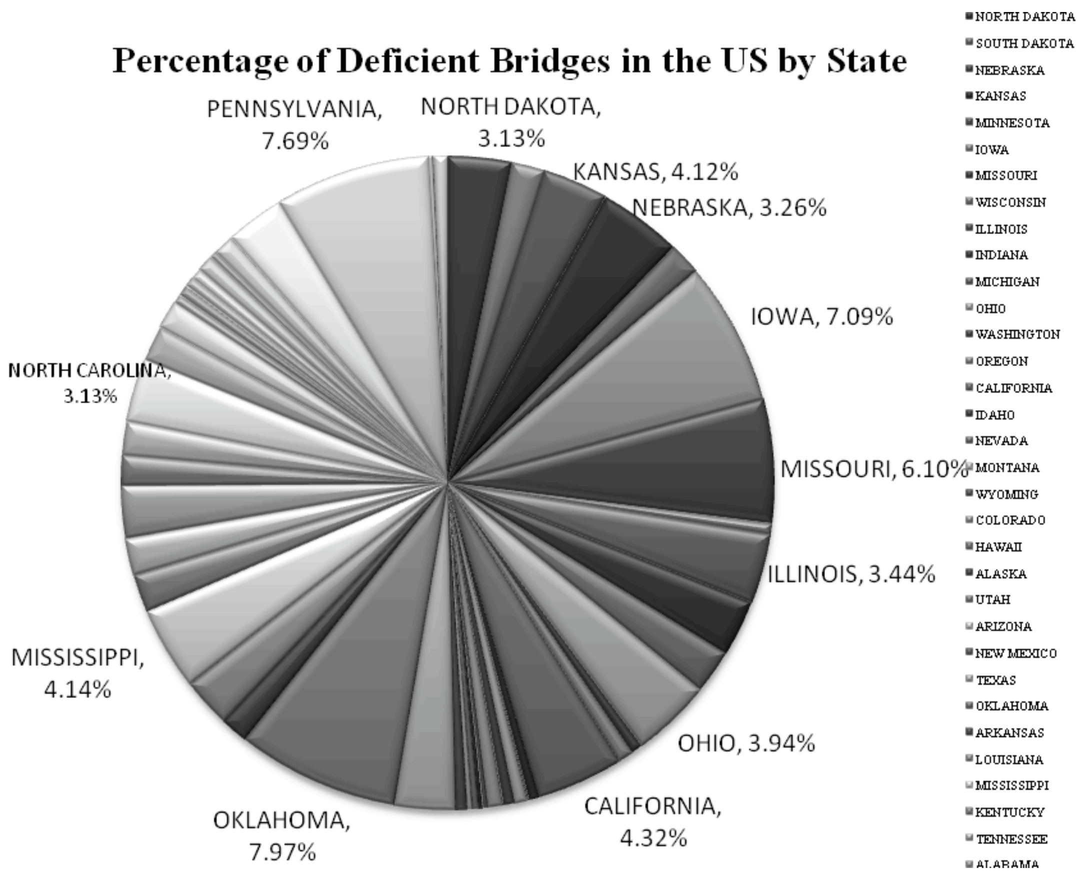

Figure 2.7: Percentage of deficient bridges by state (Federal Highway Administration, 2007)

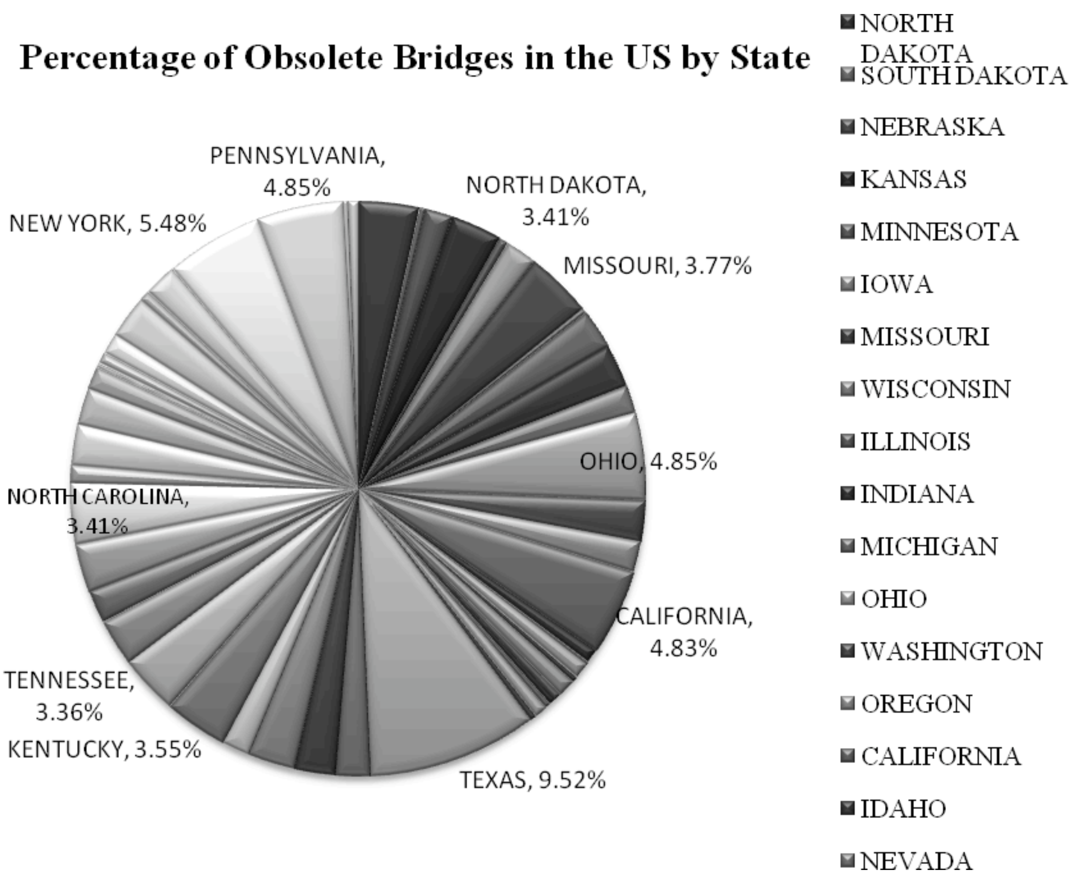

Figure 2.8: Percentage of obsolete bridges by state (Federal Highway Administration, 2007)

Figure 2.9 An old stone arch bridge in Pennsylvania (Source: PENNDOT, 2008)

2.3 The Impact of Inflation and Gas Prices on Material Prices

Source of income is one of the biggest issues facing bridge maintenance cost management. This ultimately affects the frequency of maintenance and inspection to be carried out by government agencies (American Association of State Highway and Transportation Officials, 2008). Even with sufficient budget money, inflation and material prices increase vary. The study “Bridging the Gap” by AASHTO, 2008 showed that between 2003 and 2008, the price of building materials for bridges increased radically. Paving materials such as concrete and asphalt increased 36% and 70% respectively (Figure 2.10). Most structural components of many bridges are made of steel, and the cost of steel is the majority of the material prices of the bridge. The price of steel can impact the cost of maintenance work. The high demand of steel in developing countries like China, Russia, and India drive up the global price of steel between 2003 and 2008 (American Association of State Highway and Transportation Officials, 2008). The price of steel mill products also increased 105% (American Association of State Highway and Transportation Officials, 2008). In the summer of 2008, the gas price reached $100 per barrel. Countless road projects were stopped or delayed due to the unexpected rise in gas prices (American Association of State Highway and Transportation Officials, 2008). The study by AASHTO demonstrated that the diesel fuel for construction equipment went up 306% during 2003-2008. The overall maintenance cost increased 50% due to the soaring price of materials. Tight budget situation was worsened by the rapid increase in material prices. Maintenance projects need to be delayed and cancelled, that further deteriorates the infrastructure.

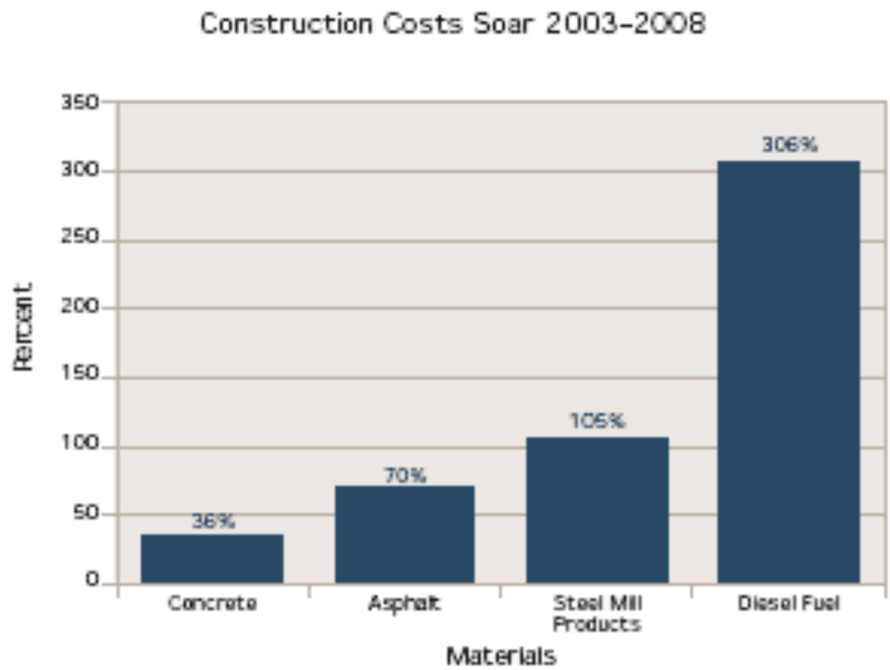

Figure 2.10 Construction material cost increases from 2003-2008 (Source: AASHTO, 2008)

Material prices constitute a significant part of construction cost. As such, material prices fluctuation impact the progress of projects. Government agencies will need to look for alternative materials to overcome the rising prices of materials. Currently, most used steel can easily be recycled at a relatively low cost. Alternatively, concrete and asphalt can also be recycled even though the process is relatively more expensive than steel compared to using new concrete and asphalt, and steel recycling (Federal Highway Administration, 2008). In addition, concrete is a localized material and its price is less affected by international demand. Asphalt is a residue product of oil refinery and it tends to be driven by the price of oil.

2.3.1 Recycled Concrete

A study by the Federal Highway Administration, the structural strength of recycled concrete performs as good as new concrete (Federal Highway Administration, 2008). However, the recycled concrete absorbed more water (Figure 2.11). As such, recycled concrete should be mixed with new aggregate to reduce water absorption (Federal Highway Administration, 2008). Currently, 38 states are using recycled concrete as a base aggregates (Figure 2.12).

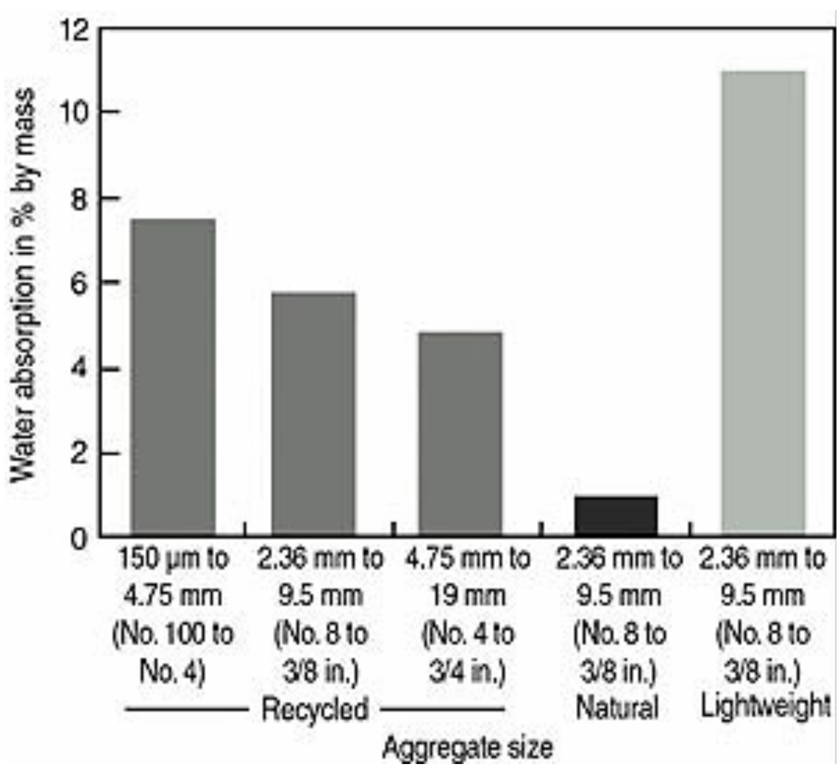

Figure 2.11Comparison of water absorption of three different recycled (Source: AASHTO, 2008)

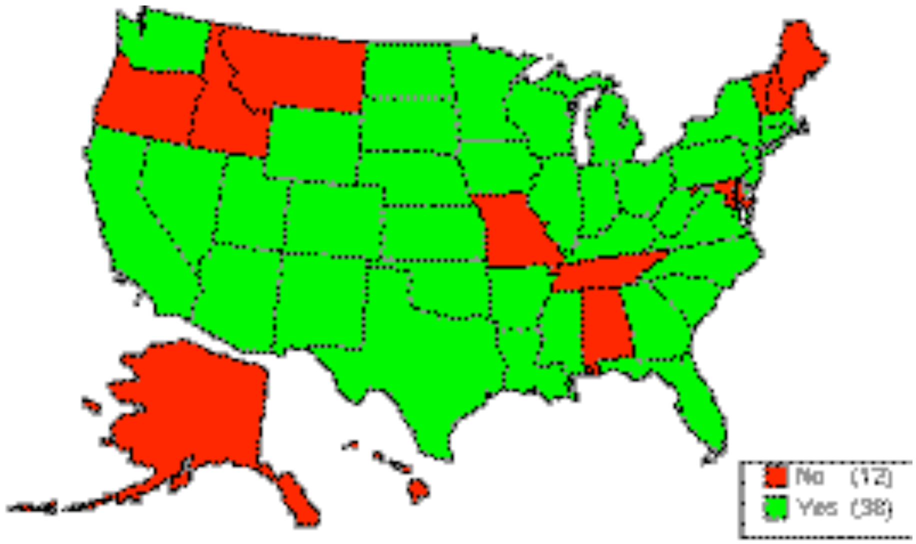

Figure 2.12States where recycled concrete used as base aggregate (Source: FHWA, 1998)

2.3.2 Recycled Asphalt

The price of asphalt binder varies throughout the year because its price depends on the price of petroleum (American Association of State Highway and Transportation Officials, 2008). In the last few years, rising oil price force up the price of asphalt by 40% as mentioned (American Association of State Highway and Transportation Officials, 2008). Fortunately, asphalt reclaimed from highways can be reused or recycled in new road. When the idea was first introduced in the early 90s, it was uncommon practice due to the lack of guidelines. The specification of Superpave, which is now commonly used on highways, did not address how to incorporate with Reclaimed Asphalt Pavement (RAP) into new construction (McDaniel & Nantung, 2005). The North Central Superpave Center (NCSC) and the Asphalt Institute carried out three research projects under the supervision of the National Cooperative

Highway Research Program (NCHRP) on RAP and the results were completed in March, 2000 (McDaniel & Nantung, 2005). The results showed that the Superpave mixture could be designed with 40% to 50% of RAP. Even though an additional 20 to 25% of RAP could be used, the stiffness would increase and the permanent strain would decrease. The same study determined that if the Indiana DOT used 5% RAP in all their Superpave mixture, they would be able to save $330,000 per year on highway construction (McDaniel & Nantung, 2005).

2.4 Change of Functions of the Bridges & Inspection Rating Conflicts

During the inspection on the East River Bridges in New York, technicians found out that the current rating system has some flaws (Dubin & Yanev, 2007). The condition of components on the bridges was actually better than it was rated during the inspection. The inspectors did not consider the design and the original function of the bridges during the rating on the bridge components. The bridges design was relatively conservative and these bridges originally had railways running on them. However, the railways were abandoned years ago and were converted into pavement for automobiles. The live load was significantly less than they were initially designed for. Thus, the inspection data did not reflect such condition, and a new rating system was needed (Dubin & Yanev, 2007). In a study "As-Built Information Model for Bridge Maintenance", also highlighted similar problems in Michigan. The paper proposed that design and construction data (As-Built Data) of bridges should be included in the bridge maintenance and inspection database (Abudayyeh & Al-Battaineh, 2003). The bridge inspectors should provide proper rating to the bridge components according to their real functions and durability. Such inspection method would result in better estimate of the bridge condition.

In addition to the rating problems mentioned above, there are also conflicts between inspection and maintenance data. For example, the inspection data from New York State did not incorporate into the New York City maintenance plan (Dubin & Yanev, 2007). Such disintegration of data caused premature failure or deterioration on newly rehabilitated elements due to the undiscovered accumulated debris and other corrosive materials. A management system that can better predict the lifecycle of bridges is needed to incorporate the data from different government agencies. Most of the data are spread across different agencies. A coordinated database is required so that government agencies from different levels or locations can share valuable inspection and maintenance data.

2.5 Unsustainable Bridge Design

The decades long maintenance program for the East River Bridges was supposed to improve the functions of the bridges so that the bridge can be adapted for modern use. Such program would improve the rating of the bridges in order to better predict the safety of them. In one instance during the rehabilitation process, the technicians found out that numerous elements installed during portions of the program would make future maintenance work difficult (Dubin & Yanev, 2007). Some components were difficult to access while the others were duplications of the original parts (Dubin & Yanev, 2007). Technicians should have access to the damaged area in order to repair the bridge effectively. However, repair was difficult due to the unique environmental factors of a bridge. The moisture from the stream and river speed up the corrosion underneath the steel bridge, and technician should have access to such area to perform regular maintenance. Nonetheless, the most common practice is to build a scaffold where the technicians can climb under or an inspection motor machine has to be used. The cost of scaffolding is expensive and it is time consuming to install. In addition, if the inspection and maintenance work is done in-house, the technicians need to participate in a 4-day Scaffold Safety Training in order to use scaffolding or a truck mounted platform (New York State Department of Transportation, 2008). To improve the complicated inspection and maintenance, engineers, and designers should take future inspection and repair into account in their bridge designs. For instance, a bridge inspector access should be built-in on future bridges so that they can inspect most of the NBI items without equipments.

2.6. Inspection Technologies and the Impact in Costs

Inspection and repair usually require heavy duty equipment and these equipments can be expensive. The cost of maintenance of the machine, storage, mobility, and the price of the machine should be considered while designing a bridge. The cost of moving large equipments can be expensive (Reed Construction Data, Inc., 2006). Costly professionals can also drastically increase project costs. Divers may be needed to inspect piers under the water and the cost of devices can be high. It also increases the risk of the bridge inspectors and increases cost of insurance.

Maintenance needs for deteriorating highway bridges has far outpaced available resource for highway maintenance that US federal and state highway agencies can provide (Liu & Frangopol, 2006). In order to solve this, advanced technologies including new inspection and monitoring techniques all become important if DOTs wish to reduce inspection and maintenance cost (Liu & Frangopol, 2006). Different technologies are used on different components of bridges during inspections currently. According to the article “Bridging the Gap”, steel pins and other steel components on bridges were tested by ultrasonic device (Figure 2.13) (American Association of State Highway and Transportation Officials, 2008). The device is a non-destructive testing method that can detect cracks and other failures deep inside the steel structures, micro mechanical failures such as creep, fatigue, rupture, yielding that cannot be seen by human eyes.

Figure 2.13 An engineer tests a bridge pin using ultrasonic technology (AASHTO, 2008)

Some states use Ground Penetrating Radar (GPR) to detect corrosion on rebar space and voids in concrete structures. A GPR mounted on a vehicle will emit short radar pulses to detect corrosion and void when the vehicle drives across a bridge. The GPR will generate images from the pulses and the image will physically presents any corrosion and voids problem inside the concrete and steel (American Association of State Highway and Transportation Officials, 2008). The inspectors are no longer required to physically enter the inspection area. Thus, these technologies save time for inspection and reduce the risk of exposure to unsafe working condition of the inspector.

Bridges across the nation are normally inspected every 24 months. However, any components failures that happen in between the inspection period will be undetected. Currently, some states use electronic sensor to constantly monitor the bridge condition. In Iowa, the DOT uses strain gauges-accelerometers and displacement transducers to monitor the vibrations and deflection of bridges. The data is automatically transferred to the headquarter and used to measure the condition of the bridges in the state (American Association of State Highway and Transportation Officials, 2008). In Florida, scour monitoring devices with temperature sensors are installed adjacent to the bridge piers to detect changes in the temperature (American Association of State Highway and Transportation Officials, 2008). Any temperature change will trigger the device to automatically alert the DOT engineers of the potential danger. Such technologies can monitor bridge 24 hours a day 7 days a week. These technologies will alert the proper agency and they can act accordingly without delay. However, these new technologies are currently not deployed in the nation. If used widely, regularly scheduled inspection intervals can be lengthened and then save both money and time for the states. At the same time, government agencies will be more responsive to the aging bridges with regards to maintenance.

2.7 Environmental Issues

Environmental issues pose greater challenge to the states located around the Great Lakes area and other parts of the Midwest, as there are a lot of rivers and streams, and the Southeast of the US contains number of wetlands. Bridges are often needed to cross these rivers and wetland. Extra cares are needed during maintenance and inspection so that the local environment can be better protected. However, environmental disaster did occur during maintenance For instance, paint used on US bridges prior to 1975 contained lead, chromium, or cadmium (Center for Environmental Excellence by AASHTO, 2008). If the paint needs to be removed from these bridges, it has to be removed strictly according to the EPA and OSHA guidelines and disposed of as a hazardous waste (Table 2.1) (Center for Environmental Excellence by AASHTO, 2008).

Impacting Regulation	Effect on Coating Operations
OSHA; CFR 29 1926.62, Lead in Construction	Establishes guidelines for protection and monitoring of workers removing lead paint from bridges. Requires lead training and monitoring for workers.
EPA; Resource Conservation and Recovery Act (RCRA)	Regulates the handling, storage, and disposal of lead (and other heavy metals) containing waste. Can increase the cost of disposal of waste from bridge paint removal by 10 times.
EPA; Comprehensive Environmental Response Compensation and Liability Act (CERCLA or Superfund)	Assigns ownership of and responsibility for hazardous waste to the generator "into perpetuity."
EPA; Clean Water Act	Regulates discharge of materials into waterways.
EPA; Clean Air Act Amendments	Mandates restrictions on allowable volatile-organic-compound (VOC) content of paints and coatings. Regulates discharge of dust into air from bridge painting

Table 2.1: Regulations Impacting the Bridge Painting Industry (Center for Environmental Excellence by AASHTO, 2008)

Table 2.1 shows that bridge painting involves toxic chemicals such as lead and VOC. These chemicals can damage the wildlife in the streams and rivers if these materials are not disposed off or used according to the EPA. In addition, handling these materials requires protection and special training of the workers specified by the OSHA regulations. Bridges use steel, concrete, asphalt and the release of materials into the environment may also affect the environment. A study in Australia by New South Wales, Australia Road Traffic Authority found the impact on road maintenance is significant (Center for Environmental Excellence by AASHTO, 2008) and they cited in the following tables.

ACTIVITY/FACILITY (and related issues)	ENVIRONMENTAL ASPECT (part of activity that could have an impact on the environment)	ENVIRONMENTAL IMPACT (possible effect on the environment)
Resealing (sealed road)	Possible sedimentation and erosion	Soil/water pollution
- stockpile management	Waste generation	Waste disposal
- chemical containment	Noise generation	Noise pollution
	Dust generation	Air pollution
	Potential for explosions	
	Odor generation	
	Potential for leaks and spills	

Table 2.2Maintenance Activities and Associated Environmental Aspects and Impacts at the New South Wales, Australia Roads, and Traffic Authority (NSW RTA, Center for Environmental Excellence by AASHTO)

ACTIVITY/FACILITY (and related issues)	ENVIRONMENTAL ASPECT (part of activity that could have an impact on the environment)	ENVIRONMENTAL IMPACT (possible effect on the environment)
Concrete saw cutting	Dust generation Noise generation Waste generation Wastewater generation	Air pollution Noise pollution Waste disposal Water pollution
Grading (unsealed road) - vegetation protection - drainage	Waste generation Dust generation Possible sedimentation	Waste disposal Air pollution Water pollution
Resheeting (sealed road)	Disturbance to vegetation Soil disturbance Generation of debris Generation of dust Generation of solid waste	Destruction of vegetation Spread of weeds Waste disposal Air pollution
Drain maintenance - clean table drains - clean benches on a cut	Vegetation disturbance Possible erosion/sedimentation	Destruction of vegetation Water pollution
Roadside maintenance, painting/replacement: - guide rails - signposts - fencing - noise walls	Vegetation disturbance Waste generation Potential for paint leaks and spills Disturbance of natural environment	Destruction of vegetation Waste disposal Water/soil contamination Aesthetics

Table 2.3Maintenance Activities and Associated Environmental Aspects and Impacts at the New South Wales, Australia Roads, and Traffic Authority (NSW RTA, Center for Environmental Excellence by AASHTO)

ACTIVITY/FACILITY (and related issues)	ENVIRONMENTAL ASPECT (part of activity that could have an impact on the environment)	ENVIRONMENTAL IMPACT (possible effect on the environment)
Pavement sweeping	Waste generation Generation of dust	Waste disposal Air pollution
Illegal dumping - waste storage and disposal - licenses	Dumping of waste	Soil contamination Water pollution
Landscape works maintenance - herbicide use - chemical storage	Damage to flora Potential spread of weed Potential batter erosion Potential leaks or spills Waste generation	Destruction of vegetation Aesthetics (weed die off) Noxious weed spread Water pollution Soil/water contamination Waste disposal

Table 2.4Maintenance Activities and Associated Environmental Aspects and Impacts at the New South Wales, Australia Roads, and Traffic Authority (NSW RTA, Center for Environmental Excellence by AASHTO)

ACTIVITY/FACILITY (and related issues)	ENVIRONMENTAL ASPECT (part of activity that could have an impact on the environment)	ENVIRONMENTAL IMPACT (possible effect on the environment)
Vegetation management - waste management - herbicide spraying - tree cutting	Damage to flora Use of herbicides/pesticides Potential spread of weed "green" waste generation	Destruction of vegetation Aesthetics (weed die off) Noxious weed spread Waste disposal Soil/water/air pollution
Roadside rest area maintenance	Litter removal and collection Syringe collection	Waste disposal Medical waste disposal
Bridge maintenance - flaming off bolts/decking - resurfacing with tar/aggregate - fuel storage - plant/vehicle parking - oxyacetylene storage/use	Generation of hazardous/non-hazardous waste Air emissions Potential for spills/leaks	Waste disposal Air pollution Water/soil contamination

Table 2.5Maintenance Activities and Associated Environmental Aspects and Impacts at the New South Wales, Australia Roads, and Traffic Authority (NSW RTA, Center for Environmental Excellence by AASHTO)

ACTIVITY/FACILITY (and related issues)	ENVIRONMENTAL ASPECT (part of activity that could have an impact on the environment)	ENVIRONMENTAL IMPACT (possible effect on the environment)
Paint removal	Waste generation (paint flake) Wastewater generation Waste ends up in natural environment Dust generation	Waste disposal Water/soil contamination Air pollution
Wood treatment (creosoting) - use of chemicals - chemical storage	Potential for leaks and spills	Chemicals in natural environment Soil/water contamination
Line mark removal (grinding)	Sedimentation Noise generation Dust generation	Water pollution Air pollution Noise pollution
Loop Cutting (asphalt road)	Dust generation Wastewater discharge (sediments & oil, fuel) Noise generation Waste generation	Air pollution Soil/water contamination Noise pollution Waste disposal
	Generation of wastewater from washing Potential for spreading weeds through machinery Potential for spills (fuels, oils etc)	Soil/water contamination Weed spread

Table 2.6: Maintenance Activities and Associated Environmental Aspects and Impacts at the New South Wales, Australia Roads, and Traffic Authority (NSW RTA, Center for Environmental Excellence by AASHTO)

ACTIVITY/FACILITY (and related issues)	ENVIRONMENTAL ASPECT (part of activity that could have an impact on the environment)	ENVIRONMENTAL IMPACT (possible effect on the environment)
Septic tank - maintenance	Potential leakage Generation of septic tank waste	Soil/water contamination Waste disposal
Road milling	Dust generation Waste generation Sedimentation Odor generation Noise generation	Air pollution Waste disposal Water pollution Noise pollution
Cleaning plant & equipment	Soil compaction Noise production Discharge of exhaust gasses	Damage to trees and plants Local noise pollution Air pollution

Table 2.7: Maintenance Activities and Associated Environmental Aspects and Impacts at the New South Wales, Australia Roads, and Traffic Authority (NSW RTA, Center for Environmental Excellence by AASHTO)

The study showed that concrete cutting during maintenance would generate dust and waste that contaminated rivers and streams around the area and produce noise that affected the wildlife. In addition, flaming off bolts and decking may have polluted the air and soil. Therefore, environmental issues during bridge maintenance should also be considered and government agencies should look into different alternatives in bridge design in order to lower the impact on the environment during bridge construction and maintenance.

2.8 Current Bridge Maintenance System

Bridges in the US are monitored by the Bridge Management System (BMS) (American Association of State Highway and Transportation Officials, 2008). BMS is management software that arranges inspections and maintenance schedules for bridges that are in need. The software usually contains the bridge specification and component data that are used to set the priority of the work (American Association of State Highway and Transportation Officials, 2006). Pontis, one of the Bridgeware by the AASHTO, is a comprehensive BMS software that organizes bridge maintenance and inspection for the DOT (Federal Highway Administration, 2007). The purpose of this software is to plan and schedule repairs for bridges under federal and local DOTs funding. The research survey conducted by the research team shows that all the DOTs use Pontis as their BMS to monitor and plan their bridge maintenance and inspection work. In addition, some states use the software to import and export data from the National Bridge Inventory, and monitor the inspection on 166 NBI specified items. Therefore, Pontis is used in the study to determine how BMS schedule inspections and maintenance for the aging bridges in the US and what scheduling strategy is normally used in the process.

Decisions concerning the work needing to be performed have to be made before using the software. Maintenance of bridges is governed by the condition of the bridges, available funding, and government policies (federal, state, or local) (Hearn, Purvis, Thompson, Bush, McGhee, & McKeel, 2006). Due to such complexity, AASHTO developed a data analysis and decision-making function in Pontis. During a bridge inspection, technicians will record the data of the bridge condition such as worn-out, damaged, or rusty components in the software. The data is sent to the Federal Highway Administration and the National Bridge Inventory (NBI) for updating. Pontis contains "The Gateway Module" that allows the import and export the data in and out of the NBI. The Graphic User Interface of the function is shown in Figure 2.14.

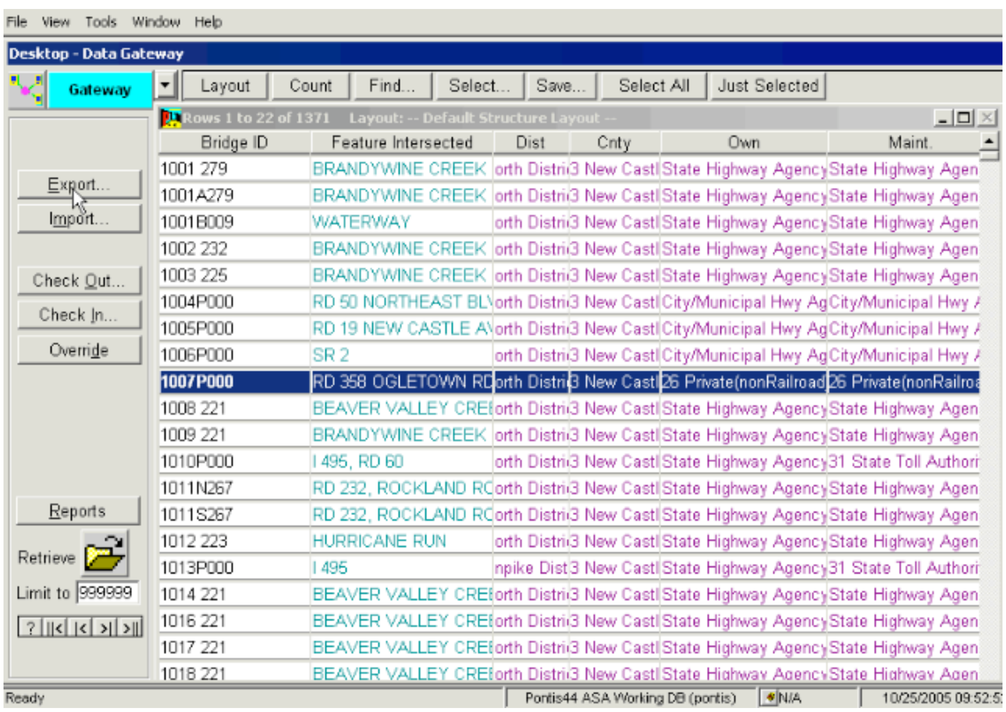

Figure 2.14: The Graphic User Interface of "The Gateway Module" in Pontis (FHWA, 2008)

The software obtains the information on the location, ownership, distance, and current condition from the NBI. The records help the software to rank and organize the priority of the maintenance schedule from another function module.

In addition to the inventory data, Pontis can also handle data on the cost difference of different types of preservation work on the bridges. For example, if a certain part of a bridge is deteriorated, and work is needed to be carried out in order to keep the bridge in a serviceable condition then different methods of maintenance will have different costs. It will also affect the lifecycle of a bridge. Consequently, Pontis contains a Cost Elicitations module that could optimize the plan for the maintenance program. In the same module, it has a function called "Deterioration Elicitations." In this module, users can input the type of environment that a component of a bridge is subjected to and the probability of the deterioration in the different stages of the bridges lifecycle. Also, the recommendation of the work will be set in this module.

Like other scheduling software, budget data has to be imported into Pontis in order to manage the finances of bridge maintenance more efficiently. Due to the complex ownerships of most bridges, the budget handling of bridges and highways are extremely difficult. Money for maintenance may come from the city, district, county, state, and federal government. Sometimes, different government agencies may share the cost of maintenance. However, Pontis users can input such budget, the resources required, and budget years to the program for analysis as shown in Figure 2.15.

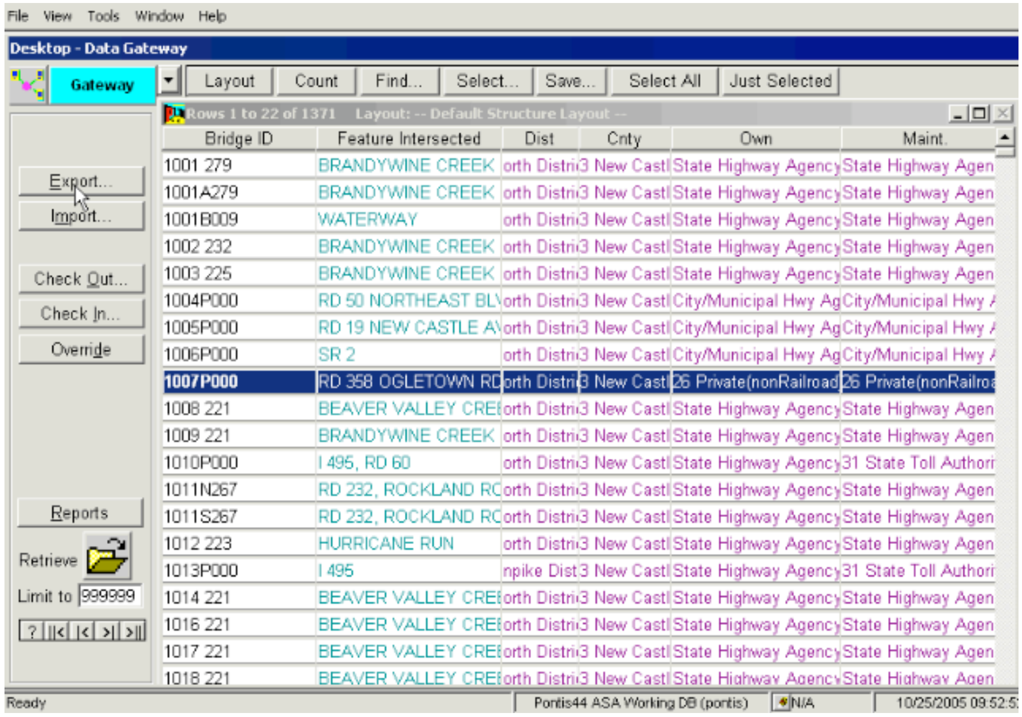

Figure 2.15: Budget and Resources Input in Pontis (FHWA, 2008)

The results module of the software can be used to perform program simulations, including work, total program needs, performance measures, and preservation needs for any scenario or work program. After the software has obtained the bridge data and all the cost and deterioration criteria are input to the system, the software will calculate the total needs and benefits of work and cost on a bar chart. For example, the software will show the improvement work needed for one single part on a bridge. In addition, it will show the benefit of performing all the needed jobs. However, the provided budget may not be able to cover the cost of all the required work. Thus, the software will program all the critical work first according to the budget. A sample result is shown in Figure 2.16.

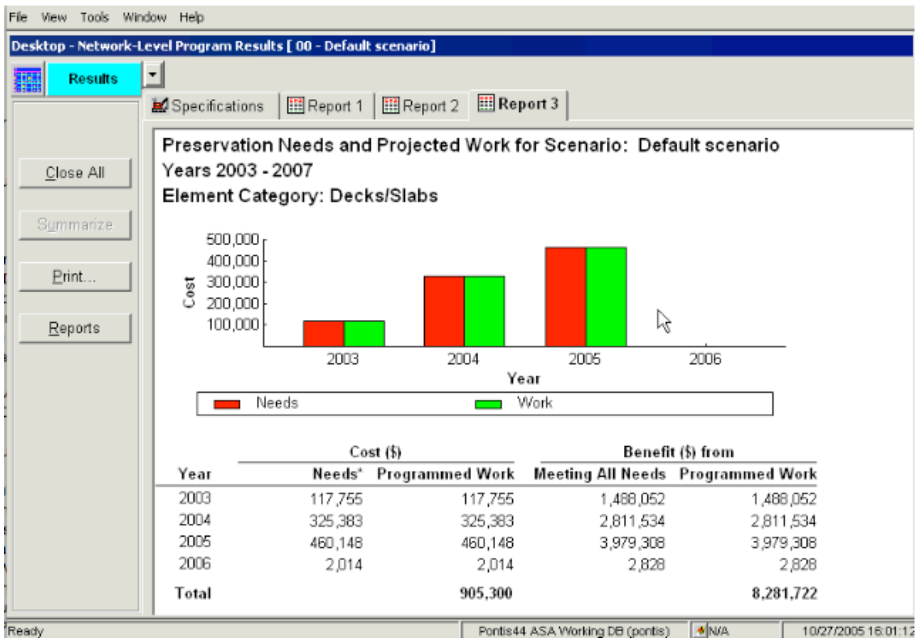

Figure 2.16: Sample Result on Preservation Needed and Projected Work in Pontis (FHWA, 2008)

After completing the analysis is finished, Pontis schedules the necessary work and saves it in the system. In the Planning Module, users can view the description of each bridge and the work required will be shown on the software panel. Moreover, it will show the cost of the work and the monetary benefit of the work after it has been completed as seen in Figure 2.17. Projects can also be arranged and displayed by each fiscal year. This function is very useful for government agencies to be able to review what work is required to be carried out in a given year. They can release the projects for bidding on time and maintenance work can be in progress promptly.

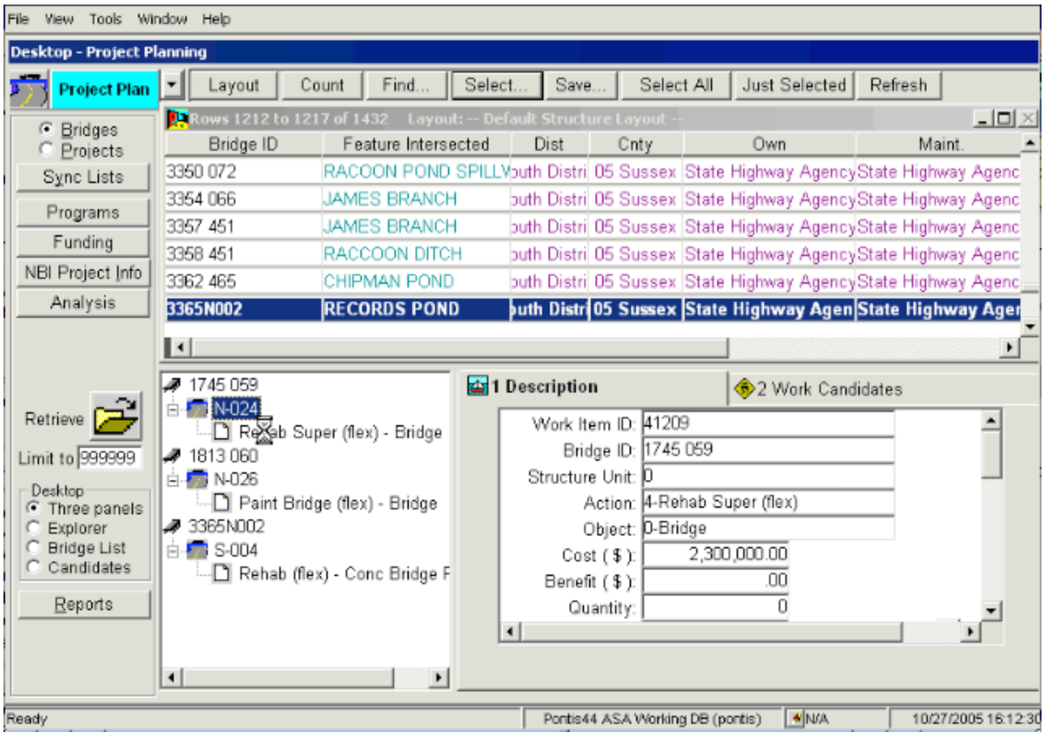

Figure 2.17: The Graphical User Interface of "the Planning Module" in Pontis (FHWA, 2008)

Even though the software can arrange projects according to the needs and budget, government agencies have to create new plans if additional funding sources become available. The work candidates in the computer software are ranked in order of priority. Users can create a new project by choosing the highest priority candidate on the list that the system provides.

Although Pontis can perform analysis and show users the monetary benefits for each project, the information may not be understood by the users. For highway and bridge maintenance, the most important factor is the time that the repairs will last. In addition, users would like to be able to predict the condition of the bridges and when the next repair should be carried out. Fortunately, Pontis can perform a bridge analysis on a specific bridge element and the result will show how the component will deteriorate over time as shown in Figure 2.18.

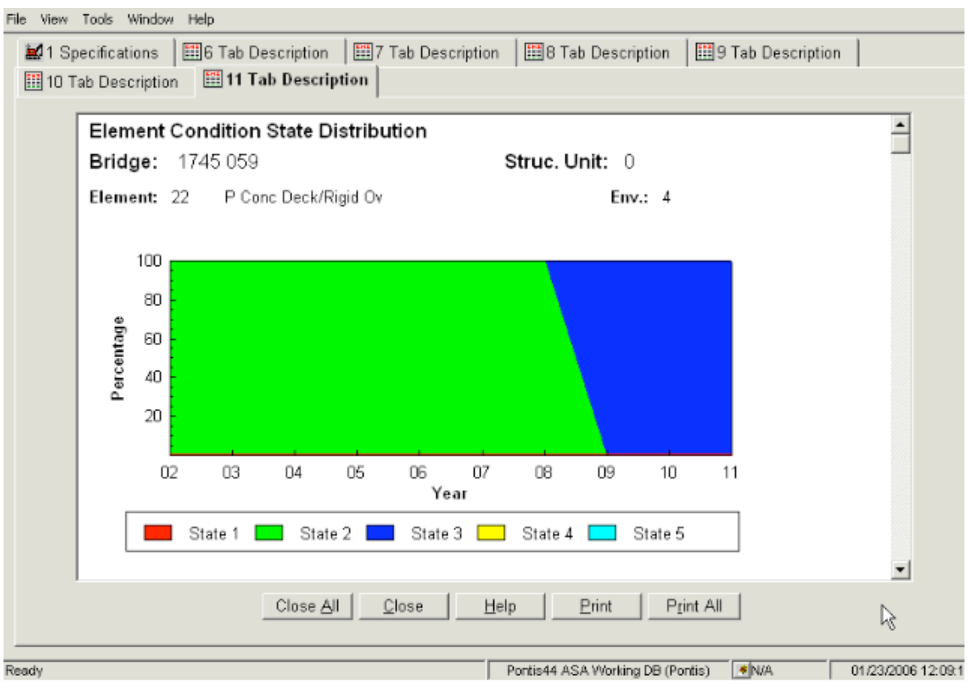

Figure 2.18: Component Deterioration Prediction in Pontis (FHWA, 2008)

The figure shows how Pontis presents the conditions of the concrete deck of a bridge. Results shows that the condition of the bridge is 100% from 2002 to the beginning of 2008. After the first quarter of 2008, the condition of the deck deteriorates. In 2009, the condition of the deck is 0%, which is no longer serviceable. This type of analysis will aid the government to forecast the future spending used so that they can request sufficient funding from taxpayers for their future highway improvement or maintenance projects.

As mentioned above, Pontis is a very powerful software product that can predict of the deterioration of components on a bridge and can analyze the cost, budget, and benefit for bridge maintenance projects. The software displays analysis results graphically so that engineers and government officials can schedule appropriate maintenance and rehabilitation projects for bridges that are in need. However, the final decision on a project is made by engineers. Besides, the software does not consider some important factors, which affect the frequency of inspection and maintenance, and the deterioration rate of bridges.

Pontis, like other BMS has limitations including its inability to address geographic and environmental factors (Liu & Frangopol, 2006). These factors may influence the deterioration rate and work performance of the bridge. Future BMS should take these factors into consideration. The capacity of bridges affects the deterioration rate directly. If a bridge is subjected to high traffic flow, it will deteriorate much faster than a bridge with less traffic. Also, work schedules depend on the traffic load and the nearby network as well. When construction is in progress on nearby bridges or highways, it is impossible to schedule any work on a bridge that requires detour.

Therefore, other factors should be considered in future BMS software in order to streamline the inspection and maintenance work on bridges.

Chapter 3. Research Objective Scopes and Methodology

The purpose of this study is to determine the optimum cost per mile in bridge inspection and maintenance for the aging highway system in the US and investigate the possible improvements to future systems. The marginal utility of the inspection and maintenance cost per mile will be determined by this study.

The inspection and maintenance improvements, repair, and check-up methods and means will first be studied. The training guidelines for bridge inspectors in the US are documented by the Bridge Inspectors' Manual, written by Federal Highway Administration (American Association of State Highway and Transportation Officials, 2008). The manual provides guidance and instruction for bridge inspectors as well as instruction on conducting and reporting bridge inspection under the FHWA Inspection Standard, reporting and coding system. The repairs of bridges are carried out in accordance with the AASHTO Guide for Bridge Maintenance Management, the AASHTO Manual for Bridge Maintenance, and the AASHTO Maintenance Manual (American Association of State Highway and Transportation Officials, 2008). The manuals are well written and they provide details on each possible component an inspector may see on a bridge and they have systematic guidelines on inspection and maintenance. Most state DOTs have modified the manuals to fit to the individual state needs but follow the guidelines throughout the maintenance process. The rehabilitation process of bridges is well regulated by the USDOT and FHWA (Federal

Highway Administration, 2007). Therefore, the methods and means of bridge maintenance do not have a negative impact on the issue. The cause of insufficient bridge maintenance in the US is more likely due to inadequate management. Hence, this study does not focus on the methods and means of bridge maintenance.

The United States has 3.7 million square miles of land which covers a variety of climates and geography (United Nation, 2008). The southern tip of the state of Florida and Hawaii has a tropical climate. The southwest side of the continent is a desert while the northern most states are subarctic or polar (United Nation, 2008). The 597,876 bridges in the country are subjected from mild to extreme climates (Bureau of Transpostation Statistics, 2007). Different levels of government agencies have unique bridge management procedures. Some bridges are managed by several agencies. In order to study thoroughly the bridge maintenance in the US, programs from different regions of the country should be considered. In this research, bridge maintenance in the US is broken down into five regions according to the states climate, location, and type of land (United Nation, 2008).

The five regions are Northeast, Southeast, Midwest, Southwest, and West. In this study, a survey was conducted in two states for each region. The survey was filled out by the maintenance engineers of the Department of Transportation for each state. In the survey, several variables were determined in order to compare different values per mile. The variables include:

1. Number of employees in the maintenance team
2. The State budget on bridge maintenance per year
3. The Federal budget on bridge maintenance per year
4. Length of bridges
5. Number of bridges
6. Percentage of contracted-out projects
7. Database of inspection and maintenance data
8. Bridge maintenance management software
9. Technical difficulties in inspection and maintenance

In order to determine the resources that the Department of Transportation in each of the studied states allocated for bridge maintenance, the number of employees of the maintenance team and the overall employment should be determined. Therefore, questions on employment will be included in the survey. The number will be significant for bridge maintenance and inspection management because an insufficient work force will affect the productivity of the repair work. It will directly affect the structural health of the bridges. In addition to manpower and the maintenance budget, the length and the number of bridges will be investigated in the survey. This study was designed to determine the cost of inspection and maintenance on bridges per year for each state. It was compared to the number of deficient bridges in each state to find the optimum model for bridge management. Furthermore, the number of contracted repair projects is studied to see if it is a better method to maintain the bridges in the country.

According to the Bureau of Transportation Statistics, the land area of each state does not reflect the number of bridges in that particular state (Bureau of Transpostation Statistics, 2007). For example, the state of Washington has a land area similar to states in the Midwest like Illinois, Kansas, and Missouri (United Nation, 2008). However, the numbers of bridges in the Midwest states are more than 3 times the number of bridges in Washington. Also, the number of deficient bridges in the Midwest are much higher than the rest of the country. In addition, many bridges are over 50 year old in the Midwest. To determine possible improvements to the existing management system, states with older bridges will be investigated. In this paper, a questionnaire was completed by the Kansas Department of Transportation. The coordination of their BMS between different levels of government agencies would be investigated. Since most of the DOTs in the country use computer software, information on software would be included in the questionnaire and further study on data technology would be carried out to see how it helps bridge inspection and maintenance. The paper would further suggest how it should be altered to improve future bridge maintenance process.

For older bridges, a large overhaul may be needed in order to keep the bridges in service. On the contrary, new bridges may require less maintenance work if they are maintained in an as-built condition after they are constructed. According to statistics from the Bureau of Transportation Statistics, a number of new bridges are built in the

US each year (Bureau of Transpostation Statistics, 2007). States like Minnesota and Ohio have Bridge Preventive Maintenance for the new bridges. The purpose of the program is to keep them in like new condition. The program would be studied to find out the cost effectiveness and to determine if it is the best management scheme for older bridges as well.

The survey for this research was conducted in Kansas, Florida, Hawaii, Nebraska, Vermont, Utah, and Tennessee. The survey was sent to the Department of Transportation in these states. The survey for the Kansas DOT is a longer version with more in depth questions on inspection and maintenance processes. Variables mentioned above would be found from the survey.

The percentage of deficient and obsolete bridges was used to plot against the annual maintenance cost per mile to determine the marginal utility for maintenance cost. The percentages were also used to plot against the percentages of human resources on bridge maintenance to determine the best human resources arrangement for better bridge maintenance in the future. The survey showed that state DOTs are spending more of their resources on new construction. However, the current condition of bridges in the country is not acceptable. Resources should be spent on aging infrastructures. Therefore, the new construction budget was also considered in the data analysis section.

About 130 years ago, four bridges crossing the East River and the Harlem River were built and connected Manhattan, Brooklyn, Queens, and the Bronx. The bridges were the Brooklyn Bridge, Williamsburgh Bridge, Manhattan Bridge, and the Queensboro Bridge. The bridges have wide side spans and long main spans over the East and Harlem Rivers (Dubin & Yanev, 2007). In the late 70s, the bridges were approximately 90 years old and they were rated on average from 1 to 3 on a New York State 7 point rating scale during an inspection. It implied that the bridges were not functioning as originally designed and some items were totally deteriorated, or in a failed condition. Therefore, the New York state Department of Transportation carried out the East River Bridges rehabilitation program in 1980. In the 20 year program, the New York State DOT found that there are a few problems in the existing Bridge Maintenance System. First of all, the annual construction to maintenance cost ratio was only 1:0.56 between 1905 and 1912 in New York City. Even though they kept this ratio till 1999, the actual ratio decreased to 0.2 from state funding. The other income came from tolls from the Port Authorities of New Jersey and New York. A similar study was carried out in Tokyo, Japan, and the same percentage was determined. The maintenance to construction cost ratio was considered to be low since the bridges in the state were aging and needed to be repaired. Therefore the ratio was determined from the result of the survey.

The research process is summarized as follow:

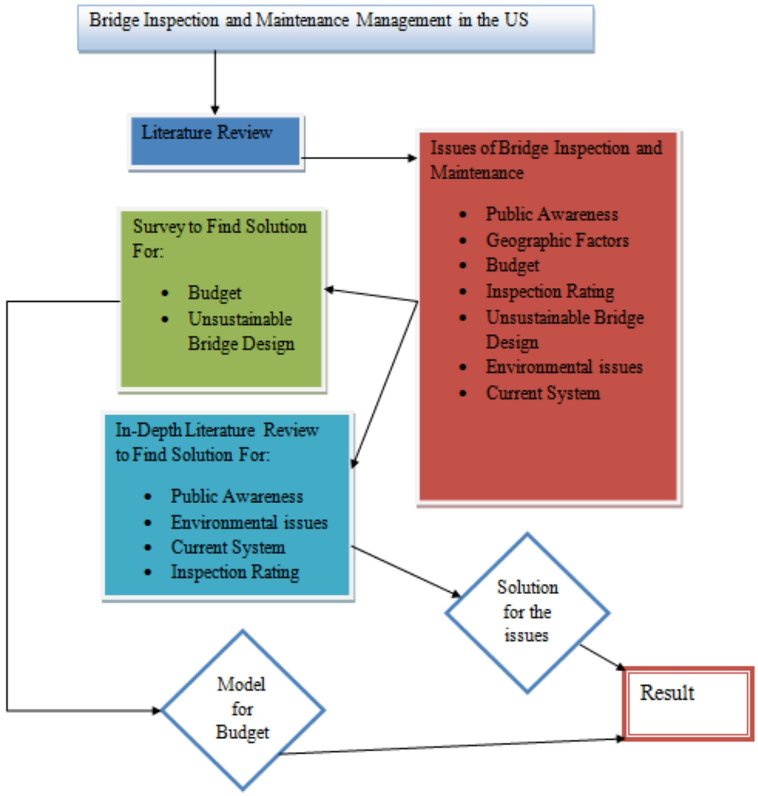

Figure 3.1 Research Flow Chart

Chapter4. Data Collection and Analysis

4.1 Budget Arrangement Analysis

In the survey conducted in Kansas, Florida, Hawaii, Nebraska, Vermont, Utah, Tennessee, and Washington the maintenance to construction ratios in four of the states are less than 10% while the maintenance budget in Florida is 1.7 times higher than the construction budget as shown in Figure 4.1.

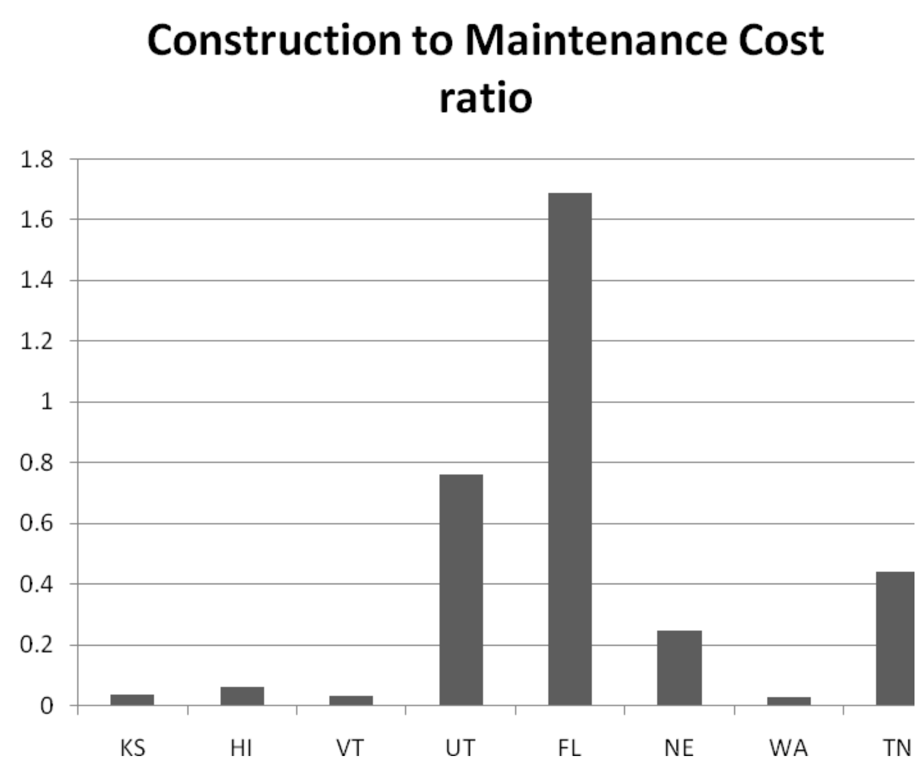

Figure 4.1 Construction to Maintenance Cost ratio

From the data collected in the survey, the number of deficient bridges in Florida is about 10% less than other states in this research. The construction to maintenance cost ratio in each state may contribute to the percentage of deficient and obsolete bridges in the state. In Figure 4.2, it shows that the percentage of deficient and obsolete bridges tends to go down when construction to maintenance cost ratio goes up. In Florida, the ratio is at 1.68 and the percentage of deficient bridges is at 2.38%. That percentage is much lower than the national percentage (more than 50%). At the same time, the percentage of obsolete bridges in Florida is at about 15%, which is much lower than Hawaii, has a low construction to maintenance cost ratio. Therefore, if the transportation agency in each state puts more of its construction resources on maintenance, it may improve the current condition of the bridges.

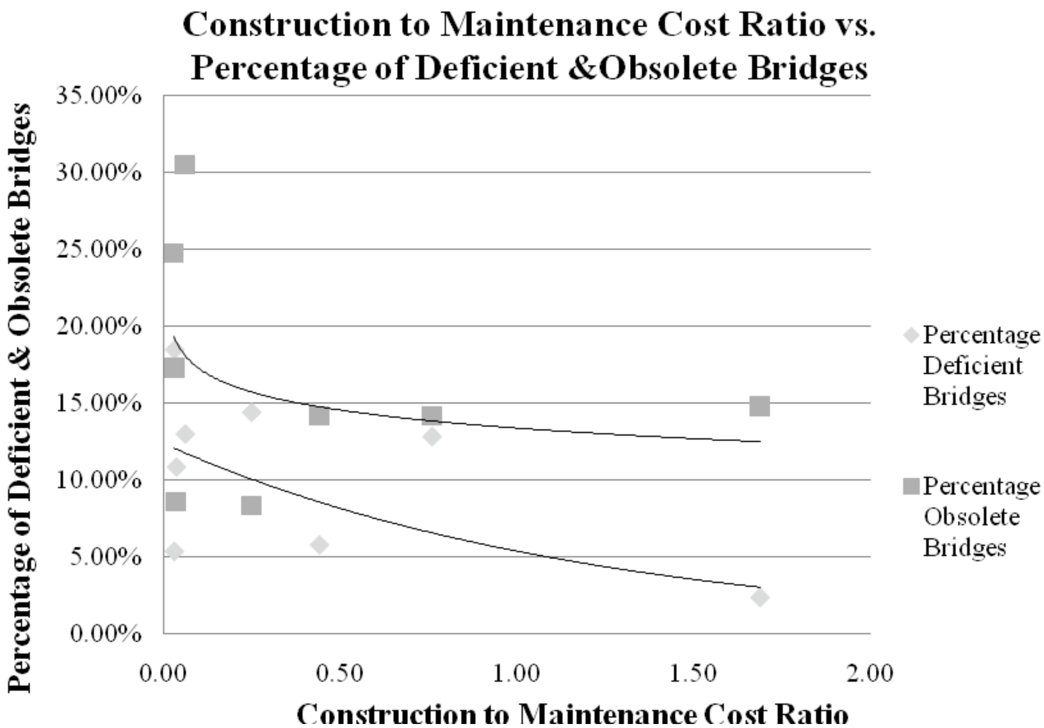

Figure 4.2 Construction to Maintenance Cost Ratio vs. Percentage of Deficient & Obsolete Bridges

Another aspect of the budget issue may be due to the local government strategies. Local DOTs spend as little as possible on maintenance while trying to maximize service life because of limited federal funding for bridge inspection and maintenance (Dubin & Yanev, 2007). Repair funding normally comes from local taxes only. A similar situation occurred in 2004 in Virginia. VDOT received $35 million in federal bridge funds in 2004. The money was spent right away on small bridges but none of it went for the maintenance of 15 structurally deficient bridges in the state. It happened due to restrictions on federal funding. Federal regulations dictate that a project can only receive federal maintenance money when it is in the planning and engineering phase or during construction. Because the 15 deficient bridges were not in development stages, the federal money cannot be spent on these bridges. Also, if the money was not spent, it must to be returned to the federal government and cannot be used for other maintenance projects (Holden, 2007).

The survey shows that other than Florida and Hawaii, the DOTs in other states do not obtain such funding from the federal government for bridge maintenance. When asked about the problems they are facing in bridge maintenance, all of the participants were concerned that bridge maintenance has very limited funding and it is a low priority of the federal government. In the survey, the DOTs were asked to provide the annual federal & state budget and the number of miles of the bridges. The annual spending per mile for each state is determined as below:

States	Number of miles of Bridges	Annual Spending / Mile
Kansas	495	$42,424.24
Hawaii	42	$35,714.29
Vermont	51	$58,823.53
Utah	69	$157,246.38
Florida	603	$1,807,628.52
Nebraska	241	$753,526.97
Washington	306	$73,758.17
Tennessee	432	$122,222.22

Table 4.1 Summary of Annual Spending on Maintenance and Inspection

The numbers determined above are reasonable because states that have more miles of bridges will need to spend more on inspection and maintenance each year. In order to find an ideal model for annual spending per mile, graphs are plotted against the percentage of deficient and obsolete bridges as shown in Figure 4.3a to 4.3h & Figure 4.4a to 4.4h:

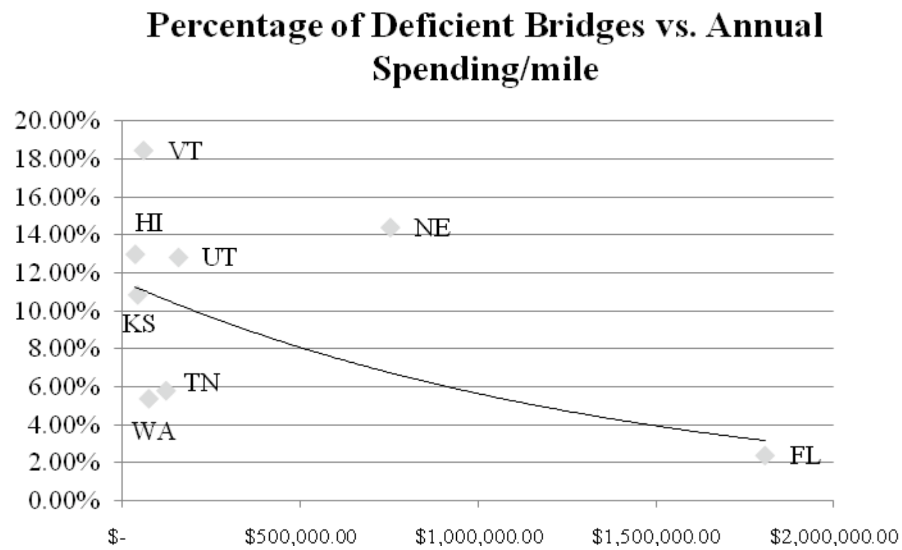

Figure 4.3a Percentage of Deficient Bridges vs. Annual Spending/Mile

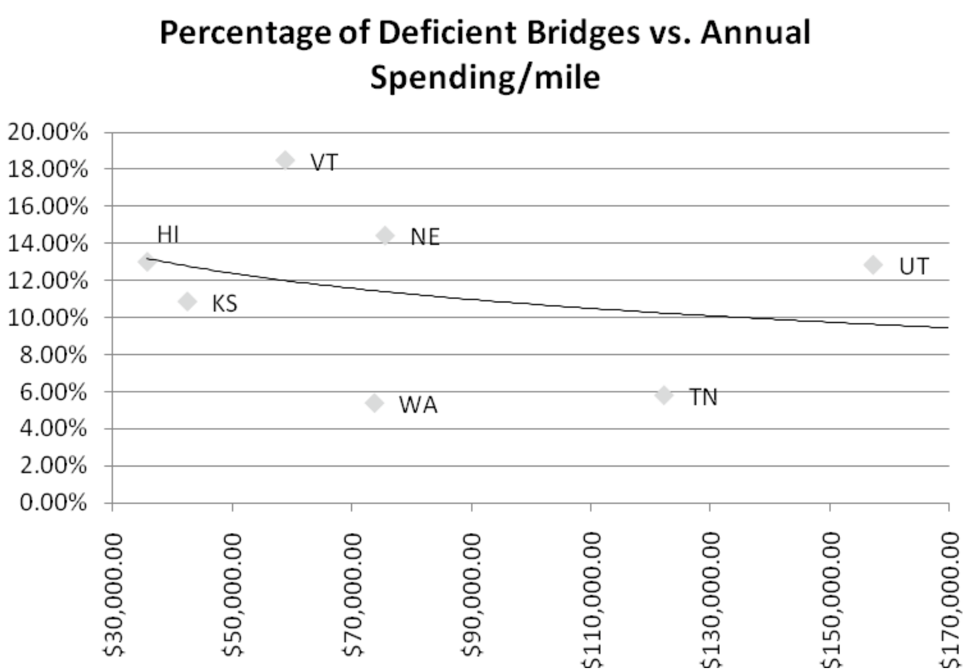

Figure 4.3b Percentage of Deficient Bridges vs. Annual Spending/Mile (without Florida)

Figure 4.3a shows approximately an exponential curve. In other words, the number of deficient bridges is lower when the annual budget on inspection and maintenance increases. The graph drops drastically in the initial data points and it does not change much when the annual spending is over $2 million per year. From the graph, an ideal annual spending model can be determined. Since the percentage of deficient bridges decreases by more than 6% at the beginning, one can conclude that about $1 million per mile would be the ideal annual spending to lower the percentage of deficient bridges in the country. Without a doubt, more money spent on maintenance will lower the percentage close to zero. However, state and federal budgets are limited. More money is needed but is unavailable. At the same time, the bridges age simultaneously, even during maintenance. It is not feasible to push the deficient percentage to zero.

Since the data from Florida is an individual result that does not fit properly into other data, Figure 4.3b is plotted without the influence of Florida. Figure 4.3b also shows exponential curves, but the spending per mile is a lot less than the projections in Figure 4.3a. Results show that if more money is spent on the maintenance, the percentage of deficient and obsolete bridges will be lower. Without the data of Florida, the annual spending per mile will be $130,000 per mile to lower the percentage of deficient bridges by 3%.

In Figure 4.3a and 4.3 b, the points are fluctuated and they cannot show a perfect trend. To determine other factors that affect the annual maintenance spending per mile, comparison graphs are plotted between two states. Figure 4.3c is the comparison between Hawaii and Utah. The graph shows that the percentages of deficient bridges between two states are very close while there is a wide difference between annual maintenance spending. The data from the survey shows that Utah has a bigger spending because the state has more bridges and the mile of bridges is longer. Similar finding is determined in Figure 4.3d and 4.3 f in the cases of Washington vs. Tennessee and Hawaii vs. Kansas. However, Figure 4.3h shows that Nebraska has shorter length of bridges than Washington does while the annual spending is much higher than Washington is. We can conclude that a state with fewer miles of bridges may have higher maintenance cost if they have more bridges. Other factors may contribute the annual spending. There are some stone arch bridges in Utah while the majority of bridges in Hawaii are made out of steel and concrete. Also, there are some suspension bridges in Utah that go across canyons (American Association of State Highway and Transportation Officials, 2006). These bridges may require higher cost of maintenance due to the accessibility to inspection and maintenance. Figure 4.3d shows that the annual spending per mile in Kansas is a lot lower than Washington while the number of bridges and number of mile of bridges are higher. The percentage of deficient bridges in Kansas is more than 5% higher than Washington. The result shows that the annual spending can lower the percentage of deficient bridges. In the survey, it shows that the annual spending on maintenance per mile in Florida is a lot higher than other states and the point does not fit into the plots with other states in Figure 4.3a and Figure 4.4a. With more than a thousand miles of coastline, many rivers and waterways, and lakes in its interior, the state requires many bridges for traffic (Florida Department of Transportation, 1996). Some of them have long span across water such as Overseas Highway that connects Key West to the mainland, and Bahia Honda Rail Bridge that connects Bahia Honda Key to Spanish Harbor Key. The other examples are Sunshine Skyway across lower Tampa Bay, and the Roosevelt Bridge in Stuart (Florida Department of Transportation, 1996). Thus, long span of bridges is another factor of higher annual spending per mile. In addition to bridge span, some of the long span bridges are steel bridges with railway. Repair cost may be higher due to high steel expenses.

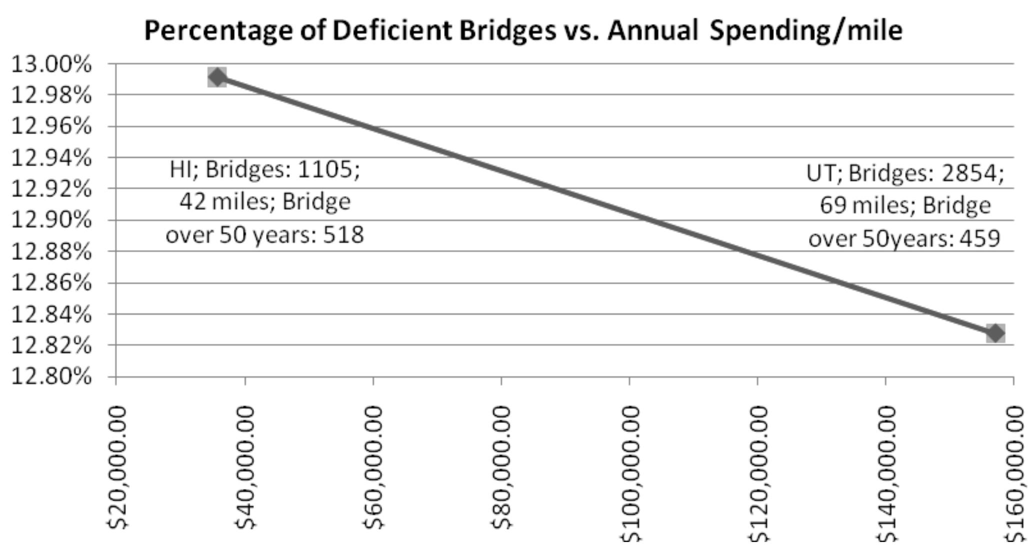

Figure 4.3c Percentage of Deficient Bridges vs. Annual Spending/Mile (Hawaii vs. Utah)

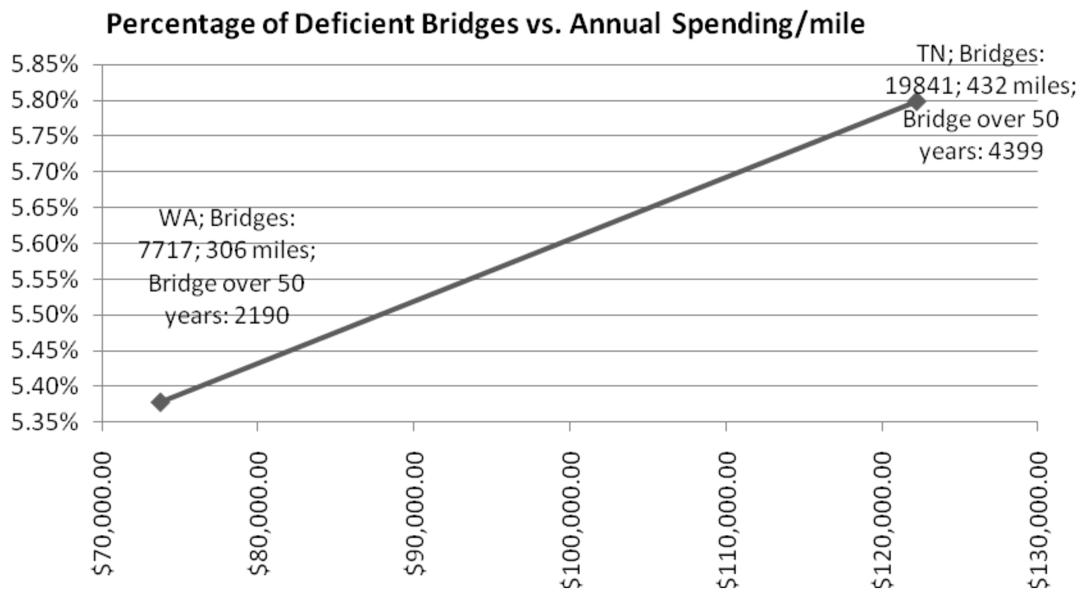

Figure 4.3d Percentage of Deficient Bridges vs. Annual Spending/Mile (Washington vs. Tennessee)

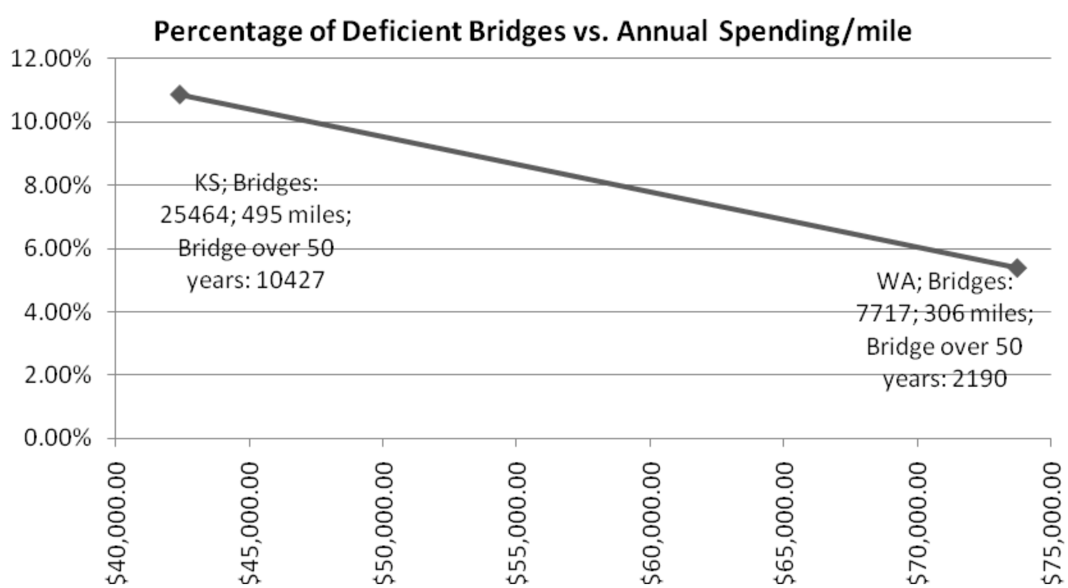

Figure 4.3e Percentage of Deficient Bridges vs. Annual Spending/Mile (Kansas vs. Washington)

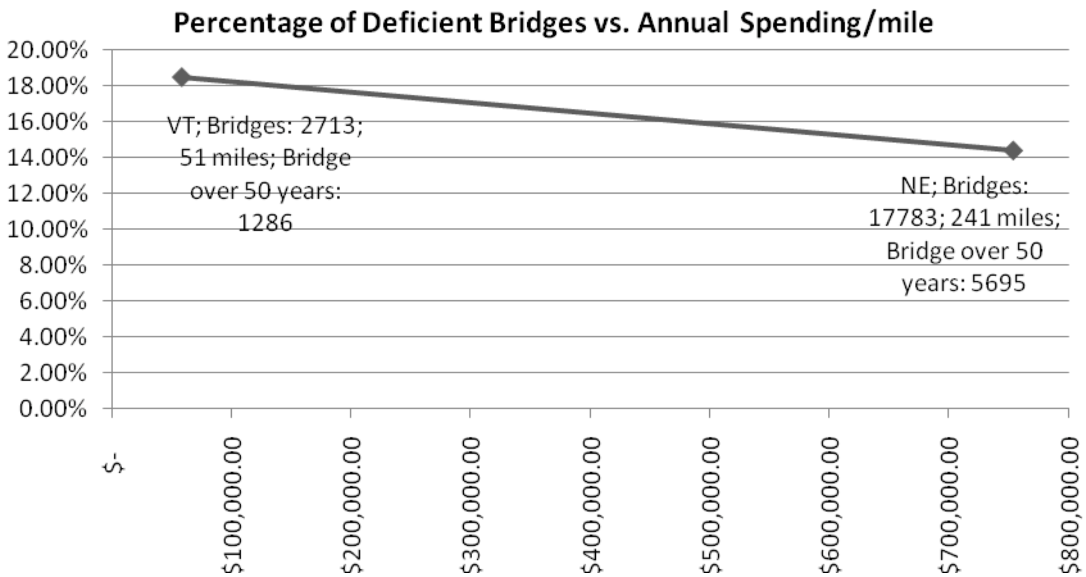

Figure 4.3f Percentage of Deficient Bridges vs. Annual Spending/Mile (Vermont vs. Nebraska)

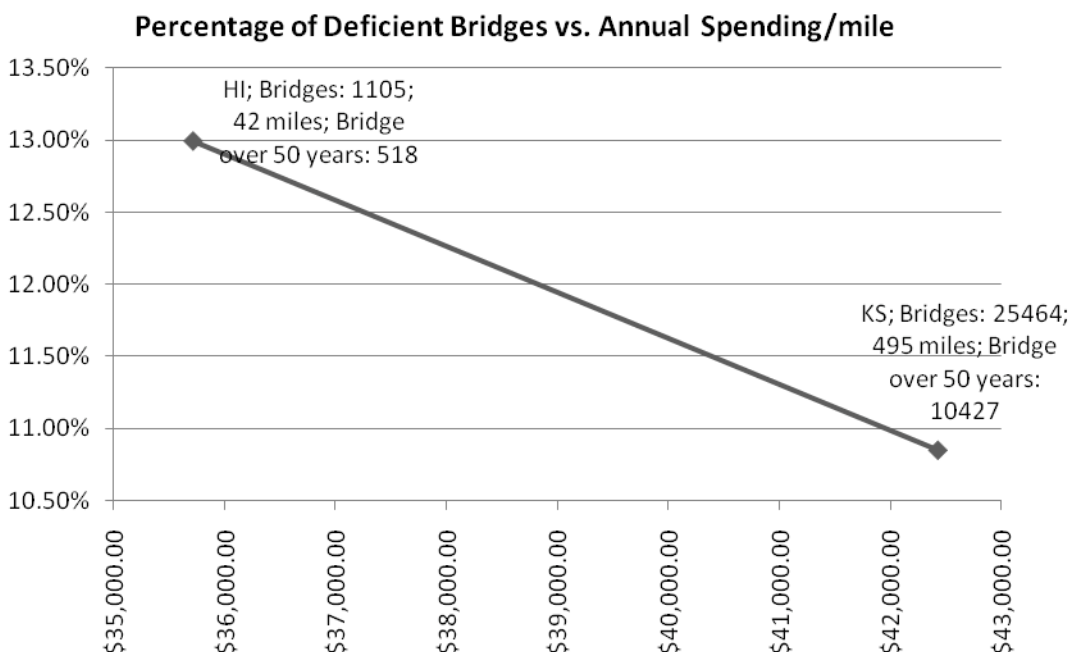

Figure 4.3g Percentage of Deficient Bridges vs. Annual Spending/Mile (Hawaii vs. Kansas)

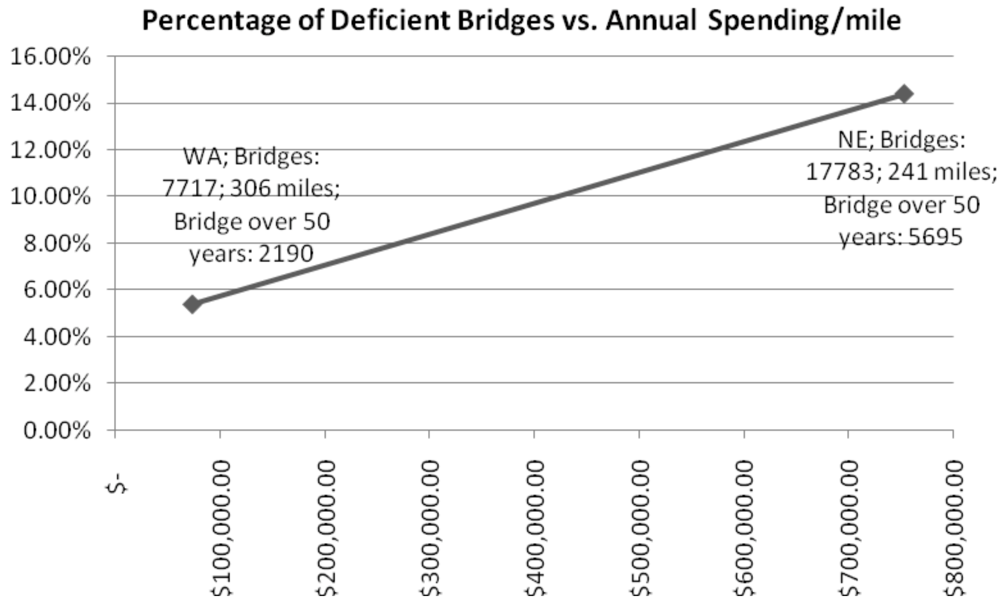

Figure 4.3h Percentage of Deficient Bridges vs. Annual Spending/Mile (Washington vs. Nebraska)

A similar argument of Figure 4.3a is shown in Figure 4.4a. The percentage of obsolete bridges decreases radically in the first few points and the curve goes flat and tends to stay at 10% after $2 million per mile. Therefore, annual spending of $1 million per mile for inspection and maintenance will be an ideal number for state DOTs in the US. This will reduce the number of obsolete bridges to approximately 10%. To reduce the number of obsolete bridges further, about $2 million per mile would need to be spent each year. If they do so, future annual spending would be lower than these projections since the condition of the bridges will be improved. However, Figure 4.4a shows that Florida is spending a lot more money and their human resources than other states. Since the data from Florida is an individual result that does not fit properly into other data, Figure 4.4b is plotted without the influence of Florida. Figure 4.4b also show exponential curves, but the spending per mile is a lot less than the projection in Figure 4.4.a. Results show that if more money is spent on the maintenance, the percentage of deficient and obsolete bridges will be lower. Without the data of Florida, the annual spending per mile will be $150,000 per mile to lower the percentage of deficient bridges to 15%. Figure 4.4b shows a unique pattern according to the location of these states. The plot shows that the states near the Pacific coast have higher percentages of obsolete bridges than the bridges in the Midwest. The percentages of obsolete bridges in the other states stay in the middle. Higher obsolete percentages o the coast may due to the effect by salt water. The metal components on these bridges are more likely to be corroded due to the fact that saltwater is a perfect electrolyte for corrosion (Nystrom, 2008). The bridges in Tennessee have higher annual spending per mile than five states in Figure 4.4b. According to Tennessee Department of Transportation, the state has some historical bridges called Bible Covered Bridges (Tennessee Department of Transportation, 2009).They are classified as state heritage and require extra care on the wooden and metal parts on the bridges. The TNDOT also require extra fund for their exterior appearance (Tennessee Department of Transportation, 2009). This factor may increase the annual spending per mile on maintenance. As mentioned earlier, some bridges in Utah go across canyons (American Association of State Highway and Transportation Officials, 2006). It will increase the maintenance cost due to the difficulties on inspection and maintenance.

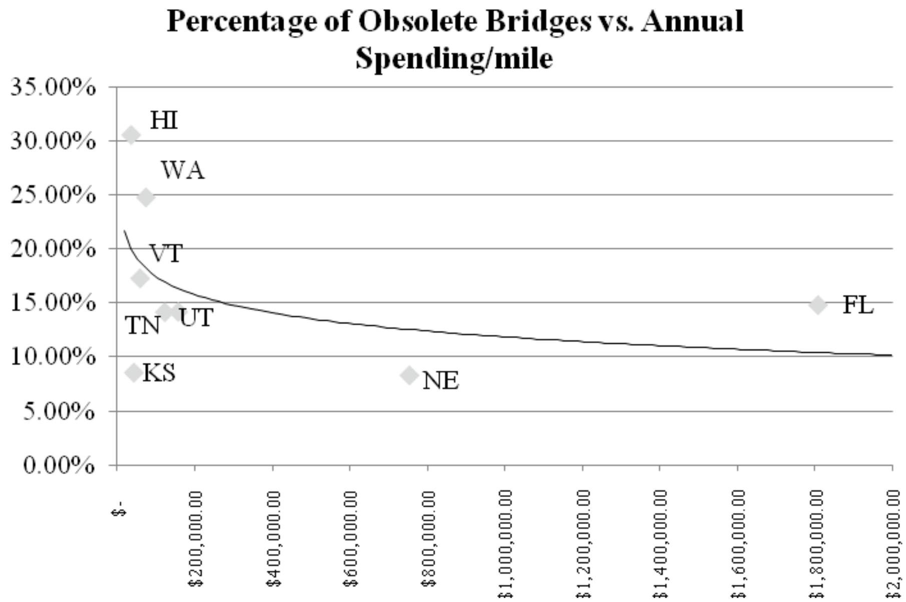

Figure 4.4a Percentage of Obsolete Bridges vs. Annual Spending/Mile

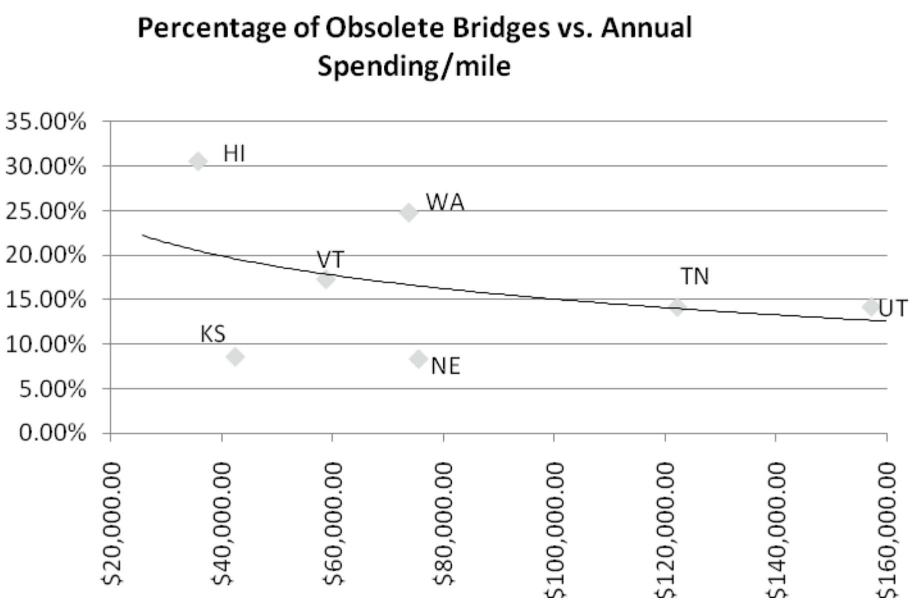

Figure 4.4b Percentage of Obsolete Bridges vs. Annual Spending/Mile (without Florida)

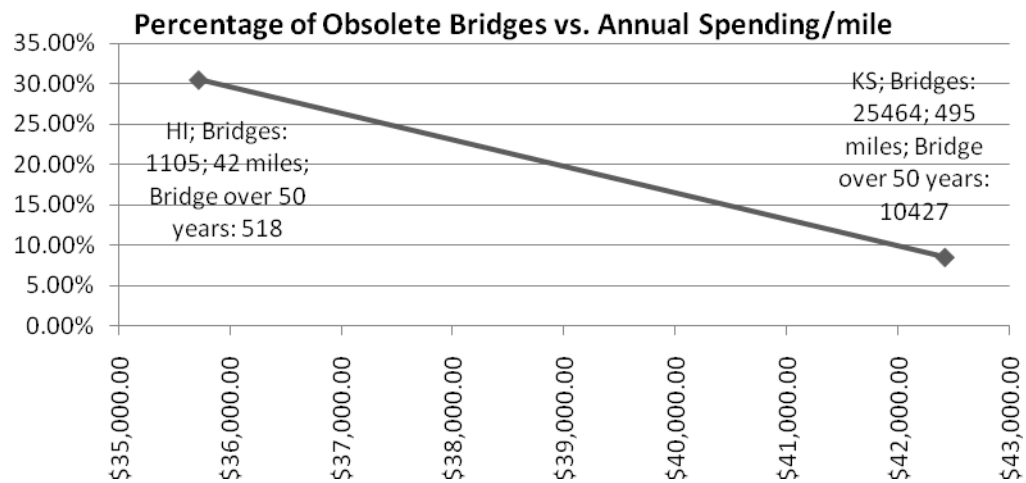

Figure 4.4c Percentage of Obsolete Bridges vs. Annual Spending/Mile (Hawaii vs. Kansas)

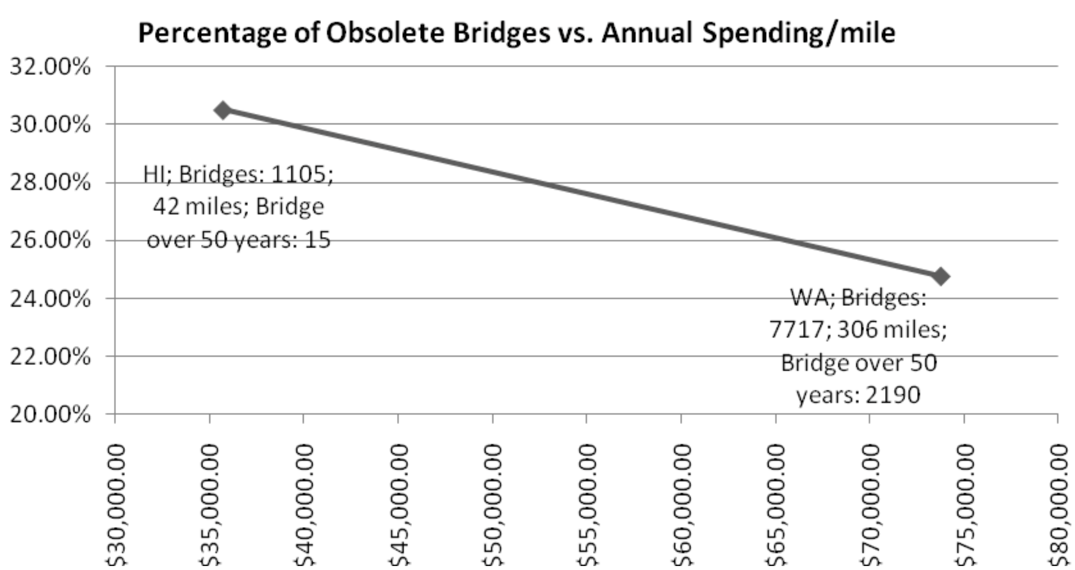

Figure 4.4d Percentage of Obsolete Bridges vs. Annual Spending/Mile (Hawaii vs. Washington)

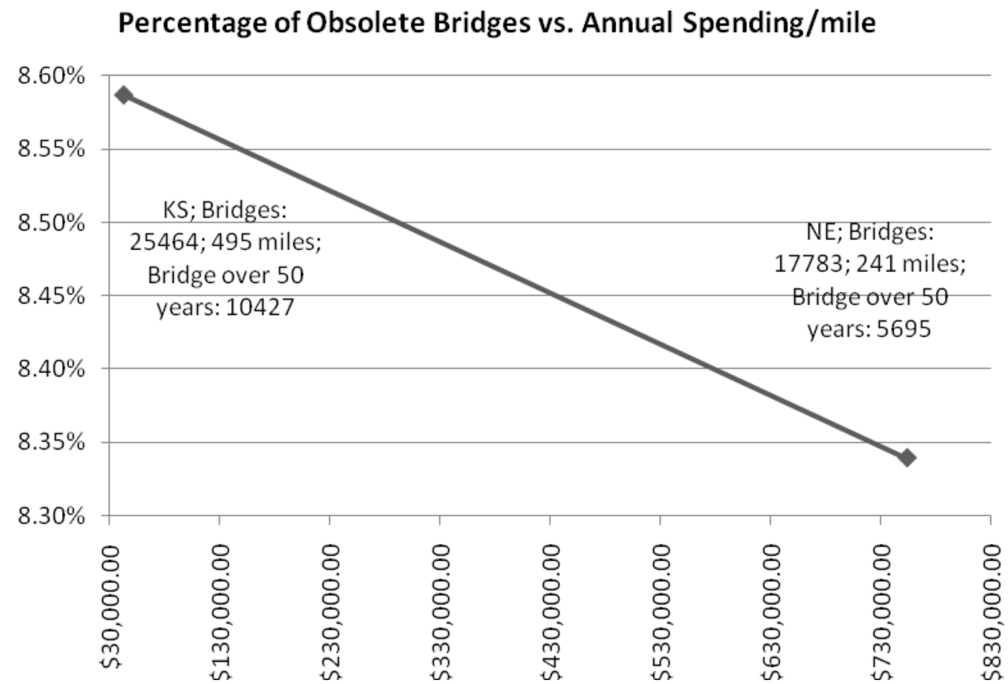

Figure 4.4e Percentage of Obsolete Bridges vs. Annual Spending/Mile (Kansas vs. Nebraska)

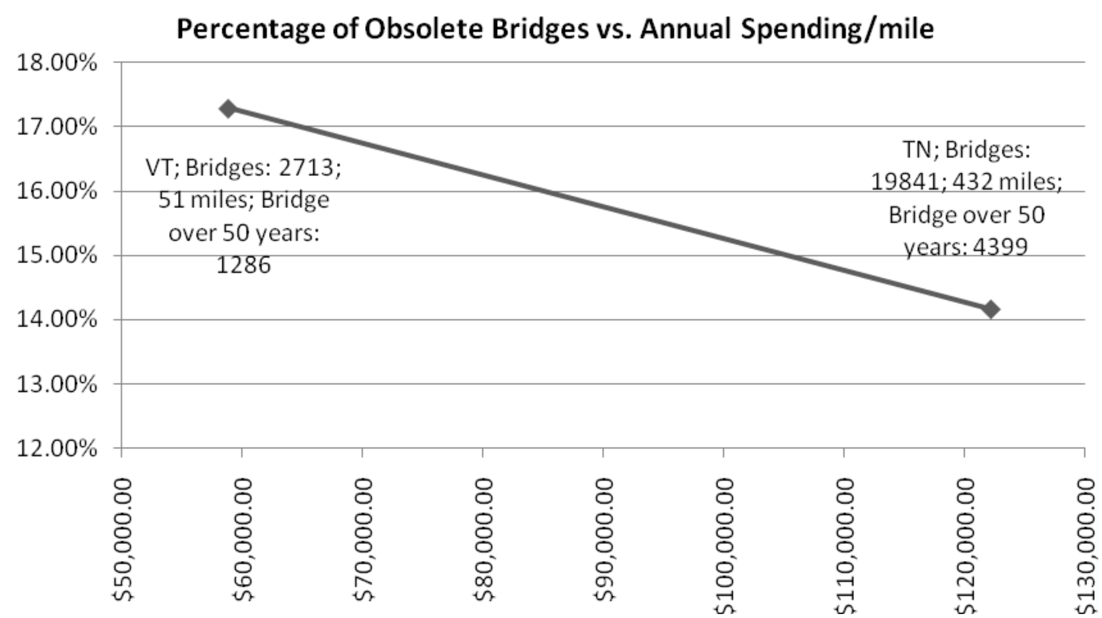

Figure 4.4f Percentage of Obsolete Bridges vs. Annual Spending/Mile (Vermont vs. Tennessee)

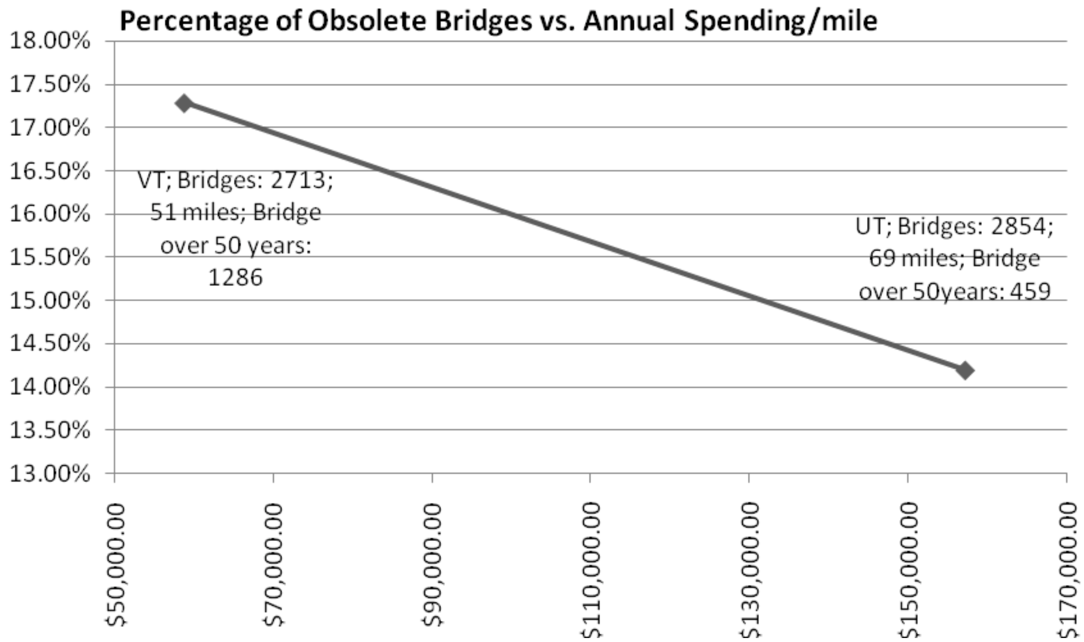

Figure 4.4g Percentage of Obsolete Bridges vs. Annual Spending/Mile (Vermont vs. Utah)

In summary, the location, the region, the environment, the types, the span, the materials, the heritage values, the number, the ages, and the miles of bridges can directly affect the annual spending on bridge maintenance, and the percentage of deficient and obsolete bridges.

Figure 4.4h shows the percentage of deficient and obsolete bridges versus annual spending per mile on maintenance determined in the survey. With the $2.2 trillion maintenance cost determined by ASCE in the Infrastructure Report Card 2009, the plot projects that the cost of maintenance for the nation's bridges is $1.7 trillion to lower the percentage to10%. This projection is determined with the assumption that the percentage can be lowered to zero and the highest percentage is close to 45%.

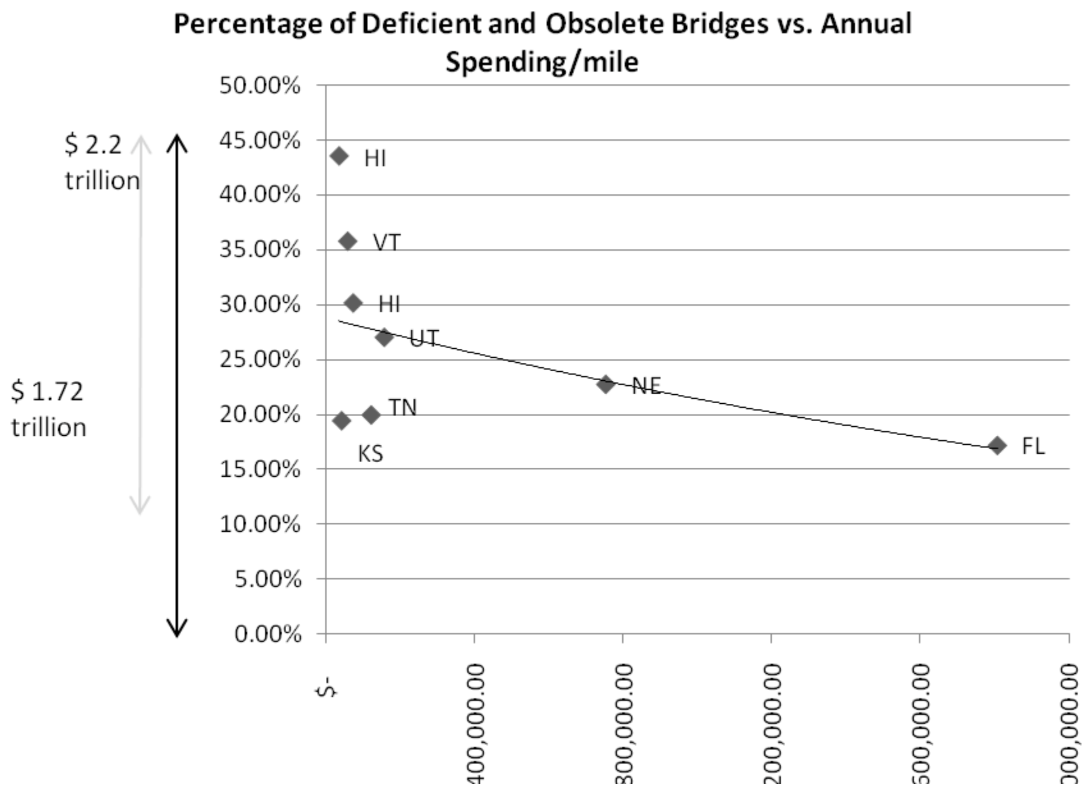

Figure 4.4h Percentage of Deficient and Obsolete Bridges vs. Annual Spending/Mile (Projection from ASCE Infrastructure Report Card 2009)

In the survey, the DOT representatives were asked if their inspection and maintenance projects are contracted out to private business. Most of the states contract their maintenance projects to private companies while some states conduct their own inspections. We then compare this data to the percentage of deficient and obsolete bridges as shown in Table 4.2. The outcome demonstrates that contracting out inspection or maintenance projects does not affect the condition of the bridges. On the other hand, it has a great impact on cost.

States	Percentage of Deficient Bridges	Percentage of Obsolete Bridges	Percentage of Contracted-out Inspection	Percentage of Contracted-out Maintenance
Kansas	10.85	8.59	0.12	100.00
Hawaii	12.99	30.51	75.00	100.00
Vermont	18.47	17.29	3.00	100.00
Utah	12.83	14.19	3.00	100.00
Florida	2.38	14.81	80.00	80.00
Nebraska	14.40	8.34	100.00	40.44
Washington	5.38	24.76	95.00	0.00
Tennessee	5.80	14.16	0.00	90.00

Table 4.2 Summary of the Compact on Contracting Out Projects

In the past, most of the DOTs in the US carried out their bridge inspection and maintenance in house. In the mid 70s, state DOTs such as the Pennsylvania DOT started progressively to contract out their maintenance projects to private companies. This method was not popular until the 90s. According to a study by the Transportation Research Board (TRB), the Massachusetts Highway Department began to outsource parts of their highway maintenance as of 1991. Nowadays, the program in Massachusetts has expanded to 50% outsourced. A study showed that outsourcing between 1991 and 1999 precipitated a drop in maintenance budgets from $40 million to $25 million, while maintenance projects increased. It also determined that outsourcing increases productivity among the state maintenance work force (McLawhorn, 2002). Thus, outsourcing has a very positive impact on bridge inspection and maintenance.

4.2 Human Resources Problems

There are 600,000 bridges in the nation, and there are more than 10,000 bridges in each state on average (Federal Highway Administration, 2007). One would imagine the Department of Transportation in each state would spend much of their manpower on bridge inspection and maintenance in order to provide safe transportation to the citizens. Unfortunately, this is not the case. According to the survey collected from 6 agencies, most of the states utilize only 1% or less of their staff on bridge inspection and maintenance. The state of Florida has a higher percentage but it is still lower than half of their labour resources. The percentage of staff used on bridge inspection and maintenance is shown on the table below:

States	Percentage of Deficient Bridges	Percentage of Obsolete Bridges	Labor Resources in Bridge Inspection and Maintenance
Kansas	10.85	8.59	1.42
Hawaii	12.99	30.51	1.00
Vermont	18.47	17.29	0.11
Utah	12.83	14.19	0.30
Florida	2.38	14.81	4.23
Nebraska	14.40	8.34	0.00
Washington	5.38	24.76	2.11
Tennessee	5.80	14.16	2.64

Table 4.3 Summary on Labor Resources in Bridge Inspection and Maintenance in Participated States

The table implies that the higher the labour percentage, the lower the percentage of deficient bridges will be. Similar results are confirmed in obsolete bridges. Graphs are plotted to determine the optimum level of labour resources that should be used. Figure 4.5 illustrates that the percentage of deficient bridges drops exponentially and that using 5% of labour resources would help the percentage of deficient bridges drop to nearly 10%. In Figure 4.6, the curve shows that the percentage of obsolete bridges in each state would drop to nearly 17.5% if each state DOT put about 5% of staff on bridge maintenance work. Therefore, state DOTs should put 5% of their staff on bridge inspection and maintenance in order to improve the condition of the aging bridges in the US. However, according to the 23 CFR 650D Part 650.405, obsolete bridges are eligible to the Highway Bridge Replacement and Rehabilitation Program that is funded by the federal aid (Federal Highway Administration, 1994). Under 23 U.S.C. 144, federal government shall fund 80 percent of bridge replacement projects

(Federal Highway Administration, 1994). As mentioned in Chapter 1, state DOTs are more willing to replace the obsolete bridges because these projects are funded by the federal government (Dubin & Yanev, 2007). Since replacement projects are considered as new constructions, they may not directly related to the maintenance department.

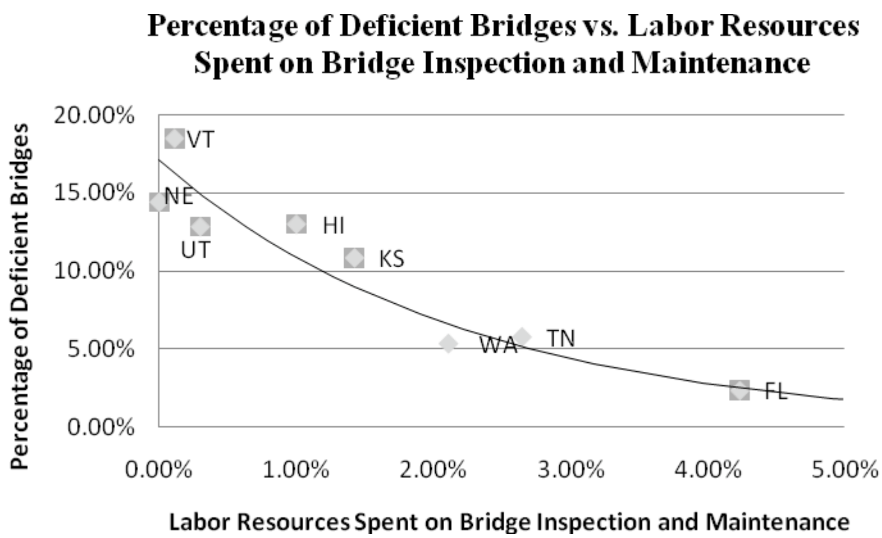

Figure 4.5 Percentage of Deficient Bridges vs. Labor Resources Spent on Bridge Inspection and Maintenance

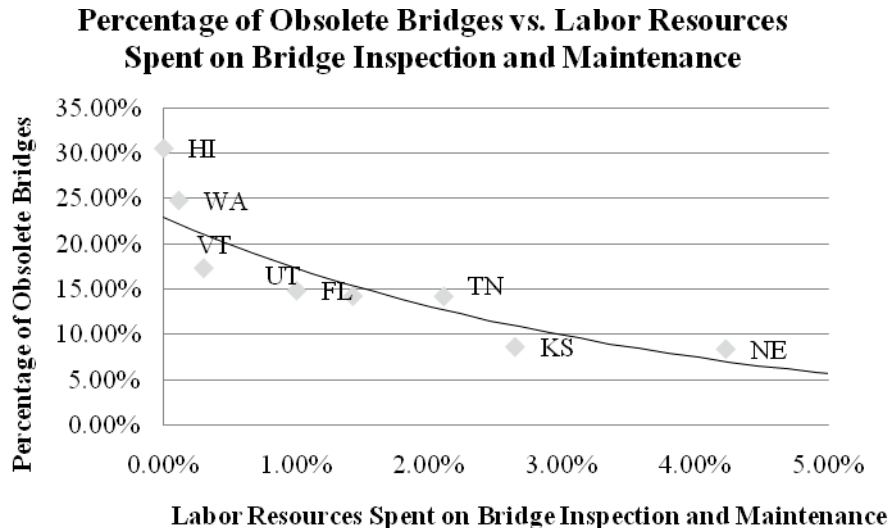

Figure 4.6 Percentage of Obsolete Bridges vs. Labor Resources Spent on Bridge Inspection and Maintenance

The survey also showed that there are only a few number engineers and technicians in the maintenance teams in most of the state DOTs survey. The reason for this is due to project outsourcing as mentioned before. The Hawaii DOT pointed out that bridge maintenance lacks priority in their agency. They do not train their staff on the technical knowledge and experience necessary to support such contracted-out projects. In the last few years, some DOTs in the country have experienced budget cuts from the state and federal governments. They had to necessitate the streamline of the number of staff in their departments. In the 90s, the New York City DOT was in the process of staff restructuring. A severe staffing cutback was experienced and the number of engineers on bridge maintenance decreased. Studies show that it affected the maintenance work for the bridges on the East River (Dubin & Yanev, 2007).

4.3 Issues that DOTs Are Facing During Inspection and Maintenance

There are common issues concerning current bridge design that increases the maintenance workload and complicate the repair tasks. According to the responses from the Kansas and Utah DOT, there are problems with the bridge expansion joints as shown in Figure 4.7. It is difficult to keep these joints level and sealed between slabs. They also require a stronger and more durable concrete patch material for deck repairs. From the article “Development and Laboratory Analysis of Silicone Foam Sealant for Bridge Expansion Joints,” silicone foam may be a good material for bridge expansion joint sealant. The study showed that silicone foam has a high shear, compressive, and tensile strength. The material is also waterproof, and can be subjected to high thermal energy without deterioration (Malla, Shaw, Shrestha, Brijmohan, & ASCE, 2007).

Figure 4.7 A Sample Bridge Expansion Joint During Maintenance (Source: WSDOT, 2009)

Different states have different environmental regulations. Some states especially on the west coast have stricter environmental requirements than the others. Inspection and maintenance in Washington State faces many challenges as it has tight environmental regulations that limit the type and method of work. The schedule windows do not allow efficient work schedules and then decreases productivity. In addition, bridge access is limited if any listed endangered species are present on site. This causes conflict with the aging bridge inventory. Additional difficulties include the logistics of traffic control and lane closures in congested urban areas and limited hours of work and noise variances. The state DOT, therefore, should have exemptions on environmental regulations so that they are able to complete maintenance within their work schedule. These additional requirements and imitations made maintenance more expensive and difficult. As such, project costs may be escalated as a result.

Chapter 5. Understandings and Models Development

5.1 Flowcharts for the Causes and Solution on Deficient and Obsolete Bridges

The collapse of I-35W bridge across the Mississippi River in Minneapolis shows that there are problems in the current maintenance program in the US. One year before the collapse, MnDOT had concerns about the welding under the bridge. No maintenance or in-depth inspection was schedule before it collapsed. The current maintenance management is not responsive to the scheduled inspection. Even though the Bridge Maintenance System software schedule maintenance on bridges accordingly, nothing is done and the condition of the bridges stays the same, or even gets worse.

Chapter 2.8 mentioned that Pontis could handle scheduling and budget arrangement. The software was used all the states that are included in this research according to the survey. The literature review found that Pontis has some limitations. The software does not consider environmental factors, changing material prices, geographic factors, sustainability in bridge design, and environmental restrictions (Liu & Frangopol, 2006). These factors are important because they may affect the price and the duration of a project. For example, the survey from the Washington State Department of Transportation shows that the state of Washington has strict environmental code. It limited the type and method of work that can be done and it does not allow an efficient work schedule. The study carried out by Center for Environmental

Excellence shows that bridge maintenance has to comply with many OSHA and EPA regulations (Center for Environmental Excellence by AASHTO, 2008). These environmental guidelines will increase the cost of bridge maintenance (Center for Environmental Excellence by AASHTO, 2008).

Chapter 2.1 pointed out that the public was not aware of the condition of the bridges in the US before the accident in Minneapolis. The survey from DOTs shows that state DOTs do not put bridge maintenance to their top priority, and the federal government generally does not fund maintenance projects. According to the survey, most of the DOTs are facing budget problems to carry out their maintenance program on bridges. As mentioned in earlier chapters, some states outsource their maintenance work to decrease the cost, and fewer technicians are employed. From the survey, some states only have 5 to 10 full-time technicians for bridge maintenance. Without enough in-house staff, emergency maintenance may not be carried out on time for bridges that require immediate attention, and contracting out a project requires extra time for competitive bidding process (The World Bank, 2006). Therefore, the lack of staff may lead to the responsiveness problem in the current arrangement.

According to the Report Card for Americas’ Infrastructure 2009 by the American Society of Civil Engineers, the cost of repairing for the infrastructure in the US costs $2.2 trillion dollars to reach to acceptable levels (American Society of Civil

Engineers, 2009). The cost increased $0.6 trillion dollars within 4 years since 2005. It implies that if bridges are not repaired accordingly now, it will cost more in the future and the current limited budget will be impossible to catch up. The budget problems on bridge maintenance will get worse if nothing is done now. In Chapter 4, the survey determines that the location, the region, the environment, the types, the span, the materials, the heritage values, the number, the ages, and the numbers of mile of bridges in state can directly affect the annual cost of bridge inspection and maintenance, and the percentage of deficient and obsolete bridges. All the issues cause deficient and obsolete bridges in the US as shown in Figures 5.1.

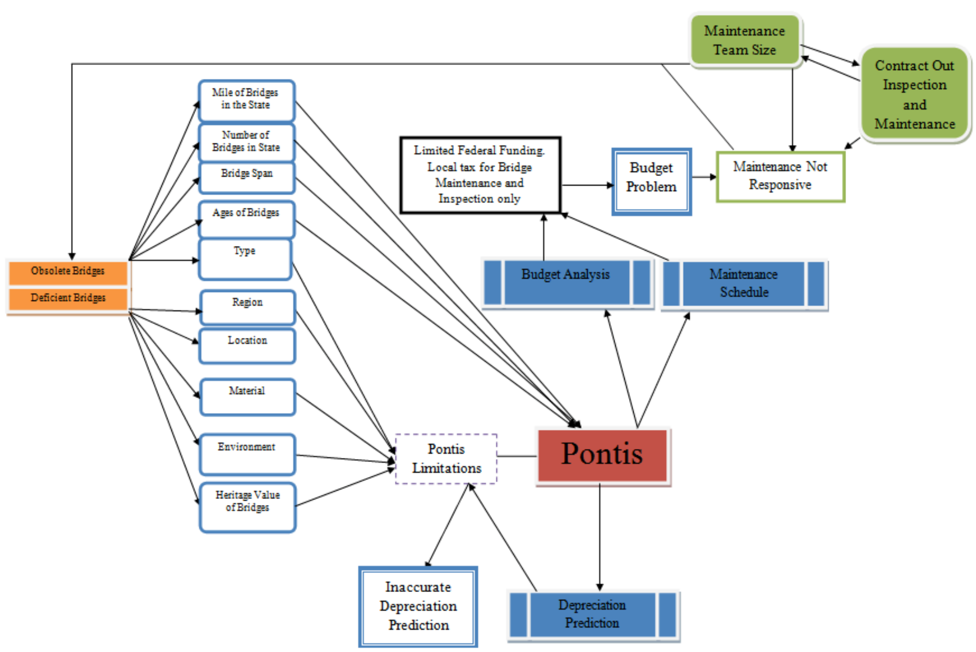

Figure 5.1 Deficient and obsolete bridges flowchart

As mentioned in early chapter, the current bridge inspection and maintenance management is facing a lot of serious issues such as the lack of manpower on it at DOTs, the lack of funding, and other items that may affect the cost of the construction. The staffing problem makes them unable to support required bridge maintenance, and the system becomes unresponsive causing disaster like the one in Minnesota. These issues can be improved by increasing federal funding, using recycled materials, improving Pontis, and more responsive maintenance programs. A model for improvements was developed as shown in Figure 5.2.

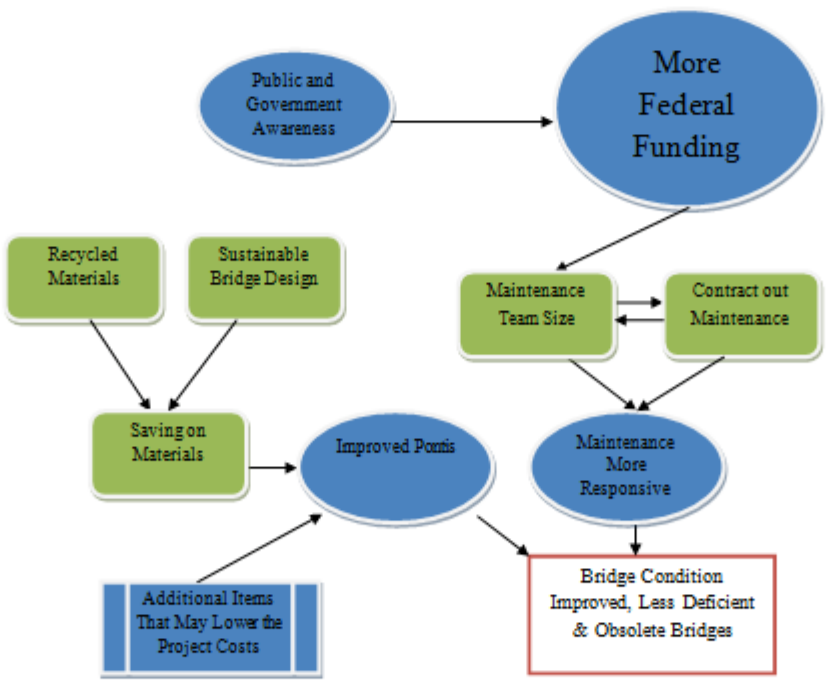

Figure 5.2 Improvements for bridge inspection and maintenance flowchart

5.2 Models for Deficient and Obsolete Bridges

In Chapter 4, Figure 4.3a to 4.3h, Figure 4.4a to 4.4h, Figure 4.5, and Figure 4.6 show that the percentage of deficient and obsolete bridges have close relationship to annual spending per mile in the state DOTs. All the graphs show a decreasing exponential tendency. To approach the model for the relationships, we let variable $\frac{dy}{dx}$ is the slopes of these graphs, and variable x is the annual spending per mile. The slopes of these graphs are decreasing, and the rate of change of the slopes is negative while the annual spending per mile is increasing. Therefore, with factor k that controls the shape of the graph, we can set up a formula as follow:

$$\frac{dy}{dx} = \frac{-1}{kx}$$

$where\ y = percentage\ of\ deficient\ or\ obsolete\ bridges$

$x = annual\ spending\ per\ mile$

In order to obtain a general formula for the graphs, we integrate the formula above:

$$\int \frac{-1}{kx} dx$$

$$y = \frac{-1}{k} \ln (kx) + C$$

The variable x in the equation controls the rate the percentage of deficient or obsolete bridges while C controls how far the percentage will be lowered when unlimited amount of money is applied to current bridge inspection and maintenance management. As mentioned in Chapter 4, the annual spending per mile is affected by a few factors that change the percentage of deficient or obsolete bridges. Factor k in the equation represents these factors, and it is actually a function with vary factors. C is a constant that represent the convergence of the percentage of deficient or obsolete bridges. The function is modified below:

$$y = \frac{-1}{k(a, b, c \ldots)} \ln\left[k(a, b, c \ldots) \cdot x\right] + C$$

$$where\ a, b, c \ldots\ are\ the\ factors\ that\ affects\ the\ percentage\ of\ deficient\ or\ obsolete\ bridges$$

Figure 4.3c Hawaii vs. Utah shows that the mile of bridges in each state affect the annual spending per mile in each state with similar percentage of deficient bridges. Figure 4.3h Nebraska vs. Washington shows that the annual spending per mile in the state of Nebraska is much higher than in the state of Washington while the length of bridges in Nebraska is shorter. It concludes that mile of bridges in one states is one of the factors of function k. In chapter 4, we determine that other factors such as the type of bridges, the location of bridges, and the span of bridges will affect the annual spending per mile on inspection and maintenance, and the percentage of deficient bridges. When Nebraska is compared to Washington, the annual spending per mile is similar, but the percentages of deficient bridges are a lot different. According to the data on number of bridges over 50 years, Nebraska has a lot more bridges over 50 years than Washington. C may be affect by the number of bridges over 50 years. Therefore, for annual spending per mile vs. percentage of deficient bridges, the model equation is shown as follow:

$$y = \frac{-1}{k(a,b,c,d,e)} \ln[k(a,b,c,d,e) \cdot x] + C$$

$where\ y = percentage\ of\ deficient\ bridges$

$x = annual\ spending\ per\ mile$

$a = mile$

$b = number\ of\ bridges$

$c = type$

$d = location$

$e = span$

$C = number\ of\ bridges\ over\ 50\ years$

Same factors are affect the annual per mile and the percentage of obsolete bridges in each state. Figure 4.3b shows that region is also a factor that affects the convergence of the percentage of obsolete bridges as well as the number of bridges over 50 years in the state because the percentages of obsolete bridges for states in the same region are similar. Therefore, the model function is determined to be as follow:

$$y = \frac{-1}{k(a,b,c,d,e)} \ln[k(a,b,c,d,e) \cdot x] + C + K$$

$where\ y = percentage\ of\ obsolete\ bridges$

$x = annual\ spending\ per\ mile$

$a = mile$

$b = number\ of\ bridges$

$c = type$

$d = location$

$e = span$

$C = number\ of\ bridges\ over\ 50\ years$

$K = region$

Figure 4.5 and 4.6 show that the percentages of deficient and obsolete bridges are related to the labor resources spent on bridge inspection and maintenance, and the graphs are two decreasing exponential function like Figure 4.3a and 4.4a. However, previous model cannot be used for labor resources because some states spend close to zero percent of the labor resources on bridge inspection and maintenance due to outsourcing. While logarithm of zero does not exist, a new model is needed for the effect of labor resources on the percentage of deficient and obsolete bridges. Since the slopes of Figure 4.5 and 4.6 are decreasing and the rate of change is negative, we can propose the equation of slopes with factor k:

$$\frac{dy}{dx} = -e^{-kx}$$

$where\ y = percentage\ of\ deficient\ or\ obsolete\ bridges$

$$x = labor\ resources\ on\ bridge\ inspection\ and\ maintenance$$

To obtain the equation of the graphs, similar to the models above, we integrate the slope function and the general equation is obtained as follow:

$$\int -e^{-kx} dx$$

$$y = \frac{1}{k} e^{-kx} + C$$

C controls how far the percentage will be lowered when unlimited labor is applied to current bridge inspection and maintenance management. Similar to annual spending per miles, the percentages of deficient and obsolete bridges are affected by a few factors. Factor k in the equation represents these factors, and it is actually a function with vary factors. C is a constant that represent the convergence of the percentage of deficient or obsolete bridges. The function is modified below:

$$y = \frac{1}{k(a,b,c,\ldots)} e^{-k(a,b,c,..)\cdot x} + C$$

$where\ a, b, c\ \ldots\ are\ the\ factors\ that\ affects\ the\ percentage\ of\ deficient\ or\ obsolete\ bridges$

These factors have similar effect on labor resources on bridge inspection and maintenance and the percentage deficient and obsolete bridges. In Figure 4.6, the region factor affects the relationship between obsolete bridges and labor resources. States in the same region spend similar percentage of labor resources on bridge inspection and maintenance. Therefore, by similarity, we propose the models for the percentage of deficient and obsolete bridge versus labor resources below respectively:

$$y = \frac{1}{k(a,b,c,d,e)} e^{-k(a,b,c,d,e)\cdot x} + C$$

$where\ y = percentage\ of\ deficient\ bridges$

$x = percentage\ of\ labor\ resource\ in\ DOT$

$a = mile$

$b = number\ of\ bridges$

$c = type$

$d = location$

$e = span$

$C = number\ of\ bridges\ over\ 50\ years$

$$y = \frac{1}{k(a,b,c,d,e)} e^{-k(a,b,c,d,e)\cdot x} + C + K$$

$where\ y = percentage\ of\ obsolete\ bridges$

$x = labor\ resources\ in\ DOT$

$a = mile$

$b = number\ of\ bridges$

$c = type$

$d = location$

$e = span$

$C = number\ of\ bridges\ over\ 50\ years$

$K = region$

The models proposed in this section is only an approximation. Due to the limited data points, it cannot conclude the equations. More data points are need from different states in the country in future researches.

Chapter6. Conclusions and Recommendations

The literature review determined that there are a few serious problems in the current bridge inspection and maintenance management programs. Data obtained from the survey completed by the Department of Transportation's in different states justify the findings in the literature. These results are crucial because the current system obviously needs improvement in order to keep up with the maintenance of bridges. Further research in specific areas may be needed to search for possible solutions for the current management problems.

6.1 Findings

Due to the federal regulations on bridge inspection and maintenance, most of the state Department of Transportation's in the country do not receive sufficient funding for bridge maintenance and inspection. State DOTs do not apply the much needed manpower and financial resources. The federal government should introduce new programs or include such a program in the 2009 economy stimulus package to fund bridge maintenance instead of risking another bridge tragedy. If state and local DOTs have sufficient funding from new federal grants, they can perform the required inspection and maintenance for the aging bridges. Thus, the federal government needs to take the leading role. Besides, some states, especially in the Midwest, have a large number of bridges. Some of them build new bridges every year and have a big budget for new construction. These states have the most deficient and obsolete bridges. Texas has the most deficient and obsolete bridges of any state in the country. To remedy this, new regulations should be introduced to limit new bridge construction until states can properly maintain their current bridge inventory.

The data analysis of the survey implies that in order to lower the number of deficient and obsolete bridges in the country, the construction to maintenance cost ratio may requires to be more than 50%. Ideally, the findings also suggests that $1 million per mile per year on aging bridges may need to be spent by each states DOT in order to lower the percentage of deficient bridges. Because some obsolete bridges need to be replaced, $130,000 per mile each year may be spent by state DOTs in order to lower the percentage of obsolete bridges by 3%. The ideal spending may seem high but it only includes the initial improvement cost. Once the condition of the bridges has been improved, the cost per mile incurred by each states DOT may be lowered. From the study carried out by TRB, it is recommended that inspection and maintenance should be contracted out to the private sector (McLawhorn, 2002). Their study shows that the Massachusetts Highway Department needed less money between 1991 and 1999 for bridge maintenance due to the practice of out sourcing. More projects were done during this period and productivity increased.

Apart from the budget, state DOTs should utilize more human resources for bridge maintenance. From the survey, some states do not have enough engineers, inspectors, and technicians in their maintenance departments. Even states with many bridges use the same amount of labor as other states. The study shows that these states generally have a higher percentage of deficient and obsolete bridges. According to the data analysis, state DOTs ideally should use about 5% of their total human resources on bridge maintenance in order to improve the condition of the bridges in their state. Florida, which has a close to ideal value, has the lowest percentage of deficient and obsolete bridges.

With sufficient funds and resources, the required inspections and maintenance for bridges can be performed to improve their conditions by the DOTs. However, the taxpayer's money should be spent wisely. The costs of materials for maintenance have rapidly risen over the last few years, and the trend seems to indicate this will continue. With this in mind, government agencies should look for alternative materials. Asphalt and concrete removed during maintenance are recyclable, and should be reused. This practice saves energy, the cost of transportation and lowers the carbon footprint of construction.

Some states have stricter requirements than others. Inspection and maintenance in Washington State faces many challenges. Washington has tight environmental regulations limiting the type and method of the work that can be done. The work windows do not allow an efficient work schedule. In addition, bridge access is limited due to the listed endangered species. This conflicts with the aging bridge inventory, which requires more maintenance. Additional difficulties include the logistics of traffic control and lane closures in congested urban areas, limited hours of work and noise variances. The state DOT, therefore, should have an exemption on environmental regulations in order to complete their maintenance work within a reasonable work schedule.

In the case of the East River Bridges in New York, due to the change of function of the bridges, the inspection data conflicts with the components in the database. At the same time, New York State has its own rating system with seven scales instead of the nine scale rating system of the Federal Highway Administration. The current rating system for bridge components is vague and is difficult for inspectors to rate the 116 components. The actual condition of the components may not be recorded due to bias by the inspectors. At the same time, the rating does not provide a clear picture for the engineers, contractors, and government agencies on the actual condition of the bridges. A new universal rating system is needed so that different levels of government can understand the actual bridge conditions. This new system should show the type and level of damage. Pontis should be used as a platform nationwide so that government agencies can share valuable inspection and maintenance data.

Pontis is a powerful Bridge Maintenance System for bridge maintenance and planning. Many countries around the world such as Italy are using Pontis for their bridges. However, in the US, it is only being used only in 44 states, and some states use it only in certain counties and cities. For example, The California Department of Transportation uses Pontis only in the Santa Barbara County while the Kansas Department of Transportation uses it only in the Kansas City area. Even though the software is powerful and well organized, it may be missing some required functions. For this reason, government agencies have not completely adopted this BMS. From the literature review, Pontis does not contain data on the geographic and environmental data of the bridges. These factors are critical on deterioration. For example, when a bridge is subjected to a humid environment, components on it will corrode faster than a bridge in a desert. Therefore, the software should add the environmental and geographic constraints. In addition, the software should have a Work Plan module that can produce a sample work plan for the contractor (Liu & Frangopol, 2006). It would accelerate the bidding process and shorten the duration of a project. The maintenance can be more responsive to the condition of bridges with the improved Work Plan module of Pontis.

6.2. Future Research Directions

The condition of the bridges in the nation has been given a failing grade by engineers and their professional organizations. Serious measures should be taken to prevent future disasters from happening like those in Minnesota, and Tennessee. Fortunately, due partly to media attention, public awareness has risen and the federal government has started new funding programs for bridge inspection and maintenance. Even though the federal government must take the lead role to fix the national infrastructure, professionals, academics, and organizations should also invest in researches on bridge maintenance, inspection, and management.

Pontis is used to plan and schedule bridge inspection and maintenance. It is also used to import and export inspection data to the National Bridge Inventory. As mentioned, the system does not include any geographic, environmental, or climate data. Therefore, its accuracy with regard to bridge disintegration is questioned because the environment plays a major role in the corrosion of the bridges. Software designers should work with environmental and material professionals and include these factors in future software development. In addition to the software, government agencies should develop a better system to share their bridge inventory data in order to prevent the inspection data conflict they had in New York.

Construction materials are getting more and more expensive in the last few years due to rising oil prices. Due to the high demand for fuel, the price of materials will continue to rise. The technology used for recycling construction materials is still immature and there are still possibilities to improve it. Research on highway materials should find profitable and sustainable ways to recycle asphalt, concrete, steel…etc so that it can lower the bridge maintenance cost.

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Bridges by Year Built
As of December 2007

Yr Built	2003-2007	1998-2002	1993-1997	1988-1992	1983-1987	1978-1982	1973-1977	1968-1972	1963-1967	1958-1962	1953-1957	1948-1952	1943-1947	1938-1942	1933-1937	1928-1932	1923-1927	1918-1922	1913-1917	1907-1912	1904 and earlier	No Value
Age	0-4	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-84	85-89	90-94	95-100	>100	Reported
ALABAMA	575,155	548,512	889,247	756,990	744,639	1,095,612	865,209	1,064,224	755,888	570,634	353,155	221,619	69,077	200,818	116,656	94,216	69,716	11,481	16,640	3,265	10,536	0
ALASKA	43,124	40,697	48,075	57,960	52,246	52,626	117,082	59,901	79,761	22,595	30,744	10,251	17,137	2,532	3,611	0	0	275	0	4,017	165	1,552
ARIZONA	431,619	670,154	481,077	762,050	481,815	384,910	218,187	227,028	394,825	189,042	102,399	54,022	15,197	51,848	47,239	56,717	13,685	10,466	7,919	1,888	6,067	199
ARKANSAS	380,756	540,354	564,035	332,723	361,760	557,697	788,183	460,469	551,927	413,087	164,748	207,442	34,223	108,646	106,664	249,584	34,072	5,404	1,256	2,170	196	0
CALIFORNIA	498,957	1,419,690	2,271,564	1,831,984	845,214	1,040,262	2,307,549	4,368,309	4,522,776	3,128,090	1,716,725	800,542	325,505	436,871	738,708	332,755	180,389	75,756	92,914	48,970	15,905	49,384
COLORADO	356,129	436,643	522,133	559,776	471,283	239,046	284,851	342,763	408,907	331,812	132,815	112,652	12,470	52,254	91,603	42,668	17,207	4,622	2,148	4,601	1,369	126
CONNECTICUT	48,777	94,890	105,349	251,962	155,499	115,197	208,180	289,259	640,688	776,027	159,294	81,993	62,754	91,709	42,793	30,757	11,228	19,324	7,139	15,314	22,567	0
DELAWARE	27,587	53,937	107,419	56,108	33,848	65,852	92,692	127,078	149,050	51,336	16,783	72,884	679	43,245	6,827	7,002	3,700	7,028	712	686	7,004	0
DIST. OF COL.	0	2,879	0	0	498	0	1,937	64,714	112,113	96,469	37,923	59,634	13,473	38,429	36,552	26,394	13,653	0	4,500	25,599	1,010	0
FLORIDA	1,526,171	1,244,621	1,437,313	1,672,160	1,326,517	1,452,477	1,514,640	1,419,666	1,302,650	1,245,051	409,651	196,055	65,324	85,768	13,200	41,197	64,563	3,789	2,905	23,628	775	0
GEORGIA	457,082	550,513	664,323	784,483	899,957	562,373	868,413	780,322	1,012,354	743,911	420,661	256,565	85,185	152,151	86,108	95,297	62,086	30,640	9,930	7,218	3,675	0
HAWAII	1,788	26,309	58,040	33,326	81,528	305,093	169,088	230,254	78,911	37,267	33,221	40,025	8,962	16,592	28,127	14,231	7,359	8,785	1,601	2,936	1,859	289
IDAHO	65,649	88,153	72,816	156,276	84,231	124,055	181,744	203,844	208,306	151,027	85,609	35,294	4,055	22,834	36,311	19,455	7,232	5,796	2,487	2,441	0	124
ILLINOIS	448,177	540,242	798,202	827,077	973,268	974,134	916,463	1,057,983	1,535,420	1,694,979	531,163	318,120	72,534	255,073	307,857	367,504	236,849	102,691	47,133	87,658	128,737	143,395
INDIANA	217,290	410,292	419,206	556,714	554,822	331,426	618,689	811,600	974,775	846,477	455,124	154,469	44,265	138,676	142,717	190,510	98,591	58,742	31,661	39,916	53,847	192
IOWA	483,556	544,491	529,026	517,310	619,464	687,122	724,260	761,567	656,282	591,807	414,190	309,698	68,642	150,408	199,997	86,838	62,624	67,477	50,198	31,935	115,355	0
KANSAS	328,612	560,451	593,359	526,072	625,160	594,901	737,892	633,882	708,231	684,776	626,658	237,634	74,182	197,792	202,707	199,947	60,560	75,305	16,755	61,482	77,802	0
KENTUCKY	126,431	436,242	386,343	436,585	443,459	407,366	572,206	590,377	604,999	348,445	187,298	174,328	43,557	125,900	110,042	183,259	37,017	10,754	3,353	2,545	16,826	0
LOUISIANA	411,272	646,373	1,268,522	1,281,786	1,318,756	1,263,508	2,172,587	2,423,455	1,490,206	801,763	1,179,868	257,892	119,128	183,487	159,784	74,050	6,541	4,457	199	1,291	0	147
MAINE	39,135	99,837	47,507	30,806	64,314	42,672	78,535	103,392	116,744	129,866	146,445	53,498	43,521	41,725	51,078	51,646	19,568	9,585	4,083	3,170	3,131	0
MARYLAND	97,465	173,419	198,953	433,671	299,689	409,884	714,047	456,763	462,330	443,547	316,802	198,519	44,883	124,258	61,607	85,771	27,477	20,493	23,021	20,180	37,476	2,756
MASSACHUSETTS	104,432	437,253	102,431	47,383	56,312	189,076	165,773	305,102	569,886	530,019	510,228	241,255	20,384	83,755	126,267	75,824	39,187	47,996	28,051	29,787	180,843	906
MICHIGAN	211,596	425,271	275,950	212,673	380,789	332,307	473,966	930,176	900,163	893,750	400,930	126,247	46,920	113,008	80,003	162,625	61,133	34,815	9,718	8,941	15,899	0
MINNESOTA	439,042	399,416	474,577	460,870	558,733	780,490	486,235	726,789	628,919	398,737	138,933	70,046	11,720	82,649	50,087	58,705	89,909	23,989	48,471	14,461	12,278	383
MISSISSIPPI	743,132	765,677	851,388	851,985	620,396	736,297	815,167	619,771	751,709	588,809	257,212	165,282	30,141	140,659	99,588	31,148	13,281	4,358	3,493	656	3,812	0
MISSOURI	676,103	1,152,980	900,215	703,919	705,619	520,850	709,762	738,633	934,135	792,633	428,413	250,066	93,095	154,307	231,805	318,529	112,993	91,594	37,750	52,790	107,374	109
MONTANA	53,736	74,582	81,621	59,364	111,324	221,893	187,181	315,713	280,305	197,232	60,795	58,480	18,376	64,180	57,343	34,201	4,391	7,933	7,710	6,845	4,928	260
NEBRASKA	245,982	287,028	342,732	386,219	342,945	251,110	264,822	300,262	296,172	309,719	117,681	94,719	24,838	70,300	371,056	42,504	25,126	13,282	12,991	11,892	3,012	0
NEVADA	141,729	165,371	168,346	90,485	190,179	64,949	104,386	155,039	116,778	44,937	7,949	3,939	7,835	5,017	8,710	7,585	797	1,780	0	377	421	0
NEW HAMPSHIRE	22,892	70,788	57,851	47,958	51,486	66,425	110,371	133,496	96,842	131,451	61,757	24,863	9,512	34,940	37,200	28,593	13,283	10,213	4,439	3,439	14,977	0
NEW JERSEY	209,487	231,487	309,266	252,833	172,868	142,792	594,113	987,902	510,397	364,869	855,544	703,745	37,998	158,357	172,889	369,790	158,953	26,376	22,730	35,646	68,074	531
NEW MEXICO	67,869	175,630	117,603	79,605	143,091	146,106	195,342	253,109	137,469	121,991	53,558	22,407	13,663	22,489	23,229	15,137	1,318	580	1,080	1,156	0	150
NEW YORK	298,037	521,178	446,368	604,255	371,689	584,386	572,284	1,421,051	1,477,817	1,713,803	1,381,354	456,849	100,741	534,535	588,012	551,816	124,112	80,777	90,537	366,436	293,968	0
NORTH CAROLINA	808,687	1,003,929	672,856	541,307	462,627	659,087	698,280	804,195	596,886	631,539	516,274	244,565	30,816	78,550	56,574	56,127	52,476	48,061	1,441	1,154	277	237
NORTH DAKOTA	70,790	65,980	62,173	64,408	118,030	103,154	112,866	122,759	116,668	126,011	47,257	32,408	15,103	25,479	26,332	17,063	5,211	16,667	5,558	4,572	2,143	138
OHIO	594,706	836,886	685,796	620,270	594,940	491,164	1,011,585	2,001,482	1,912,201	1,482,312	1,006,111	236,568	95,048	229,780	124,438	338,353	78,775	50,365	110,307	64,449	224,657	0
OKLAHOMA	321,848	811,082	580,660	905,885	547,820	496,090	550,813	671,893	844,440	545,300	383,880	252,996	94,134	397,961	216,664	192,974	69,514	44,422	10,530	32,819	2,032	0
OREGON	273,025	180,458	163,694	215,996	260,098	347,661	402,634	454,226	744,118	550,744	352,919	157,083	32,214	60,454	128,762	128,886	108,389	29,985	35,328	45,932	366	0
PENNSYLVANIA	328,635	685,276	373,026	664,346	800,104	311,725	1,449,793	1,531,415	1,223,955	1,143,660	895,115	664,020	64,548	338,420	288,669	512,722	309,106	149,519	113,200	116,643	209,637	12,612
RHODE ISLAND	3,608	5,225	31,983	75,390	17,616	6,442	21,440	162,619	156,684	79,498	38,569	24,255	6,537	3,767	8,029	26,405	8,962	6,791	5,982	3,660	14,393	105
SOUTH CAROLINA	398,072	661,272	624,546	674,437	363,540	356,145	415,938	545,214	525,487	593,354	248,172	148,130	60,840	210,888	88,675	160,987	41,431	10,516	1,032	2,166	12,214	0
SOUTH DAKOTA	68,556	93,828	89,534	86,952	58,544	102,449	185,011	176,958	252,700	221,063	119,670	51,303	9,244	39,660	39,525	43,273	23,192	6,107	3,067	10,360	3,018	0
TENNESSEE	466,127	645,318	936,917	759,078	921,811	515,505	700,014	800,986	967,746	826,261	288,061	287,128	63,945	158,422	139,492	254,647	94,993	16,175	15,950	5,028	7,188	0
TEXAS	3,841,473	3,921,882	3,521,654	4,030,055	2,542,381	2,146,235	2,967,727	3,791,748	3,433,673	2,836,473	1,538,854	976,232	308,483	824,389	768,269	685,754	207,628	65,084	39,287	42,846	8,796	789
UTAH	75,408	436,721	58,930	111,806	167,105	91,372	146,057	191,519	224,323	81,291	29,557	18,567	4,837	8,113	16,171	7,108	3,973	1,698	1,362	260	0	78
VERMONT	18,936	22,710	20,672	21,172	58,234	33,634	61,450	107,789	126,648	112,695	24,579	20,198	13,834	47,314	32,942	48,423	12,267	15,469	2,328	2,816	12,425	563
VIRGINIA	674,406	881,942	506,776	1,004,760	517,293	907,682	775,847	817,306	1,161,601	557,883	234,739	174,239	57,243	161,011	88,976	161,504	57,738	11,845	15,634	4,466	7,580	171
WASHINGTON	248,702	319,859	422,052	448,723	400,745	477,159	358,466	828,821	1,109,149	643,838	360,360	303,315	49,702	190,443	132,429	187,238	66,865	28,423	42,976	50,585	7,010	0
WEST VIRGINIA	213,974	253,213	326,862	240,072	241,961	346,045	511,555	329,035	230,255	148,383	110,338	73,612	20,938	38,066	37,298	55,483	36,878	28,307	20,649	10,022	21,035	0
WISCONSIN	561,615	462,899	486,422	487,543	398,015	491,873	719,668	559,275	583,343	593,089	172,380	104,716	16,444	97,804	95,866	103,831	45,700	23,301	12,159	10,973	5,313	225
WYOMING	37,872	49,109	50,347	71,211	107,145	100,225	118,341	177,605	169,850	193,276	61,431	26,197	6,173	11,043	14,331	8,029	5,066	3,647	1,482	3,208	0	0
PUERTO RICO	100,118	147,937	526,217	174,871	60,831	123,389	248,794	223,779	90,133	43,423	45,767	23,850	12,123	15,941	4,120	4,477	7,689	7,502	2,925	650	4,956	0
TOTALS	18,885,328	25,320,889	25,731,972	26,861,650	22,782,236	22,849,932	30,288,114	37,662,535	37,937,593	30,796,050	18,269,660	9,890,413	2,602,182	6,922,718	6,743,937	6,939,542	2,914,454	1,440,445	1,034,721	1,335,947	1,752,926	215,422

Structurally Deficient Bridges by Year Built

As of December 2007

Year Built	2003-2007	1998-2002	1993-1997	1988-1992	1983-1987	1978-1982	1973-1977	1968-1972	1963-1967	1958-1962	1953-1957	1948-1952	1943-1947	1938-1942	1933-1937	1928-1932	1923-1927	1918-1922	1913-1917	1907-1912	1904 and earlier	No Value
Age	0-4	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-84	85-89	90-94	95-100	>100	Reported
ALABAMA	0	0	4,567	5,438	9,660	7,402	14,900	41,173	46,749	42,546	53,635	50,771	9,795	41,984	31,659	28,167	19,573	6,359	13,018	2,427	2,805	0
ALASKA	0	0	200	892	1,903	6,974	5,669	7,678	18,010	5,286	3,433	6,157	2,485	408	1,307	0	0	275	0	0	50	187
ARIZONA	0	0	1,864	0	3,521	5,312	8,219	6,038	15,717	29,080	17,876	6,942	881	532	4,759	5,112	2,932	906	1,689	0	482	0
ARKANSAS	0	0	3,000	7,193	5,802	50,455	35,747	27,030	41,958	34,488	23,416	25,584	4,071	9,593	18,647	29,605	24,798	2,892	957	1,383	196	0
CALIFORNIA	0	0	89,787	209,150	124,246	122,545	345,021	941,562	1,067,891	620,602	603,898	194,385	132,371	106,779	383,051	100,773	52,959	21,189	38,029	5,410	9,604	7,096
COLORADO	0	0	1,594	473	4,484	12,586	10,633	24,714	108,406	50,679	27,023	17,367	1,358	17,404	23,343	8,782	5,005	1,804	266	529	469	0
CONNECTICUT	0	0	38,360	10,150	2,756	1,872	6,286	18,463	87,857	121,887	19,647	19,482	1,158	23,949	7,795	5,976	1,094	9,592	438	6,551	4,252	0
DELAWARE	0	0	0	0	81	0	0	0	5,878	216	0	1,357	0	0	168	322	0	0	193	459	376	0
DIST. OF COL.	0	0	0	0	0	0	0	7,981	1,975	206	2,462	36,117	0	9,130	0	0	0	0	0	994	472	0
FLORIDA	0	0	618	535	4,611	8,406	11,965	157,457	37,478	55,795	25,225	25,226	11,439	20,762	134	9,390	20,228	339	0	23,318	0	0
GEORGIA	0	0	611	2,073	7,301	8,863	12,101	16,682	27,904	55,006	58,989	38,586	13,807	28,605	11,070	23,148	21,277	9,305	1,151	2,403	2,462	0
HAWAII	0	0	111	0	147	0	14,544	3,416	1,807	0	316	2,923	279	2,994	3,379	3,449	1,587	1,402	1,052	1,806	587	0
IDAHO	0	0	0	494	2,395	2,769	4,615	16,745	24,735	21,266	14,301	3,283	505	9,636	19,261	6,149	3,007	3,834	1,378	1,024	0	34
ILLINOIS	0	0	3,697	1,572	81,383	24,346	39,477	60,250	201,942	222,360	77,900	58,554	5,663	50,526	49,275	77,467	72,526	29,997	18,022	57,777	52,561	5,142
INDIANA	0	0	9,749	5,404	86,086	10,041	17,369	59,427	127,921	46,458	72,669	22,848	7,724	38,101	31,300	53,012	22,882	21,892	11,070	12,725	26,418	0
IOWA	0	0	801	1,996	3,995	33,564	29,854	57,124	109,756	172,271	153,129	116,759	23,075	61,944	107,388	33,774	21,023	24,168	28,963	18,400	68,057	0
KANSAS	0	0	319	3,385	1,198	6,017	18,633	30,692	40,979	51,982	49,628	32,437	12,634	55,915	28,998	53,309	14,628	47,121	7,236	48,367	20,869	0
KENTUCKY	0	0	326	3,949	18,395	6,704	23,368	15,396	122,424	69,307	18,395	24,329	10,127	21,845	37,234	49,120	11,969	5,427	2,573	2,199	14,421	0
LOUISIANA	0	0	1,860	111,057	32,471	30,723	111,106	86,437	434,902	155,591	89,023	104,845	4,948	142,829	105,443	36,691	1,626	2,351	199	1,156	0	0
MAINE	0	0	208	286	240	287	1,188	1,582	2,316	11,709	36,585	5,029	8,667	12,360	9,686	24,730	10,511	1,567	1,934	757	1,488	0
MARYLAND	0	0	363	326	174	1,356	1,377	15,211	32,055	80,919	26,445	25,815	4,971	7,296	9,302	8,839	2,601	6,475	1,108	6,697	4,714	0
MASSACHUSETTS	0	0	62	110	3,615	5,878	9,778	23,043	146,490	40,582	51,892	27,816	6,720	21,376	23,737	30,787	10,669	20,049	10,729	7,253	52,423	0
MICHIGAN	0	0	289	1,551	2,735	5,051	62,796	153,423	219,715	125,742	74,473	20,963	7,081	23,346	17,920	41,616	15,589	12,864	4,566	4,215	8,477	0
MINNESOTA	0	0	34	77	321	12,951	13,377	38,352	70,300	36,526	24,942	14,763	2,198	25,292	16,918	11,267	17,044	8,660	17,677	3,229	6,352	102
MISSISSIPPI	0	0	20,768	25,580	22,829	27,241	51,625	54,507	60,764	112,373	109,133	43,558	8,310	64,811	54,411	21,497	5,011	2,570	3,398	197	3,185	0
MISSOURI	0	0	2,703	4,767	17,098	7,896	53,653	34,455	173,465	188,265	112,948	64,954	30,271	63,699	115,072	154,758	40,326	48,836	11,967	26,816	33,146	0
MONTANA	0	0	429	903	2,012	7,339	3,134	9,821	13,209	5,866	1,839	2,900	2,520	11,430	6,340	8,294	1,974	2,652	4,107	3,619	2,452	43
NEBRASKA	0	0	220	432	1,848	2,190	10,289	24,222	13,065	15,226	27,293	10,394	7,968	18,522	145,331	17,294	15,917	6,424	6,795	7,340	2,239	0
NEVADA	0	0	1,961	0	181	0	888	1,038	6,178	407	181	389	338	1,604	3,537	557	164	1,465	0	0	101	0
NEW HAMPSHIRE	0	0	0	289	878	3,924	13,380	4,359	4,693	16,550	14,824	7,102	2,278	19,304	11,118	9,914	489	7,095	2,101	846	8,111	0
NEW JERSEY	0	0	0	295	931	109	16,330	52,375	38,522	61,417	75,506	72,855	4,049	54,078	66,270	206,297	43,583	9,345	5,048	17,740	23,281	271
NEW MEXICO	0	0	166	525	2,140	8,541	23,728	43,247	29,423	33,010	16,866	8,365	748	11,427	8,867	8,446	445	175	513	0	0	39
NEW YORK	0	0	689	5,152	7,285	19,073	32,187	47,354	223,913	278,527	169,421	54,817	16,779	158,979	94,184	114,452	16,704	43,099	22,880	22,442	90,945	0
NORTH CAROLINA	0	0	1,177	7,452	40,265	31,147	41,743	129,229	145,391	216,132	195,919	102,091	13,856	28,183	13,751	28,776	17,179	20,318	1,293	522	190	0
NORTH DAKOTA	0	0	222	267	487	15,817	1,672	7,957	4,483	9,061	7,587	7,621	6,746	9,464	8,520	4,920	2,447	4,814	3,581	3,862	1,751	0
OHIO	0	0	1,458	3,097	5,163	10,964	32,792	154,227	80,095	195,028	83,832	27,673	17,568	29,468	25,671	108,877	26,799	20,416	34,931	33,351	67,081	0
OKLAHOMA	0	0	11,574	21,157	14,260	54,393	73,887	165,498	266,959	141,354	103,878	92,490	40,004	145,480	97,070	82,705	35,404	31,031	9,012	31,075	1,566	0
OREGON	0	0	170	642	2,561	2,551	2,665	46,752	33,007	77,815	84,348	27,433	5,968	6,215	30,201	39,541	19,520	6,730	4,591	3,248	0	0
PENNSYLVANIA	0	0	2,494	9,406	18,256	16,486	230,683	343,412	322,503	266,589	182,936	125,767	26,743	117,992	119,699	210,200	116,503	67,686	70,444	43,541	95,545	2,589
RHODE ISLAND	0	0	0	50,651	398	767	5,240	34,664	34,450	47,113	28,753	17,438	968	1,689	3,641	4,000	729	1,021	3,194	1,294	1,616	0
SOUTH CAROLINA	0	0	1,665	2,391	1,869	11,837	19,008	40,684	46,558	101,651	114,590	68,134	32,709	100,556	19,199	47,981	9,161	2,840	233	1,827	3,488	0
SOUTH DAKOTA	0	0	0	1,339	4,108	5,031	14,880	12,819	21,888	30,821	19,317	14,867	2,892	16,819	18,844	19,904	7,753	4,350	2,296	9,262	1,780	0
TENNESSEE	0	0	4,176	4,455	22,929	5,130	26,053	34,427	59,167	87,879	26,542	43,928	12,510	21,232	33,831	59,457	22,364	4,177	11,305	519	500	0
TEXAS	0	0	21,385	17,080	26,278	23,676	25,012	193,062	109,117	116,917	113,799	80,165	15,384	56,214	84,700	65,070	14,850	9,956	19,334	31,395	7,977	0
UTAH	0	0	178	329	1,175	866	1,712	10,738	59,935	3,536	9,679	2,430	1,973	1,668	5,058	1,292	575	616	354	260	0	78
VERMONT	0	0	0	230	89	226	830	23,269	25,852	21,986	9,060	5,021	4,728	13,613	10,787	19,067	4,028	5,284	727	2,372	6,635	0
VIRGINIA	0	0	6,798	3,033	4,427	10,767	10,103	21,753	94,910	60,372	33,228	45,537	12,420	63,406	18,307	49,919	31,068	5,873	4,844	2,739	4,042	0
WASHINGTON	0	0	25,234	0	290	11,205	4,921	33,976	72,568	51,287	23,905	110,758	6,211	22,704	32,160	52,400	24,533	5,080	10,334	13,120	1,086	0
WEST VIRGINIA	0	0	30	18,480	1,385	5,214	36,840	17,837	44,620	32,556	24,274	35,007	7,986	14,130	11,013	22,098	12,875	11,120	12,463	6,452	13,297	0
WISCONSIN	0	0	151	838	1,487	15,698	30,043	47,643	53,863	72,726	33,663	24,608	5,588	24,067	16,846	36,410	14,251	8,833	5,532	5,097	1,956	0
WYOMING	0	0	1,480	4,339	4,873	11,722	13,901	25,364	24,204	17,907	6,459	7,806	3,100	3,481	6,347	5,350	2,988	2,374	1,111	649	0	0
PUERTO RICO	0	0	54,794	23,698	2,554	5,395	18,827	35,769	16,188	5,058	10,028	3,212	4,369	2,630	2,270	1,739	2,587	2,579	646	286	2,426	0
TOTALS	0	0	318,341	572,939	605,578	679,307	1,594,050	3,460,334	5,074,158	4,317,930	3,165,106	1,989,659	566,941	1,815,475	2,004,820	2,042,697	843,751	575,224	415,283	478,949	651,929	15,581

Functionally Obsolete Bridges by Year Built
As of December 2007

Year Built	2003-2007	1998-2002	1993-1997	1988-1992	1983-1987	1978-1982	1973-1977	1968-1972	1963-1967	1958-1962	1953-1957	1948-1952	1943-1947	1938-1942	1933-1937	1928-1932	1923-1927	1918-1922	1913-1917	1907-1912	1904 and earlier	No Value
Age	0-4	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-84	85-89	90-94	95-100	>100	Reported
ALABAMA	0	0	42,886	91,132	20,240	21,615	80,448	185,808	213,021	202,098	156,417	83,933	34,742	95,616	52,570	29,323	31,126	1,837	1,871	344	1,646	0
ALASKA	0	0	4,543	9,681	7,173	6,663	24,024	9,864	252	4,637	18,240	1,466	710	1,257	1,942	0	0	0	0	0	115	1,302
ARIZONA	0	0	72,858	181,341	37,448	25,323	28,430	32,965	93,800	32,784	15,380	2,728	1,628	8,911	6,119	11,033	6,556	2,020	4,163	938	1,177	0
ARKANSAS	0	0	35,160	26,228	31,288	51,970	75,892	73,043	108,303	106,775	58,268	81,311	6,939	61,003	41,439	68,103	4,278	1,244	45	539	0	0
CALIFORNIA	0	0	381,162	249,595	124,169	76,088	315,950	574,161	902,677	979,750	414,450	270,354	83,760	141,715	210,719	105,001	39,151	25,212	23,554	21,351	3,067	6,619
COLORADO	0	0	73,586	57,934	95,480	8,977	21,969	51,547	63,535	89,392	20,676	14,039	406	2,184	9,222	14,631	7,899	239	334	328	0	0
CONNECTICUT	0	0	17,682	81,199	32,882	17,077	36,492	54,506	207,874	233,741	43,639	25,967	55,523	34,493	21,073	13,423	2,226	3,924	1,542	5,755	11,694	0
DELAWARE	0	0	581	3,624	1,973	20,574	17,735	3,662	59,988	3,312	9,581	53,516	581	36,028	1,625	3,408	2,231	606	232	0	1,226	0
DIST. OF COL.	0	0	0	0	0	0	1,937	45,472	60,341	48,643	11,118	2,697	10,759	11,595	20,744	24,608	13,653	0	1,884	24,605	539	0
FLORIDA	0	0	62,435	98,247	307,097	104,196	157,987	178,443	322,736	383,548	166,997	64,331	17,218	24,913	6,111	14,312	19,523	1,465	2,733	310	0	0
GEORGIA	0	0	40,511	42,452	35,395	37,746	55,592	57,980	220,634	226,807	115,107	112,594	37,493	44,967	33,107	15,881	11,453	7,760	7,619	1,646	113	0
HAWAII	0	0	167	674	5,189	9,968	6,192	22,055	20,523	22,810	13,743	11,391	4,391	5,358	17,045	6,911	4,825	4,656	477	858	497	0
IDAHO	0	0	2,229	39,389	6,392	6,044	11,042	31,692	39,639	36,976	7,426	11,572	117	1,327	6,219	5,209	273	1,092	593	241	0	52
ILLINOIS	0	0	128,442	73,005	78,370	42,307	57,073	145,932	251,612	418,171	119,339	107,855	3,901	43,315	76,075	104,208	47,763	40,997	17,383	12,177	31,501	62,862
INDIANA	0	0	27,956	41,041	27,991	44,941	90,589	128,586	117,345	114,060	111,271	23,682	6,167	22,374	25,818	48,677	20,923	10,402	10,054	9,708	13,506	0
IOWA	0	0	20,511	8,253	41,376	36,273	50,638	45,492	81,300	78,601	50,672	51,325	21,291	33,020	31,566	18,149	14,900	7,165	8,499	2,444	14,363	0
KANSAS	0	0	64,971	109,059	33,590	48,305	174,095	52,485	133,686	92,203	160,811	32,694	9,298	22,468	50,164	27,785	19,684	11,393	2,617	4,476	4,185	0
KENTUCKY	0	0	48,421	47,823	36,628	51,343	59,827	104,693	89,637	63,581	50,530	77,506	19,659	79,026	57,922	97,345	17,754	4,287	459	99	1,928	0
LOUISIANA	0	0	270,580	71,573	73,693	70,059	315,466	362,292	530,267	308,001	932,344	80,311	3,991	29,710	16,391	15,895	846	227	0	0	0	0
MAINE	0	0	2,082	4,607	14,167	5,242	7,477	50,343	7,600	35,013	51,017	16,549	9,800	8,914	22,703	6,460	4,171	3,169	942	1,063	203	0
MARYLAND	0	0	33,381	58,538	18,151	127,776	265,330	53,027	94,488	134,344	56,649	112,237	15,266	88,867	29,821	49,725	19,093	9,271	15,941	5,053	18,324	754
MASSACHUSETTS	0	0	42,423	19,604	21,056	74,312	90,751	138,444	266,459	233,262	291,510	137,503	5,791	25,008	47,595	25,032	12,904	21,680	7,985	13,289	69,643	245
MICHIGAN	0	0	36,553	37,716	50,110	39,396	67,250	179,781	163,232	186,399	176,811	39,951	7,098	22,392	9,506	32,226	14,207	10,828	3,008	708	2,594	0
MINNESOTA	0	0	6,969	13,721	21,529	31,587	6,596	42,307	84,753	113,876	10,759	8,709	638	4,769	12,693	8,981	31,693	1,387	6,791	6,911	3,569	0
MISSISSIPPI	0	0	10,218	8,927	5,418	18,756	33,221	20,822	201,705	230,633	63,715	81,558	14,184	57,051	29,178	5,262	5,111	520	95	459	499	0
MISSOURI	0	0	63,446	115,108	62,763	84,075	71,066	84,553	170,359	223,652	138,702	54,459	38,971	38,058	56,754	82,831	34,958	19,644	8,243	4,782	10,940	57
MONTANA	0	0	2,942	3,233	8,901	14,680	13,376	34,989	86,732	54,414	11,179	12,395	1,813	10,753	12,164	2,483	503	1,259	693	1,994	674	0
NEBRASKA	0	0	12,918	25,683	16,912	20,841	5,680	17,830	17,184	17,820	7,146	22,099	1,096	7,163	59,483	3,047	4,748	2,099	3,154	2,866	242	0
NEVADA	0	0	12,814	16,781	20,082	1,998	9,921	47,908	23,252	11,998	1,588	0	37	414	1,426	312	0	0	0	0	265	0
NEW HAMPSHIRE	0	0	5,192	10,047	6,444	2,238	7,311	3,887	18,231	17,521	12,820	5,114	1,799	5,428	10,026	6,729	8,211	991	1,872	459	2,863	0
NEW JERSEY	0	0	34,101	11,949	23,902	18,453	234,181	302,145	204,892	48,803	191,226	196,629	13,313	23,168	46,385	44,121	87,795	5,026	7,335	7,650	21,765	260
NEW MEXICO	0	0	3,994	4,789	13,026	5,069	4,475	22,104	14,718	10,459	6,678	780	1,205	9,167	5,988	1,608	178	154	0	182	0	0
NEW YORK	0	0	115,630	210,571	97,303	114,667	139,804	627,004	765,344	982,917	610,999	265,512	41,944	285,393	358,787	319,139	51,522	25,697	48,614	293,302	75,983	0
NORTH CAROLINA	0	0	60,718	44,861	50,063	42,149	44,860	77,899	145,282	157,678	189,100	78,352	11,048	27,419	24,898	11,679	19,595	14,043	0	632	0	169
NORTH DAKOTA	0	0	1,959	281	5,250	2,233	4,556	2,400	11,587	2,044	1,482	2,251	1,237	2,413	8,850	5,203	1,376	10,272	914	553	0	138
OHIO	0	0	139,674	84,778	98,668	127,402	265,275	510,889	584,374	300,220	205,582	44,948	10,129	108,499	24,241	108,278	17,535	7,063	52,578	15,514	48,474	0
OKLAHOMA	0	0	29,739	93,403	34,944	28,192	68,884	73,371	103,617	85,414	59,417	37,692	5,708	46,408	15,943	24,634	9,878	4,030	835	950	0	0
OREGON	0	0	14,789	17,122	44,919	37,994	99,906	49,289	196,401	157,771	82,815	51,271	16,317	36,237	64,704	58,119	55,131	10,659	26,300	36,776	0	0
PENNSYLVANIA	0	0	87,943	184,752	252,680	106,387	421,143	287,581	233,604	327,850	276,222	303,108	6,312	81,452	85,900	157,326	149,148	39,563	27,475	32,842	62,656	4,893
RHODE ISLAND	0	0	9,194	9,301	10,223	2,180	5,331	77,165	63,783	13,164	1,265	3,263	342	1,504	1,625	15,955	2,723	2,601	1,028	1,008	6,312	0
SOUTH CAROLINA	0	0	25,117	47,314	39,236	11,307	17,336	45,604	88,883	149,292	53,074	17,764	8,549	36,359	17,547	25,046	16,133	514	658	339	1,440	0
SOUTH DAKOTA	0	0	2,487	2,840	931	3,438	3,891	4,796	25,211	46,350	5,923	3,489	927	1,726	2,890	6,924	562	245	171	736	195	0
TENNESSEE	0	0	73,301	61,123	89,904	77,510	116,945	84,309	201,455	202,559	51,764	72,951	20,504	73,749	48,165	67,700	21,616	4,600	1,917	321	94	0
TEXAS	0	0	735,301	1,022,793	586,862	410,717	519,601	608,413	878,426	918,039	428,869	307,896	42,099	183,121	124,901	130,576	26,571	16,298	11,238	8,970	328	0
UTAH	0	0	3,074	5,209	17,423	3,549	15,265	17,056	46,548	14,194	5,846	1,874	451	779	2,147	1,317	555	0	0	0	0	0
VERMONT	0	0	719	339	1,569	2,595	4,527	8,853	22,090	16,265	1,204	3,337	5,942	8,980	8,126	8,706	2,177	2,835	548	194	1,578	285
VIRGINIA	0	0	67,386	98,519	45,118	41,043	121,379	87,525	431,317	145,346	85,309	49,010	24,427	50,030	24,920	47,506	16,028	3,025	9,687	538	1,805	0
WASHINGTON	0	0	79,128	219,216	66,706	76,692	46,413	179,968	334,790	297,139	172,939	100,607	18,521	125,335	72,676	86,089	28,984	13,258	24,787	22,366	2,226	0
WEST VIRGINIA	0	0	54,364	35,906	28,558	45,408	74,381	42,908	34,163	21,184	38,219	10,356	6,183	11,135	12,340	20,340	13,498	7,240	4,737	1,963	3,443	0
WISCONSIN	0	0	41,707	29,825	24,778	26,013	45,058	57,886	103,167	87,871	18,451	15,885	985	12,648	10,438	16,660	5,984	2,110	1,852	4,631	254	225
WYOMING	0	0	971	4,711	15,184	14,208	3,891	8,415	23,657	25,055	2,414	600	286	2,934	820	552	1,179	249	108	853	0	0
PUERTO RICO	0	0	113,795	32,500	14,440	60,128	42,810	58,716	44,763	14,939	25,845	14,211	4,012	10,371	1,468	2,443	4,246	4,258	680	186	2,342	0
TOTALS	0	0	3,218,710	3,768,315	2,803,594	2,357,708	4,459,269	6,068,865	9,209,234	8,729,374	5,812,547	3,181,634	655,506	2,106,923	1,940,978	2,006,913	933,077	369,112	354,245	553,910	424,267	77,860

Condition of U.S. Highway Bridges: 1990-2007

As of August 14, 2007

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
TOTAL all bridges	**572,205**	**574,036**	**572,197**	**573,716**	**576,460**	**581,135**	**581,863**	**582,751**	**582,976**	**585,542**	**589,674**	**589,685**	**590,887**	**591,940**	**593,813**	**595,363**	**597,340**	**599,893**
Urban	108,770	112,363	115,312	117,488	121,141	122,537	124,950	127,633	128,312	130,339	133,384	133,401	135,339	135,415	137,598	142,408	146,041	151,102
Rural	463,435	461,673	456,885	456,228	455,319	458,598	456,913	455,118	454,664	455,203	456,290	456,284	455,548	456,525	456,215	452,955	451,299	448,791
Structurally deficient bridges, total	**137,865**	**134,534**	**118,698**	**111,980**	**107,683**	**104,317**	**101,518**	**98,475**	**93,072**	**88,150**	**86,692**	**83,595**	**81,261**	**79,775**	**77,752**	**75,923**	**73,784**	**72,264**
Urban	16,847	17,032	16,323	15,932	15,692	15,205	15,094	14,846	14,073	12,967	U	12,705	12,503	12,316	12,175	12,600	12,585	12,882
Rural	121,018	117,502	102,375	96,048	91,991	89,112	86,424	83,629	78,999	75,183	U	70,890	68,758	67,459	65,577	63,323	61,199	59,382
Functionally obsolete bridges, total	**100,355**	**97,593**	**80,393**	**80,000**	**79,832**	**80,950**	**81,208**	**77,410**	**79,500**	**81,900**	**81,510**	**81,439**	**81,537**	**80,990**	**80,567**	**80,412**	**80,317**	**81,257**
Urban	30,266	30,842	26,243	26,511	27,024	27,487	28,087	26,865	27,588	29,065	29,398	29,383	29,675	29,886	30,298	31,391	32,292	33,096
Rural	70,089	66,751	54,150	53,489	52,808	53,463	53,121	50,545	51,912	52,835	52,112	52,056	51,862	51,104	50,269	49,021	48,025	48,161

KEY: U = data are not available

NOTES:

Explanations for the terms *Structurally Deficient* and *Functionally Obsolete* can be found on pages 14 and 15 in Chapter 3 of the Federal Highway Administration, 2006 Conditions and Performance Report; the following is a link to Chapter 3 of the report: http://www.fhwa.dot.gov/policy/2006cpr/pdfs/chap3.pdf.

U.S. totals include the 50 states, the District of Columbia, and Puerto Rico.

Table includes: Rural–Interstate, principal arterial, minor arterial, major collector, minor collector and local roads; Urban–Interstate, other freeways or expressways, other principal arterial, minor arterial, collector, and local roads.

Data for 1990, 1992, 1997-99, and 2001 are as of December of those years; data for 1991 and 1994-96 are as of June of those years; data for 1993 are as of September of that year; data for 2000 are as of August of that year; data for 2002-06 are as of July of those years.

Further updates to 2007 data will be made until December 31, 2007.

SOURCES:

1990-2000: U.S. Department of Transportation, Research and Innovative Technology Administration, Bureau of Transportation Statistics; based on data from Federal Highway Administration, Office of Bridge Technology, National Bridge Inventory Database, personal communication, Aug. 14, 2001.

2001-06: U.S. Department of Transportation, Research and Innovative Technology Administration, Bureau of Transportation Statistics; based on data from Federal Highway Administration, Office of Bridge Technology, National Bridge Inventory Database, *Count of Bridges by Highway System,* Internet site http://www.fhwa.dot.gov/bridge/britab.htm as of Mar. 30, 2007.

2007: U.S. Department of Transportation, Research and Innovative Technology Administration, Bureau of Transportation Statistics; based on data from Federal Highway Administration, Office of Bridge Technology, National Bridge Inventory Database, special tabulation. Data as of Aug. 14, 2007.

Condition of U.S. Highway Bridges by State: 2007
As of August 13, 2007

				Percent of State Bridges	
State	All Bridges (number)	Structurally Deficient (number)	Functionally Obsolete (number)	Structurally Deficient (percent)	Functionally Obsolete (percent)
ALABAMA	15,882	1,899	2,159	12%	14%
ALASKA	1,289	151	301	12%	23%
ARIZONA	7,389	187	594	3%	8%
ARKANSAS	12,535	997	1,874	8%	15%
CALIFORNIA	24,199	3,139	3,986	13%	16%
COLORADO	8,389	580	808	7%	10%
CONNECTICUT	4,175	358	1,042	9%	25%
DELAWARE	857	20	112	2%	13%
DISTRICT OF COLUMBIA	245	24	128	10%	52%
FLORIDA	11,666	306	1,713	3%	15%
GEORGIA	14,563	1,031	1,878	7%	13%
HAWAII	1,105	152	357	14%	32%
IDAHO	4,113	355	629	9%	15%
ILLINOIS	25,998	2,499	1,839	10%	7%
INDIANA	18,494	2,030	2,005	11%	11%
IOWA	24,776	5,151	1,457	21%	6%
KANSAS	25,464	2,991	2,372	12%	9%
KENTUCKY	13,639	1,362	2,931	10%	21%
LOUISIANA	13,342	1,787	2,194	13%	16%
MAINE	2,387	350	468	15%	20%
MARYLAND	5,128	388	981	8%	19%
MASSACHUSETTS	5,019	585	1,988	12%	40%
MICHIGAN	10,924	1,583	1,304	14%	12%
MINNESOTA	13,068	1,158	427	9%	3%
MISSISSIPPI	17,013	3,005	1,316	18%	8%
MISSOURI	24,071	4,433	3,110	18%	13%
MONTANA	5,045	481	738	10%	15%
NEBRASKA	15,453	2,370	1,287	15%	8%
NEVADA	1,704	48	160	3%	9%
NEW HAMPSHIRE	2,363	244	493	10%	21%
NEW JERSEY	6,448	750	1,501	12%	23%
NEW MEXICO	3,854	411	291	11%	8%
NEW YORK	17,361	2,128	4,518	12%	26%
NORTH CAROLINA	17,783	2,272	2,810	13%	16%
NORTH DAKOTA	4,458	743	249	17%	6%
OHIO	27,999	2,863	4,001	10%	14%
OKLAHOMA	23,530	5,793	1,612	25%	7%
OREGON	7,261	560	1,434	8%	20%
PENNSYLVANIA	22,325	5,588	4,003	25%	18%
RHODE ISLAND	748	164	232	22%	31%
SOUTH CAROLINA	9,221	1,260	809	14%	9%
SOUTH DAKOTA	5,925	1,216	261	21%	4%
TENNESSEE	19,841	1,326	2,772	7%	14%
TEXAS	50,272	2,186	7,851	4%	16%
UTAH	2,854	235	260	8%	9%
VERMONT	2,713	501	469	18%	17%
VIRGINIA	13,425	1,212	2,255	9%	17%
WASHINGTON	7,717	415	1,911	5%	25%
WEST VIRGINIA	7,008	1,056	1,526	15%	22%
WISCONSIN	13,800	1,300	788	9%	6%
WYOMING	3,038	390	243	13%	8%
PUERTO RICO	2,146	241	822	11%	38%
UNITED STATES TOTAL	**597,876**	**72,033**	**80,447**	**12%**	**13%**
TOTAL (incl. Puerto Rico)	**600,022**	**72,274**	**81,269**	**12%**	**14%**

NOTES:

Explanations for the terms *Structurally Deficient* and *Functionally Obsolete* can be found on pages 14 and 15 in Chapter 3 of the Federal Highway Administration, 2006 Conditions and Performance Report; the following is a link to Chapter 3 of the report: http://www.fhwa.dot.gov/policy/2006cpr/pdfs/chap3.pdf.

Further updates to this data will be made until December 31, 2007.

SOURCE:

U.S. Department of Transportation, Research and Innovative Technology Administration, Bureau of Transportation Statistics; based on data from Federal Highway Administration, National Bridge Inventory, *Deficient Bridges by State and Highway System*, special tabulation. Data as of Aug. 13, 2007.

Survey Questions for on Bridge Inspection and Maintenance

General Questions

1. How many employees are there in your DOT?
2. How many of them are engineers?
3. How many of them are technicians?
4. How big is the maintenance and inspection team?
5. How many engineers are there in the team? What is their average year of experience?
6. How many technicians are there in the team? What is their average year of experience?
7. What is the budget from state government on bridge construction per year?
8. What is the budget from federal government on bridge construction per year?
9. What is the budget from state government on bridge inspection and maintenance per year?
10. What is the budget from federal government on bridge inspection and maintenance per year?
11. How many miles of bridges are there in your state?
12. How many bridges are there in your state?
13. How many deficient bridges are there in your state?
14. What percent of the inspection and maintenance projects are contracted out to private companies?
15. What is the cost of contracted-out projects cost per year?
16. What is the cost of in-house projects cost per year?

Inspection

1. How often is a bridge inspected?
   What kind of data do you collect during inspection?
2. Is there any database that stores all the inspection data?
3. Are there any technical difficulties you face during inspection? What are they?

Maintenance

1. Does your state have its own maintenance manual or guidelines for Bridges?
2. How do you determine if the repair is structurally sound?
3. Is there any technical difficulty you are facing during maintenance? What is it?