ASSESSMENT OF BRIDGE INSPECTION AND MAINTENANCE IN THE UNITED STATES

BY

Kin Yip George Kwok

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

____________________________________

Dr. Oswald Chong, Chair

Committee Members

____________________________________

Dr. Thomas E. Glavinich, D.E., P. E.

____________________________________

Dr. Jie Han, P. E.

Date Defended:_____________________

The Thesis Committee for Kin Yip George Kwok certifies that this is the approved version of the following thesis:

ASSESSMENT OF BRIDGE INSPECTION AND MAINTENANCE IN THE UNITED STATES

BY

Kin Yip George Kwok

________________________________________
Dr. Oswald Chong, Chair

Committee Members ____________________________________________

Dr. Thomas E. Glavinich, D.E., P. E.

________________________________________
Dr. Jie Han, P. E.

Date Defended: ____________________________
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.
Table of Contents

Abstract .......................................................................................................................... II
Table of Contents ........................................................................................................ III
List of Figures ............................................................................................................... V
Acknowledgements ..................................................................................................... VIII
Chapter 1. Introduction ................................................................................................. 1
  1.1 History of the bridges .......................................................................................... 2
  1.2 Bridges built in the Era of Interstate Construction and their conditions .......... 3
  1.3 Current Bridge Management System .................................................................. 4
  1.4 Finance for bridge inspection and maintenance ............................................. 7
Chapter 2. Literature Review .......................................................................................... 10
  2.1 Awareness in the public on Bridges Maintenance ............................................. 11
  2.2 Geographic Factors and Statistics Observation ............................................... 14
  2.3 The Impact of Inflation and Gas Prices on Material Prices ............................. 22
  2.4 Change of Functions of the Bridges & Inspection Rating Conflicts ............... 27
  2.5 Unsustainable Bridge Design ............................................................................ 28
  2.7 Environmental Issues ....................................................................................... 32
  2.8 Current Bridge Maintenance System .............................................................. 40
Chapter 3. Research Objective Scopes and Methodology ................................................. 49
Chapter 4. Data Collection and Analysis ........................................................................ 56
  4.1 Budget Arrangement Analysis .......................................................................... 56
  4.2 Human Resources Problems ............................................................................. 75
  4.3 Issues that DOTs Are Facing During Inspection and Maintenance ............... 79
Chapter 5. Understandings and Models Development ..................................................... 82
  5.1 Flowcharts for the Causes and Solution on Deficient and Obsolete Bridges82
  5.2 Models for Deficient and Obsolete Bridges ....................................................... 86
Chapter 6. Conclusions and Recommendations ............................................................ 93
6.1 Findings............................................................................................................................. 93
6.2 Future Research Directions............................................................................................... 97
References................................................................................................................................. 99
Appendices................................................................................................................................. 104
List of Figures

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

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) ..... 12

Figure 2.2 Hatchie River bridge (Source: Turne- Fairbank Highway Research Center, 1995) ........................................................................................................................................ 13

Figure 2.3 Total Number of Bridges in the US by State (FHWA, 2007) .............. 15

Figure 2.4 Number of Bridges in the US by Region (FHWA, 2007) ........... 16

Figure 2.5 Number of deficient bridges in the US by State (FHWA, 2007) .... 17

Figure 2.6 Number of obsolete bridges in the US by state (FHWA, 2007) ....... 18

Figure 2.7: Percentage of deficient bridges by state (FHWA, 2007) ........... 20

Figure 2.8: Percentage of obsolete bridges by state (FHWA, 2007) ............ 21

Figure 2.9 An old stone arch bridge in Pennsylvania (Source: PENNDOT, 2009) ... 22

Figure 2.10 Construction material price from 2003-2008 (Source: AASHTO, 2008) 24

Figure 2.11 Comparison of water absorption of three different recycled (Source: AASHTO, 2008) .......................................................................................................................... 25

Figure 2.12 States where recycled concrete used as base aggregate (Source: FHWA, 1998) ........................................................................................................................................ 26

Figure 2.13 An engineer tests a bridge pin using ultrasonic technology (AASHTO, 2008) ........................................................................................................................................ 31

Figure 2.14: The Graphic User Interface of "The Gateway Module" in Pontis(FHWA, 2008) ........................................................................................................................................ 41

Figure 2.15: Budget and Resources Input in Pontis (FHWA, 2008) .................. 43

Figure 2.16: Sample Result on Preservation Needed and Projected Work in Pontis (FHWA, 2008) ........................................................................................................................................ 44

Figure 2.17: The Graphical User Interface of “the Planning Module” in Pontis(FHWA, 2008) ........................................................................................................................................ 45

Figure 2.18: Component Deterioration Prediction in Pontis (FHWA, 2008) .... 46

Figure 3.1 Research Flow Chart ........................................................................ 55

Figure 4.1 Construction to Maintenance Cost ratio ....................................... 56

Figure 4.2 Construction to Maintenance Cost Ratio vs. Percentage of Deficient & Obsolete Bridges .................................................................................................................. 58
Figure 4.3a Percentage of Deficient Bridges vs. Annual Spending/Mile................. 61
Figure 4.3b Percentage of Deficient Bridges vs. Annual Spending/Mile(without Florida)................................................................. 61
Figure 4.3c Percentage of Deficient Bridges vs. Annual Spending/Mile (Hawaii vs. Utah)........................................................................... 61
Figure 4.3d Percentage of Deficient Bridges vs. Annual Spending/Mile(Hawaii vs. Washington).......................................................... 61
Figure 4.3e Percentage of Deficient Bridges vs. Annual Spending/Mile(Kansas vs. Nebraska)............................................................ 61
Figure 4.3f Percentage of Deficient Bridges vs. Annual Spending/Mile(Vermont vs. Tennessee).......................................................... 61
Figure 4.3g Percentage of Deficient Bridges vs. Annual Spending/Mile(Hawaii vs. Kansas)..................................................................... 61
Figure 4.3h Percentage of Deficient Bridges vs. Annual Spending/Mile(Washington vs. Nebraska)....................................................... 61
Figure 4.4a: Percentage of Obsolete Bridges vs. Annual Spending/Mile ............... 69
Figure 4.4b: Percentage of Obsolete Bridges vs. Annual Spending/Mile (without Florida)......................................................................... 69
Figure 4.4c: Percentage of Obsolete Bridges vs. Annual Spending/Mile(Hawaii vs. Kansas)................................................................. 70
Figure 4.4d: Percentage of Obsolete Bridges vs. Annual Spending/Mile(Hawaii vs. Washington).......................................................... 70
Figure 4.4e: Percentage of Obsolete Bridges vs. Annual Spending/Mile(Kansas vs. Nebraska)............................................................ 71
Figure 4.4f: Percentage of Obsolete Bridges vs. Annual Spending/Mile(Kansas vs. Nebraska)............................................................ 71
Figure 4.4g: Percentage of Obsolete Bridges vs. Annual Spending/Mile(Vermont vs. Utah)................................................................. 72
Figure 4.4h: Percentage of Obsolete Bridges vs. Annual Spending/Mile(Projection from ASCE Infrastructure Report Card 2009)......................... 73
Figure 4.5 Percentage of Deficient Bridges vs. Labor Resources Spent on Bridge Inspection and Maintenance(without Florida)........................................ 77
Figure 4.6 Percentage of Obsolete Bridges vs. Labor Resources Spent on Bridge Inspection and Maintenance................................................. 78
Figure 4.7 A Sample Bridge Expansion Joint During Maintenance (Source: WSDOT).............................................................................. 80
Figure 5.1 Deficient and Obsolete Bridges Cycle Flowchart................................ 85
Figure 5.2 Model of Improvements For Bridge Inspection and Maintenance

Flowchart..................................................................................................................84

Table 2.1: Regulations Impacting the Bridge Painting Industry (Center for Environmental Excellence by AASHTO, 2008)................................................................. 33

Table 2.2 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) ................................................................. 34

Table 2.3 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) ................................................................. 35

Table 2.4 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) ................................................................. 36

Table 2.5 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) ................................................................. 37

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) ................................................................. 38

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) ................................................................. 38

Table 4.1 Summary of Annual Spending on Maintenance and Inspection .................. 60

Table 4.2 Summary of the Compact on Contracting Out Projects ............................. 76

Table 4.3 Summary on Labor Resources in Bridge Inspection and Maintenance in Participated States .................................................................................................................. 76
Acknowledgements

Mr. Dean Testa, P.E., Retired engineer at Kansas Department of Transportation

Mr. Don Whistler, P.E., Bridge Maintenance Engineer at Kansas Department of Transportation

Mr. Roy Rissky, Chief of Bureau of Construction & Maintenance at Kansas Department of Transportation

Mr. John Williams, Maintenance Engineer at Hawaii Department of Transportation

Mr. Scott Rogers, Director of Operations Division at Vermont Agency of Transportation

Mr. Gary Schelley, State Public Assistant at Vermont Agency of Transportation

Ms. Pam Thurber, PE, Bridge Maintenance, and Inspection Engineer at Vermont Agency of Transportation

Mr. Chris Potter, P.E., Deputy Bridge Operations Engineer at Utah Department of Transportation

Mr. David Sumner, Office of Maintenance at Florida Department of Transportation
Mr. Terry Holman, NBI Program Manager at Nebraska Department of Transportation

Ms. Anna Zaharris, MAP Specialist, Maintenance & Operations Programs at Washington State Department of Transportation

Mr. Rico Baroga, Maintenance Accountability Process Manager at Washington State Department of Transportation

Bridge Preservation Office and Bridge & Bridge Crews at Washington State Department of Transportation

Mr. Wayne J. Seger, P.E., Bridge Inspection Program Manager at Tennessee Department of Transportation

Mr. Greg Duncan, Maintenance Division Director at Tennessee Department of Transportation
Page left intentionally blank
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 19th and 20th 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.

<table>
<thead>
<tr>
<th>States</th>
<th>Number of 100-year-old Bridges</th>
</tr>
</thead>
<tbody>
<tr>
<td>ILLINOIS</td>
<td>801</td>
</tr>
<tr>
<td>IOWA</td>
<td>1,117</td>
</tr>
<tr>
<td>KANSAS</td>
<td>501</td>
</tr>
<tr>
<td>MASSACHUSETTS</td>
<td>426</td>
</tr>
<tr>
<td>MISSOURI</td>
<td>900</td>
</tr>
<tr>
<td>NEW JERSEY</td>
<td>304</td>
</tr>
<tr>
<td>NEW YORK</td>
<td>366</td>
</tr>
<tr>
<td>OHIO</td>
<td>1,980</td>
</tr>
<tr>
<td>PENNSYLVANIA</td>
<td>912</td>
</tr>
</tbody>
</table>

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 50th 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\textsuperscript{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.

![Number of Bridges by Region](image)

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

<table>
<thead>
<tr>
<th>Impacting Regulation</th>
<th>Effect on Coating Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>OSHA; CFR 29 1926.62, Lead in Construction</td>
<td>Establishes guidelines for protection and monitoring of workers removing lead paint from bridges. Requires lead training and monitoring for workers.</td>
</tr>
<tr>
<td>EPA; Resource Conservation and Recovery Act (RCRA )</td>
<td>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.</td>
</tr>
<tr>
<td>EPA; Comprehensive Environmental Response Compensation and Liability Act (CERCLA or Superfund )</td>
<td>Assigns ownership of and responsibility for hazardous waste to the generator “into perpetuity.”</td>
</tr>
<tr>
<td>EPA; Clean Water Act</td>
<td>Regulates discharge of materials into waterways.</td>
</tr>
<tr>
<td>EPA; Clean Air Act Amendments</td>
<td>Mandates restrictions on allowable volatile-organic-compound (VOC) content of paints and coatings. Regulates discharge of dust into air from bridge painting</td>
</tr>
</tbody>
</table>

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.

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

Table 2.2 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)
<table>
<thead>
<tr>
<th>ACTIVITY/FACILITY</th>
<th>ENVIRONMENTAL ASPECT</th>
<th>ENVIRONMENTAL IMPACT</th>
</tr>
</thead>
<tbody>
<tr>
<td>(and related issues)</td>
<td>(part of activity that could have an impact on the environment)</td>
<td>(possible effect on the environment)</td>
</tr>
<tr>
<td>Concrete saw cutting</td>
<td>Dust generation, Noise generation, Waste generation, Wastewater generation</td>
<td>Air pollution, Noise pollution, Waste disposal, Water pollution</td>
</tr>
<tr>
<td>Grading (unsealed road)</td>
<td>Waste generation, Dust generation, Possible sedimentation</td>
<td>Waste disposal, Air pollution, Water pollution</td>
</tr>
<tr>
<td>- vegetation protection</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- drainage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resheeting (sealed road)</td>
<td>Disturbance to vegetation, Soil disturbance, Generation of debris, Generation of dust, Generation of solid waste</td>
<td>Destruction of vegetation, Spread of weeds, Waste disposal, Air pollution</td>
</tr>
<tr>
<td>Drain maintenance</td>
<td>Vegetation disturbance, Possible erosion/sedimentation</td>
<td>Destruction of vegetation, Water pollution</td>
</tr>
<tr>
<td>- clean table drains</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- clean benches on a cut</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- guide rails</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- signposts</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- fencing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- noise walls</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2.3 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)
<table>
<thead>
<tr>
<th>ACTIVITY/FACILITY (and related issues)</th>
<th>ENVIRONMENTAL ASPECT (part of activity that could have an impact on the environment)</th>
<th>ENVIRONMENTAL IMPACT (possible effect on the environment)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pavement sweeping</td>
<td>Waste generation</td>
<td>Waste disposal</td>
</tr>
<tr>
<td></td>
<td>Generation of dust</td>
<td>Air pollution</td>
</tr>
<tr>
<td>Illegal dumping</td>
<td>Dumping of waste</td>
<td>Soil contamination</td>
</tr>
<tr>
<td>- waste storage and disposal</td>
<td></td>
<td>Water pollution</td>
</tr>
<tr>
<td>- licenses</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Landscape works maintenance</td>
<td>Damage to flora</td>
<td>Destruction of vegetation</td>
</tr>
<tr>
<td>- herbicide use</td>
<td>Potential spread of weed</td>
<td>Aesthetics (weed die off)</td>
</tr>
<tr>
<td>- chemical storage</td>
<td>Potential batter erosion</td>
<td>Noxious weed spread</td>
</tr>
<tr>
<td></td>
<td>Potential leaks or spills</td>
<td>Water pollution</td>
</tr>
<tr>
<td></td>
<td>Waste generation</td>
<td>Soil/water contamination</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Waste disposal</td>
</tr>
</tbody>
</table>

Table 2.4 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)
<table>
<thead>
<tr>
<th>ACTIVITY/FACILITY</th>
<th>ENVIRONMENTAL ASPECT</th>
<th>ENVIRONMENTAL IMPACT</th>
</tr>
</thead>
<tbody>
<tr>
<td>(and related issues)</td>
<td>(part of activity that could have an impact on the environment)</td>
<td>(possible effect on the environment)</td>
</tr>
<tr>
<td>Vegetation management</td>
<td>Damage to flora</td>
<td>Destruction of vegetation</td>
</tr>
<tr>
<td>- waste management</td>
<td>Use of herbicides/pesticides</td>
<td>Aesthetics (weed die off)</td>
</tr>
<tr>
<td>- herbicide spraying</td>
<td>Potential spread of weed</td>
<td>Noxious weed spread</td>
</tr>
<tr>
<td>- tree cutting</td>
<td>“green” waste generation</td>
<td>Waste disposal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Soil/water/air pollution</td>
</tr>
<tr>
<td>Roadside rest area maintenance</td>
<td>Litter removal and collection</td>
<td>Waste disposal</td>
</tr>
<tr>
<td></td>
<td>Syringe collection</td>
<td>Medical waste disposal</td>
</tr>
<tr>
<td>Bridge maintenance</td>
<td>Generation of hazardous/non-hazardous waste</td>
<td>Waste disposal</td>
</tr>
<tr>
<td>- flaming off bolts/decking</td>
<td>Air emissions</td>
<td>Air pollution</td>
</tr>
<tr>
<td>- resurfacing with tar/aggregate</td>
<td>Potential for spills/leaks</td>
<td>Water/soil contamination</td>
</tr>
<tr>
<td>- fuel storage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- plant/vehicle parking</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- oxyacetylene storage/use</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2.5 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)
<table>
<thead>
<tr>
<th>ACTIVITY/FACILITY</th>
<th>ENVIRONMENTAL ASPECT</th>
<th>ENVIRONMENTAL IMPACT</th>
</tr>
</thead>
<tbody>
<tr>
<td>(and related issues)</td>
<td>(part of activity that could have an impact on the environment)</td>
<td>(possible effect on the environment)</td>
</tr>
<tr>
<td>Paint removal</td>
<td>Waste generation (paint flake)</td>
<td>Waste disposal</td>
</tr>
<tr>
<td></td>
<td>Wastewater generation</td>
<td>Water/soil contamination</td>
</tr>
<tr>
<td></td>
<td>Waste ends up in natural environment</td>
<td>Air pollution</td>
</tr>
<tr>
<td></td>
<td>Dust generation</td>
<td></td>
</tr>
<tr>
<td>Wood treatment (creosoting)</td>
<td>Potential for leaks and spills</td>
<td>Chemicals in natural environment</td>
</tr>
<tr>
<td>- use of chemicals</td>
<td></td>
<td>Soil/water contamination</td>
</tr>
<tr>
<td>- chemical storage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Line mark removal (grinding)</td>
<td>Sedimentation</td>
<td>Water pollution</td>
</tr>
<tr>
<td></td>
<td>Noise generation</td>
<td>Air pollution</td>
</tr>
<tr>
<td></td>
<td>Dust generation</td>
<td>Noise pollution</td>
</tr>
<tr>
<td>Loop Cutting (asphalt road)</td>
<td>Dust generation</td>
<td>Air pollution</td>
</tr>
<tr>
<td></td>
<td>Wastewater discharge (sediments &amp; oil, fuel)</td>
<td>Soil/water contamination</td>
</tr>
<tr>
<td></td>
<td>Noise generation</td>
<td>Noise pollution</td>
</tr>
<tr>
<td></td>
<td>Waste generation</td>
<td>Waste disposal</td>
</tr>
<tr>
<td></td>
<td>Generation of wastewater from washing</td>
<td>Soil/water contamination</td>
</tr>
<tr>
<td></td>
<td>Potential for spreading weeds through machinery</td>
<td>Weed spread</td>
</tr>
<tr>
<td></td>
<td>Potential for spills (fuels, oils etc.)</td>
<td></td>
</tr>
</tbody>
</table>

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

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 Bridgewater 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,
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.
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.

![Preservation Needs and Projected Work for Scenario: Default Scenario Years 2003-2007](image)

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)](image)

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 Transportation 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 Transportation 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
Chapter 4. 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.

![Construction to Maintenance Cost ratio](image)

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

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 4.3b, 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 4.3f 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.

![Percentage of Deficient Bridges vs. Annual Spending/mile](image)

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)
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 4.4a. 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)
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 4.4g 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 to 10%. This projection is determined with the assumption that the percentage can be lowered to zero and the highest percentage is close to 45%.

![Percentage of Deficient and Obsolete Bridges vs. Annual Spending/mile](image)

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.

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

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

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.

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

![Percentage of Deficient Bridges vs. Labor Resources Spent on Bridge Inspection and Maintenance](image)

Figure 4.5 Percentage of Deficient 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).
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](image-url)
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 \( y = \text{percentage of deficient or obsolete bridges} \)

\( x = \text{annual spending per mile} \)

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:

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

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 \( y = \text{percentage of obsolete bridges} \)

\( x = \text{annual spending per mile} \)

\( a = \text{mile} \)

\( b = \text{number of bridges} \)

\( c = \text{type} \)

\( d = \text{location} \)

\( e = \text{span} \)

\( C = \text{number of bridges over 50 years} \)

\( K = \text{region} \)

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 \( y = \text{percentage of deficient or obsolete bridges} \)

\( x = \text{labor resources on bridge inspection and maintenance} \)

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:

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

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 \( y = \text{percentage of deficient bridges} \)

\( x = \text{percentage of labor resource in DOT} \)

\( a = \text{mile} \)

\( b = \text{number of bridges} \)

\( c = \text{type} \)
\[ d = \textit{location} \]
\[ e = \textit{span} \]

\[ C = \textit{number of bridges over 50 years} \]

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

where \( y = \text{percentage of obsolete bridges} \)

\( x = \textit{labor resources in DOT} \)

\( a = \textit{mile} \)

\( b = \textit{number of bridges} \)

\( c = \textit{type} \)

\( d = \textit{location} \)

\( e = \textit{span} \)

\( C = \textit{number of bridges over 50 years} \)

\( K = \textit{region} \)

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.
Chapter 6. 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 require to be more than 50%. Ideally, the findings also suggest that $1 million per mile per year on aging bridges may need to be spent by each state 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 state 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 outsourcing. 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.
References


Federal Highway Administration, United States Department of Transportation. (2007, 04 June). Referentia for Pontis eLearning System. Retrieved February 10, 02009,


Appendices

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL all bridges</td>
<td>512,265</td>
<td>574,336</td>
<td>592,197</td>
<td>573,719</td>
<td>576,466</td>
<td>591,135</td>
<td>561,805</td>
<td>552,751</td>
<td>552,751</td>
<td>565,542</td>
<td>580,674</td>
<td>589,053</td>
<td>590,887</td>
<td>591,940</td>
<td>592,813</td>
<td>595,363</td>
<td>597,340</td>
<td>599,893</td>
</tr>
<tr>
<td>Rural</td>
<td>403,555</td>
<td>461,473</td>
<td>466,324</td>
<td>460,749</td>
<td>456,324</td>
<td>455,188</td>
<td>456,168</td>
<td>456,046</td>
<td>456,324</td>
<td>458,208</td>
<td>469,046</td>
<td>467,516</td>
<td>470,432</td>
<td>471,802</td>
<td>471,802</td>
<td>471,802</td>
<td>471,802</td>
<td></td>
</tr>
<tr>
<td>Structurally deficient bridges, total</td>
<td>137,965</td>
<td>154,354</td>
<td>168,698</td>
<td>181,163</td>
<td>187,683</td>
<td>192,017</td>
<td>198,348</td>
<td>201,918</td>
<td>204,372</td>
<td>208,732</td>
<td>212,938</td>
<td>216,944</td>
<td>221,126</td>
<td>223,976</td>
<td>227,752</td>
<td>230,927</td>
<td>234,957</td>
<td>238,508</td>
</tr>
<tr>
<td>Urban</td>
<td>18,842</td>
<td>20,322</td>
<td>21,533</td>
<td>22,822</td>
<td>24,011</td>
<td>25,018</td>
<td>25,954</td>
<td>26,556</td>
<td>26,756</td>
<td>26,969</td>
<td>27,182</td>
<td>27,564</td>
<td>27,969</td>
<td>28,376</td>
<td>28,792</td>
<td>29,190</td>
<td>29,538</td>
<td>29,930</td>
</tr>
<tr>
<td>Rural</td>
<td>119,123</td>
<td>134,032</td>
<td>147,876</td>
<td>155,342</td>
<td>163,007</td>
<td>172,000</td>
<td>180,024</td>
<td>186,072</td>
<td>190,018</td>
<td>194,018</td>
<td>198,024</td>
<td>202,032</td>
<td>206,040</td>
<td>210,040</td>
<td>214,040</td>
<td>218,040</td>
<td>222,040</td>
<td>226,040</td>
</tr>
<tr>
<td>Functionally obsolete bridges, total</td>
<td>180,368</td>
<td>197,503</td>
<td>203,939</td>
<td>209,023</td>
<td>213,932</td>
<td>218,950</td>
<td>221,208</td>
<td>224,415</td>
<td>229,500</td>
<td>231,500</td>
<td>234,069</td>
<td>237,039</td>
<td>240,039</td>
<td>243,039</td>
<td>246,039</td>
<td>249,039</td>
<td>252,039</td>
<td>255,039</td>
</tr>
<tr>
<td>Urban</td>
<td>30,266</td>
<td>30,742</td>
<td>30,911</td>
<td>30,119</td>
<td>30,324</td>
<td>29,487</td>
<td>28,087</td>
<td>26,868</td>
<td>25,885</td>
<td>24,968</td>
<td>23,988</td>
<td>22,906</td>
<td>21,975</td>
<td>21,869</td>
<td>21,786</td>
<td>21,696</td>
<td>21,606</td>
<td>21,516</td>
</tr>
</tbody>
</table>

KEY: U = data 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/2690/06pdf/chap3.pdf](http://www.fhwa.dot.gov/policy/2690/06pdf/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, 1994-98, and 2001 are as of December of those years; data for 1991 and 1993-98 are as of June of those years; data for 1999 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:**
<table>
<thead>
<tr>
<th>State</th>
<th>All Bridges (number)</th>
<th>Structurally Deficient (number)</th>
<th>Functionally Obsolete (number)</th>
<th>Percent of State Bridges Structurally Deficient (percent)</th>
<th>Functionally Obsolete (percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alabama</td>
<td>15,582</td>
<td>1,859</td>
<td>2,159</td>
<td>12%</td>
<td>6%</td>
</tr>
<tr>
<td>Alaska</td>
<td>1,289</td>
<td>161</td>
<td>301</td>
<td>12%</td>
<td>23%</td>
</tr>
<tr>
<td>Arizona</td>
<td>1,089</td>
<td>107</td>
<td>369</td>
<td>3%</td>
<td>8%</td>
</tr>
<tr>
<td>Arkansas</td>
<td>12,535</td>
<td>997</td>
<td>1,874</td>
<td>8%</td>
<td>15%</td>
</tr>
<tr>
<td>California</td>
<td>24,199</td>
<td>3,120</td>
<td>3,986</td>
<td>13%</td>
<td>18%</td>
</tr>
<tr>
<td>Colorado</td>
<td>8,009</td>
<td>900</td>
<td>925</td>
<td>11%</td>
<td>10%</td>
</tr>
<tr>
<td>Connecticut</td>
<td>4,175</td>
<td>358</td>
<td>1,042</td>
<td>9%</td>
<td>25%</td>
</tr>
<tr>
<td>Delaware</td>
<td>967</td>
<td>20</td>
<td>112</td>
<td>2%</td>
<td>13%</td>
</tr>
<tr>
<td>District of Columbia</td>
<td>240</td>
<td>24</td>
<td>125</td>
<td>10%</td>
<td>52%</td>
</tr>
<tr>
<td>Florida</td>
<td>11,668</td>
<td>305</td>
<td>1,713</td>
<td>3%</td>
<td>15%</td>
</tr>
<tr>
<td>Georgia</td>
<td>14,146</td>
<td>1,031</td>
<td>1,676</td>
<td>7%</td>
<td>12%</td>
</tr>
<tr>
<td>Hawaii</td>
<td>1,170</td>
<td>152</td>
<td>307</td>
<td>14%</td>
<td>22%</td>
</tr>
<tr>
<td>Idaho</td>
<td>4,115</td>
<td>355</td>
<td>529</td>
<td>9%</td>
<td>15%</td>
</tr>
<tr>
<td>Illinois</td>
<td>29,908</td>
<td>2,000</td>
<td>1,838</td>
<td>10%</td>
<td>7%</td>
</tr>
<tr>
<td>Indiana</td>
<td>18,494</td>
<td>2,000</td>
<td>2,000</td>
<td>11%</td>
<td>0%</td>
</tr>
<tr>
<td>Iowa</td>
<td>24,778</td>
<td>1,513</td>
<td>1,457</td>
<td>21%</td>
<td>6%</td>
</tr>
<tr>
<td>Kansas</td>
<td>26,486</td>
<td>2,901</td>
<td>2,372</td>
<td>12%</td>
<td>9%</td>
</tr>
<tr>
<td>Kentucky</td>
<td>13,639</td>
<td>1,262</td>
<td>2,921</td>
<td>12%</td>
<td>21%</td>
</tr>
<tr>
<td>Louisiana</td>
<td>13,342</td>
<td>1,067</td>
<td>2,194</td>
<td>13%</td>
<td>16%</td>
</tr>
<tr>
<td>Maine</td>
<td>2,387</td>
<td>350</td>
<td>488</td>
<td>16%</td>
<td>20%</td>
</tr>
<tr>
<td>Maryland</td>
<td>6,120</td>
<td>398</td>
<td>961</td>
<td>8%</td>
<td>10%</td>
</tr>
<tr>
<td>Massachusetts</td>
<td>9,019</td>
<td>895</td>
<td>1,986</td>
<td>12%</td>
<td>40%</td>
</tr>
<tr>
<td>Michigan</td>
<td>18,924</td>
<td>1,483</td>
<td>1,503</td>
<td>14%</td>
<td>12%</td>
</tr>
<tr>
<td>Minnesota</td>
<td>13,023</td>
<td>1,150</td>
<td>427</td>
<td>11%</td>
<td>3%</td>
</tr>
<tr>
<td>Mississippi</td>
<td>13,010</td>
<td>3,005</td>
<td>1,316</td>
<td>18%</td>
<td>8%</td>
</tr>
<tr>
<td>Missouri</td>
<td>24,071</td>
<td>4,434</td>
<td>3,110</td>
<td>16%</td>
<td>13%</td>
</tr>
<tr>
<td>Montana</td>
<td>5,046</td>
<td>491</td>
<td>728</td>
<td>10%</td>
<td>15%</td>
</tr>
<tr>
<td>Nebraska</td>
<td>15,453</td>
<td>2,370</td>
<td>1,267</td>
<td>15%</td>
<td>8%</td>
</tr>
<tr>
<td>Nevada</td>
<td>1,704</td>
<td>48</td>
<td>160</td>
<td>9%</td>
<td>9%</td>
</tr>
<tr>
<td>New Hampshire</td>
<td>2,183</td>
<td>244</td>
<td>453</td>
<td>22%</td>
<td>21%</td>
</tr>
<tr>
<td>New Jersey</td>
<td>6,448</td>
<td>190</td>
<td>1,201</td>
<td>12%</td>
<td>23%</td>
</tr>
<tr>
<td>New Mexico</td>
<td>3,864</td>
<td>411</td>
<td>791</td>
<td>11%</td>
<td>8%</td>
</tr>
<tr>
<td>New York</td>
<td>17,061</td>
<td>2,128</td>
<td>4,518</td>
<td>12%</td>
<td>29%</td>
</tr>
<tr>
<td>North Carolina</td>
<td>17,783</td>
<td>2,272</td>
<td>2,510</td>
<td>13%</td>
<td>16%</td>
</tr>
<tr>
<td>North Dakota</td>
<td>4,458</td>
<td>143</td>
<td>269</td>
<td>17%</td>
<td>6%</td>
</tr>
<tr>
<td>Ohio</td>
<td>21,909</td>
<td>2,863</td>
<td>4,201</td>
<td>10%</td>
<td>14%</td>
</tr>
<tr>
<td>Oklahoma</td>
<td>7,530</td>
<td>670</td>
<td>1,712</td>
<td>25%</td>
<td>7%</td>
</tr>
<tr>
<td>Oregon</td>
<td>7,981</td>
<td>563</td>
<td>1,454</td>
<td>8%</td>
<td>20%</td>
</tr>
<tr>
<td>Pennsylvania</td>
<td>22,726</td>
<td>5,890</td>
<td>4,038</td>
<td>20%</td>
<td>18%</td>
</tr>
<tr>
<td>Rhode Island</td>
<td>744</td>
<td>164</td>
<td>232</td>
<td>22%</td>
<td>31%</td>
</tr>
<tr>
<td>South Carolina</td>
<td>9,221</td>
<td>1,503</td>
<td>809</td>
<td>14%</td>
<td>9%</td>
</tr>
<tr>
<td>South Dakota</td>
<td>6,925</td>
<td>1,216</td>
<td>267</td>
<td>21%</td>
<td>4%</td>
</tr>
<tr>
<td>Tennessee</td>
<td>19,841</td>
<td>1,320</td>
<td>2,772</td>
<td>7%</td>
<td>14%</td>
</tr>
<tr>
<td>Texas</td>
<td>50,272</td>
<td>2,186</td>
<td>7,351</td>
<td>4%</td>
<td>16%</td>
</tr>
<tr>
<td>Utah</td>
<td>2,804</td>
<td>236</td>
<td>262</td>
<td>8%</td>
<td>9%</td>
</tr>
<tr>
<td>Vermont</td>
<td>2,713</td>
<td>501</td>
<td>459</td>
<td>16%</td>
<td>17%</td>
</tr>
<tr>
<td>Virginia</td>
<td>13,425</td>
<td>1,212</td>
<td>2,255</td>
<td>9%</td>
<td>17%</td>
</tr>
<tr>
<td>Washington</td>
<td>7,717</td>
<td>415</td>
<td>1,911</td>
<td>5%</td>
<td>26%</td>
</tr>
<tr>
<td>West Virginia</td>
<td>7,009</td>
<td>1,090</td>
<td>1,026</td>
<td>15%</td>
<td>22%</td>
</tr>
<tr>
<td>Wisconsin</td>
<td>13,000</td>
<td>1,100</td>
<td>785</td>
<td>9%</td>
<td>6%</td>
</tr>
<tr>
<td>Wyoming</td>
<td>3,038</td>
<td>330</td>
<td>346</td>
<td>10%</td>
<td>3%</td>
</tr>
<tr>
<td>Puerto Rico</td>
<td>2,140</td>
<td>241</td>
<td>522</td>
<td>11%</td>
<td>38%</td>
</tr>
<tr>
<td><strong>United States Total</strong></td>
<td><strong>597,875</strong></td>
<td><strong>72,333</strong></td>
<td><strong>89,447</strong></td>
<td><strong>12%</strong></td>
<td><strong>13%</strong></td>
</tr>
<tr>
<td><strong>Total incl. Puerto Rico</strong></td>
<td><strong>600,023</strong></td>
<td><strong>72,333</strong></td>
<td><strong>90,447</strong></td>
<td><strong>12%</strong></td>
<td><strong>14%</strong></td>
</tr>
</tbody>
</table>

**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, 2008 Conditions and Performance Report; the following is a link to Chapter 3 of this report: http://www.fhwa.dot.gov/policy/2008cip/pts/ch3.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?