An Exploratory Data Analysis Of National Bridge Inventory

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16. Abstract

The National Bridge Inventory (NBI) database is the largest collection of bridge data in the world. This database contains detailed information on more than 600,000 United States highway bridges and large culverts over a period of several decades. The NBI is owned and maintained by the United States Federal Highway Administration (FHWA). There has been very little analysis performed on the NBI from the perspective of data mining and knowledge discovery; therefore, the objectives of this study are to compile and consolidate all available historical NBI data into a data warehouse, and to discover previously unknown patterns, trends and relationships hidden inside the data. The scope of the study includes data integration, summary and descriptive statistics, and knowledge discovery process for temporal and spatial patterns. Advanced analytical methods such as exploratory data analysis and knowledge discovery are utilized as research methodologies for this study. The combination of these methods, coupled with geographic information system (GIS) software, is effective in extracting information from the datasets and representing the visual patterns.

17. Key Words

National Bridge Inventory, data mining, exploratory data analysis, knowledge discovery

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An Exploratory Data Analysis of National Bridge Inventory

A Thesis Presented

To the Faculty of the School of Engineering and Applied Science

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In Partial Fulfillment

Of the requirements for the Degree

Master of Science in Civil Engineering in Transportation

By

Nien-Chun Wu

May 2010

ABSTRACT

The National Bridge Inventory (NBI) database is the largest collection of bridge data in the world. This database contains detailed information on more than 600,000 United States highway bridges and large culverts over a period of several decades. The NBI is owned and maintained by the United States Federal Highway Administration (FHWA). The principal use of the NBI is to determine the eligibility for and the amount of appropriation for funding the infrastructures in the National Bridge Program administered by FHWA.

There has been very little analysis performed on the NBI from the perspective of data mining and knowledge discovery; therefore, the objectives of this study are to compile and consolidate all available historical NBI data into a data warehouse, and to discover previously unknown patterns, trends and relationships hidden inside the data. The scope of the study includes data integration, summary and descriptive statistics, and knowledge discovery process for temporal and spatial patterns. Advanced analytical methods such as exploratory data analysis and knowledge discovery are utilized as research methodologies for this study. The combination of these methods, coupled with geographic information system (GIS) software, is effective in extracting information from the datasets and representing the visual patterns.

Through knowledge discovery and EDA, previously unknown knowledge and insights into the characteristics and performance of highway bridges have been investigated and presented in the following sections.

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Finally, sincere appreciation is given to Federal Highway Administration for providing the database, National Bridge Inventory.

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CHAPTER 1 INTRODUCTION

1.1 Background Information

With rapid advancements in information technology and data digitalization, we are becoming more aware of the value of data collection and analysis. At the same time, the datasets can be very large and may be continuously growing due to data updates or additional data collections, making them impossible to interpret and analyze manually. A large database, such as the National Bridge Inventory, provides an abundance of data that is valueless in its raw form but when analyzed and interpreted transforms into useful information. Due to the size and complexity of the NBI data set, however, little analytical research has been conducted until now.

Traditional statistical methods cannot be readily applied on databases the magnitude of NBI because the number of possible statistical, geographical and temporal hypotheses is too large to explore practically. For analyzing the NBI, although traditional approaches can be applied on small subsets of data, some important and insightful knowledge about our nation's bridges is lost due to the aforementioned limitations.

People generally assume that the large steel, concrete or prestressed concrete bridges they rely on daily are structurally sound. However, much of the uncertainty in bridge deterioration, condition and other related design problems could have been uncovered through more extensive data analysis. One tragic example is the Silver Bridge, which spanned the Ohio River from Ohio to West Virginia, collapsed on December 15, 1967, during the rush hours. It caused forty-six deaths and nine injuries. Due to this tragedy and the outcry that followed, the National Bridge Inspection Standards (NBIS) were created by the United States Department of Transportation to inspect all Federal-Aid Highway system bridges every two years, and subsequently the National Bridge Inventory was formed to store the data of the NBIS.

Although risks of similar tragedy seem minimal today, the public is still largely unaware of the conditions of the bridges they cross every day. Decision makers responsible for selecting bridges eligible for maintenance, rehabilitation or replacement still lack avenues to better understand factors related to the performance and the deterioration of bridges. Thus, identifying and applying new and effective techniques to transform data in the NBI into useful knowledge will be the focus of this research.

1.2 Research Methodology

1.2.1 Exploratory Data Analysis

Exploratory data analysis (EDA), as opposed to confirmatory data analysis (CDA), was first introduced by John Tukey in 1977 [3]. Since then it has been widely used in a variety of academic research areas such as biomedical related fields [4]. According to Tukey's idea, EDA is an approach to detective work. In EDA, the role of the researcher is to explore the data in as many ways as possible until a plausible "story" of the data emerges [3].

The primary significance of EDA is that it benefits analysts today by providing them with better tools towards the understanding of their data. In other words, users are given more chances to identify and discover patterns, relationships and trends hidden inside the data. Such advantages are utilized in the knowledge discovery process of this research.

Exploratory data analysis is different from traditional statistical and graphical methods in that it is an approach designed to more directly interact with data while revealing its underlying structure and model. It involves various techniques such as extracting important variables and detecting outliers and anomalies. Although, in certain cases, EDA may largely employ traditional collection techniques, the concept and theory of EDA are still different from the traditional statistical methods.

Exploratory data analysis techniques typically can be classified as two types of methodologies in terms of variables. One is the basic statistical exploratory methodology, and the other is multivariate exploratory methodology. The basic statistical exploratory method covers some techniques that can be used to review and examine statistical analysis. The multivariable exploratory methodology, on the other hand, is a specific approach used for discovering patterns among multivariate datasets. Currently, the techniques of EDA are mostly based on data visualization, which uses graphical presentation techniques to prompt the recognition of important traits and relationships among data [5]. For example, when dealing with spatial related data, visualization tools such as maps are typically used as they are highly capable of representing and conveying significant spatial relationships to human eyes [6].

Generally speaking, the data visualization concept is classified in six major categories in term of research goals [7]. These categories are:

1. Spotting outlier
2. Discriminating clusters
3. Checking distribution and other assumptions
4. Examining relationships
5. Comparing mean differences
6. Observing a time-based process

In this study, the above concepts would be largely utilized in numerous stages.

1. 2.2 Tools

Based on the concept of exploratory data analysis, tools used to analyze and extract information from large sets of data can all be generally classified as " EDA tools". This research project utilizes ArcGIS, a geographic information system (GIS) produced by ESRI, and Matlab to extract the information, datasets and represent the potential pattern in the NBI through knowledge discovery process.

At various stages of data preparation, Open Office, Microsoft Excel™ or Microsoft Access™ were utilized to ensure that extracted data sets are able to be linked with the geographical data and maps available in the GIS database. In addition, Microsoft Excel™

and GIS were utilized to represent tables, figures, charts, and maps in the following sections.

1.3 National Bridge Inventory

National Bridge Inventory is a database compiled by the Federal Highway Administration every year. It is composed of information of United States bridges or culverts that carry traffic and are longer than 20 feet. For the 2008 edition of the NBI, there are 717,902 records, and 591,605 of which are qualified for highway bridges based on the criterion of type of service on bridge and the National Bridge Inspection Standards (NBIS) bridge length.

Each NBI bridge record contains 116 item attributes [10]. The large number of attributes makes exploratory data analysis a more appealing method for data analysis than traditional statistical analysis. Some of the characteristics used to describe bridges include age, location, materials and deck width. Other parts indicates operational conditions including year build, type of services provided, rehabilitation year, average daily traffic, as well as information regarding to bypass and detours. The rest are conditions and appraisal ratings assigned by inspectors for each bridge in the database.

According to the NBIS, condition ratings are used to describe the current condition of bridges or culverts. It assesses the physical condition of deck, superstructure and substructure. The ratings range from 0-for a failed condition - to 9 - for an excellent condition. The appraisal ratings, however, reveal serviceability and safety of the structure.

The evaluation includes field condition, waterway adequacy, geometric and safety configurations, structural evaluation as well as safe load capacity of the bridge.

These conditions and appraisal ratings can be used for the classification of a bridge as "functionally obsolete" or "structurally deficient." If a bridge is classified as structurally deficient with the condition ratings lower than 5, it implies the bridge may need further analysis and even require maintenance, rehabilitation or replacement. However, if a bridge is classified as functionally obsolete, it reveals only that the inadequacy of the bridge's performance with respect to the transportation system.

While a lot of research has been conducted on knowledge discovery process in other relational databases, very few works deal with knowledge discovery in the National Bridge Inventory - which is why the technique, exploratory data analysis, will be utilized in this research to discover previously hidden and unknown patterns among the variables within the NBI database.

CHAPTER 2 SUMMARIZATION OF NATIONAL BRIDGE INVENTORY (NBI)

To test the notion that useful conclusions can be drawn by exploring patterns within subsets of the data, this research project first focuses on isolating and extracting key bridge attributes and summarizing them through different ways that generate insight. These attributes include bridge location (which may attribute to environmental effects and/or implications), average daily traffic (ADT), structure length, deck width, structure type, owners, maintenance responsibility, bridge design, scour and fracture critical bridges.

In order to extract the data via queries, Matlab was used. As with many other programming languages, Matlab has the ability to read and extract the information directly from large data sets stored in text files. The extraction process involves extracting small data sets from larger sets by predetermined criteria and then uploading them in the form of spreadsheet. The processed queries, extracted information and discussion of results are shown in the proceeding sections. Particularly, since there are too many queries used to generate the dataset, an example of the MATLAB queries will be included in an appendix so that future researchers can be benefitted from it.

2.1 Record Summary by ADT, Deck Area and Number

The following table (Table 1) summarizes some of the information in the NBI, specifically the number of valid highway bridges, the total deck area of those bridges and the daily traffic carried by the bridges at state level. It is extracted by Matlab queries as mentioned and the key attributes used as the base of criteria include ADT (average daily traffic), state code, deck width, and structure length.

Table 1 is intended to provide a high level overview to better understand how many highway bridges exist in the states, how much area these bridges occupy (a statistic directly related to the cost to replace or repair a bridge) , and how many vehicles use these bridges each day. With such information, comparisons can be made between states.

Such information may be relevant in terms of allocating national funds and competing for resources across different states. In addition, the scope of how large the database is and how difficult it is for analyst to discover knowledge and unknown patterns can be observed. Understandably, due to such large size, analysts have experienced difficulty in discovering and providing new information to the public. After this overview, these bridges are analyzed in more detail in different directions and the results are provided in the following sections and chapters.

States Code	**States**	**# of Valid Highway Bridges**	**Total Deck Area (Square meters)**	**Total Average Daily Traffic**
14	Alabama	15,598	8,691,049	70,385,217
20	Alaska	1,211	476,137.10	2,395,950
49	Arizona	7,038	3,709,236.00	13,600,934
56	Arkansan	12,378	5,815,422.00	107,855,289
69	California	24,275	26,865,722.00	607,849,223
88	Colorado	7,861	3,670,463.00	54,912,018
91	Connecticut	4,127	3,137,928.00	76,425,237
103	Delaware	804	840,519.20	10,577,639
113	District of Columbia	236	509,587.40	8,389,228
124	Florida	11,356	14,428,496.00	192,354,198
134	Georgia	14,608	8,613,321.00	14,213,228
159	Hawaii	1,114	1,169,906.00	24,966,681
160	Idaho	3,951	1,388,197.00	11,281,744
175	Illinois	25,115	10,622,047.00	103,353,644
185	Indiana	18,512	7,141,552.00	89,431,019
197	Iowa	24,322	7,250,873.00	29,053,118
207	Kansas	25,517	7,833,038.00	44,137,252
214	Kentucky	13,632	5,418,987.00	84,228,951
226	Louisiana	13,045	14,191,420.00	67,133,622
231	Maine	2,387	1,190,310.40	9,847,459
243	Maryland	5,163	4,696,161.50	90,021,281
251	Massachusetts	5,037	3,952,937.93	119,332,733
265	Michigan	10,879	5,998,932.26	89,271,870
275	Minnesota	13,132	6,049,870.92	52,692,496
284	Mississippi	17,026	8,074,855.33	43,939,698
297	Missouri	24,134	9,777,329.55	86,774,611
308	Montana	4,641	1,652,361.41	8,078,389
317	Nebraska	15,240	3,441,490.42	18,168,742
329	Nevada	1,734	1,291,025.54	27,937,770
331	New Hampshire	2,375	133,690.41	17,619,356
342	New Jersey	6,353	6,345,161.08	147,723,657
356	New Mexico	3,858	1,579,211.91	28,363,619

362	New York	17,344	12,535,359.01	177,520,334
374	North Carolina	16,772	6,727,478.50	88,861,752
388	North Dakota	4,281	1,004,867.59	2,912,681
395	Ohio	27,661	12,239,041.92	167,256,334
406	Oklahoma	23,578	8,020,970.80	66,445,981
410	Oregon	7,187	4,392,318.82	39,378,103
423	Pennsylvania	22,042	11,792,331.24	160,504,731
441	Rhode Island	739	713,369.68	15,039,692
454	South Carolina	8,991	6,005,480.30	40,800,138
468	South Dakota	5,916	1,678,935.02	7,084,269
474	Tennessee	19,865	8,969,530.67	147,010,884
486	Texas	48,887	33,999,278.21	451,839,849
498	Utah	2,517	1,314,214.07	23,428,871
501	Vermont	2,717	832,528.64	6,439,743
513	Virginia	13,087	8,251,238.94	108,972,091
530	Washington	7,637	6,622,086.49	66,376,293
543	West Virginia	7,041	3,278,377.73	24,398,396
555	Wisconsin	13,796	6,039,666.59	75,139,302
568	Wyoming	2,717	1,037,880.43	5,783,786
721	Puerto Rico	2,171	1,943,311.05	37,985,025

Table 1 Bridge Record Distribution by State

2.2 Record Summary by Owner/Maintenance Responsibility

Ownership is coded as Item 22 in the National Bridge Inventory. There are 29 different codes, and each code represents state, county, town and city highway agencies, federal agencies, other public agencies, toll authorities, and private owners. If more than one agency has equal ownership of the bridge, then the record would be coded through the hierarchy of state, federal, county, city, railroad, and other private agency.

Table 2 indicates the ownership summary of highway bridges in the United Sates in 2008. The percentages shown are equally weighted by count of valid highway bridges, ADT and deck area. The summary shows that more than 90% of the bridges are owned by state, county or local highway agencies. Specifically, state highway agencies own the majority of the bridges that carry more than 80 % of the daily traffic and constitute approximately 70 % of the total deck area. On the other hand, local agency such as local toll authority and town highway agency own less than 5% of the highway bridges, and carry less than 1 % of daily traffic in the United States.

Owners	**# of Valid Highway Bridges**	**Total Decks Area (Square meters)**	**Total Average Daily Traffic**	**% By Deck area**	**% By ADT**	**% By number**
State Highway Agency	269,781	231,068,859.70	3,497,620,928	70.34	80.44	45.60
County Highway Agency	229,207	44,718,085.00	317,252,567	13.61	7.30	38.74
Town or Township Highway Agency	29,535	8,570,545.27	17,339,274	2.61	0.40	4.99
City or Municipal Highway Agency	41,431	23,088,777.00	281,304,209	7.03	6.47	7.00
State Park, Forest, or Reservation Agency	1,009	190,218.40	1,852,328	0.06	0.04	0.17
Local Park, Forest, or \Reservation Agency	76	13,135.74	303,377	0.00	0.01	0.01
Other State Agencies	1,042	885,800.10	8,512,092	0.27	0.20	0.18
Other Local Agencies	1,261	1,468,649.00	4,116,350	0.45	0.09	0.21
Private (other than railroad)	492	584,990.10	3,027,660	0.18	0.07	0.08
Railroad	905	395,888.50	3,295,538	0.12	0.08	0.15
State Toll Authority	7,155	11,303,959.00	189,889,183	3.44	4.37	1.21
Local Toll Authority	640	3,430,855.00	14,773,483	1.04	0.34	0.11
Federal Agencies	9,061	2,804,015.99	9,080,705	0.85	0.21	1.53
Total	591,595	328,523,778.80	4,348,367,694			

Table 2 Distribution of US Highway Bridges by Ownership

Maintenance Responsibility is coded as Item 21 in the National Bridge Inventory. The codes used in this item are the same as those used in Item 22. Each code represents the type of agency that has the primary responsibility for maintaining highway bridges such as state, county, federal agencies and private owners. If more than one agency has equal maintenance responsibility, then it is coded through the hierarchy of state, federal, county, city, railroad, and other private agency.

Understanding the ownership and maintenance responsibilities of the nation's bridges provides a huge advantage when government authorities implement strategies for national defense or carry out rehabilitation efforts during state of national emergency such as terrorist attack or natural disasters. Funding and resources can be allocated more directly and effectively. Furthermore, understanding ownership and maintenance responsibilities of the nation's bridges is vitally important and essential in transportation planning and the coordination of the environmental and transportation planning issues as they are often the primary concern for local or state governments.

The following table and figures (Table 3 and Figure 1, 2, 3) summarize the agencies that are primarily responsible for the maintenance of the structures. The percentages shown in the table 3 and figure1, 2, 3 are equally weighted by count of valid highway bridges, ADT and Deck Area.

Evidently, state and county highway agencies are responsible for maintaining almost 80% of the bridges, bridges that carry 90% of daily traffic in the United State. On the other hand, private and other local agencies have little responsibility for maintaining highway bridges in the United States.

Maintenance Responsibility	# of Valid Highway Bridges	Total Deck Area (m2)	Total Average Daily Traffic	% number	% Deck Area	% ADT
State Highway Agency	270,132	231,485,486.8	3,455,988,707	45.66	72.65	75.12
County Highway Agency	229,594	39,245,541.40	611,841,011	38.81	12.32	13.3
Town or Township Highway Agency	29,297	4,263,641.96	17,533,806	4.95	1.34	0.38
City or Municipal Highway Agency	41,571	23,083,005.19	281,818,760	7.03	7.24	6.13
State Park, Forest, or Reservation Agency	878	136,877.35	386,739	0.15	0.04	0.01
Local Park, Forest, or Reservation Agency	73	16,857.86	169,877	0.01	0.01	0.004
Other State Agencies	863	820,020.62	7,581,988	0.15	0.26	0.17
Other Local Agencies	1,398	1,507,551.80	4,363,376	0.24	0.47	0.09
Private (other than railroad)	780	1,002,345.70	12,751,699	0.13	0.31	0.28
Railroad	763	318,211.95	2,847,858	0.12	0.1	0.06
State Toll Authority	6,966	10,749,313.40	181,314,196	1.18	3.37	3.94
Local Toll Authority	714	3,397,002.40	15,850,775	0.12	1.07	0.34
Federal Agencies	8546	2,592,254.13	7,891,087	1.455	0.792	0.161
Total	591,595	328,523,778.8	4,348,367,694	100	100	100

Table 3 Breakdown of Agencies Responsible for the Maintenance of U. S. Highway Bridges

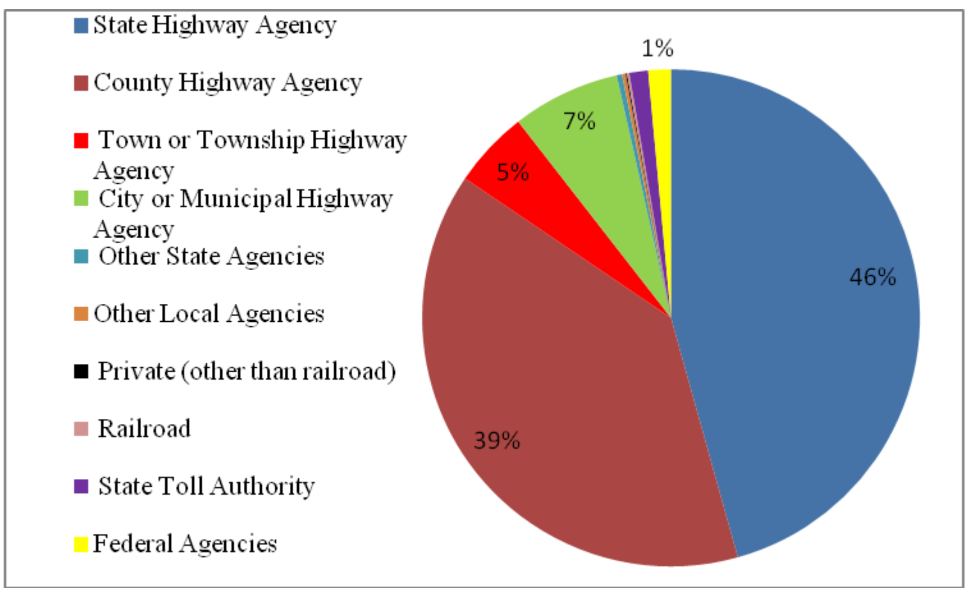

Figure 1 Distribution of Agencies Responsible for the Maintenance of Highway Bridges by Number

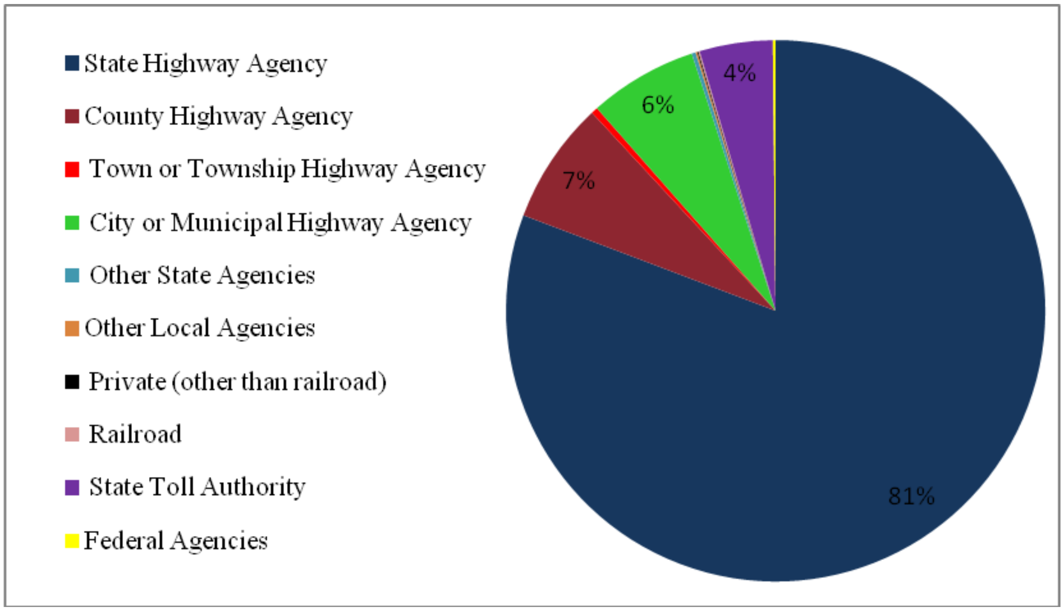

Figure 2 Distributions of Agencies Responsible for the Maintenance of Highway Bridges by ADT

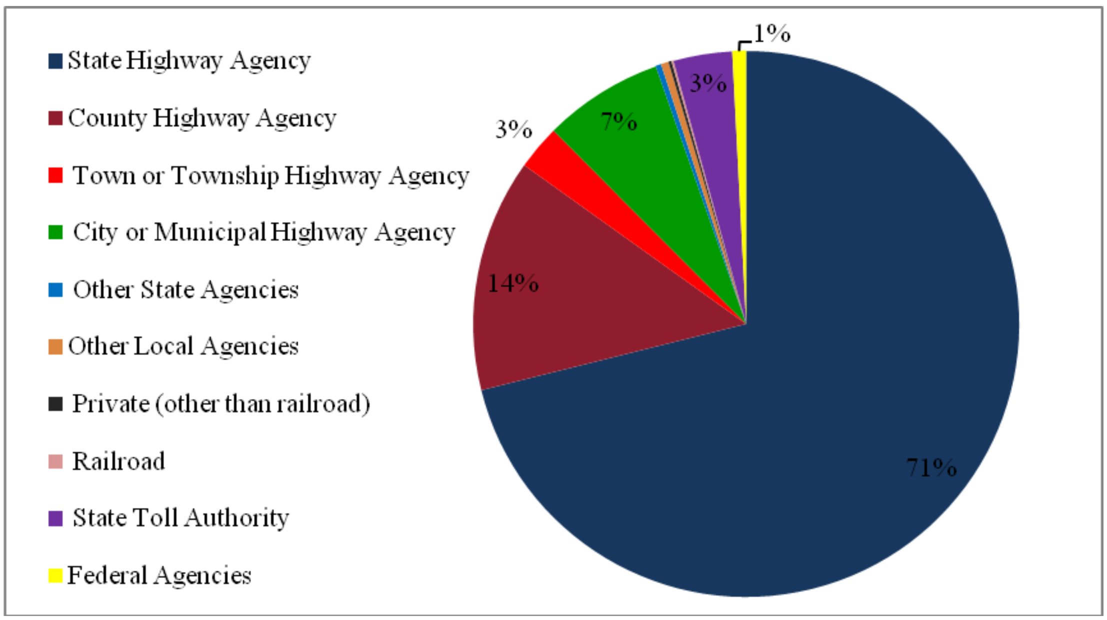

Figure 3 Distributions of Agencies Responsible for the Maintenance of Highway Bridges by Deck Area

2.3 Record Summaries by Type of Design

A bridge, defined as a structure constructed to span a valley, body of water or other physical obstacle, is used to provide passage for people and vehicles over obstacles. Since the 1st century A.D., people have understood the importance of these structures in daily life and started constructing bridges with various materials and in increasingly varying styles. Nowadays, with rapid advancements in engineering and applied sciences, more and more bridges have been proven to be safe and logical to use. However, until recently, news of bridges collapsing or failing had not ceased. Many questions remain. Are the types of design being implemented truly safe? How do these designs evolve over time? Are there geographical patterns or relationships among these types of design? Exploratory data analysis techniques will help identify and discover new knowledge and bring us closer to answers to these questions. In this chapter, all of highway bridges are first summarized in terms of materials and structure type, and then in the following chapter, further analysis will be introduced and performed.

Main Structure type is coded and recorded in the Item 43 of National Bridge Inventory. It is composed of two segments with a 3-digit number. The first digit describes predominant structural material used for the main spans of the highway bridges. There are 10 different codes for this digit, ranging from 0 to 9, and each of them depicts a different structural material such as steel or timber used for the main spans. Comprising of 23 different codes, the second and third digits indicate the predominant types of structure or design of the main spans.

2.3.1 Record Summary by Structural Material

A query was done to extract number of highway bridges based on predetermined criteria: bridges constructed as highway bridges, NBIS bridge length, and types of structural material. The result is shown in the following charts.

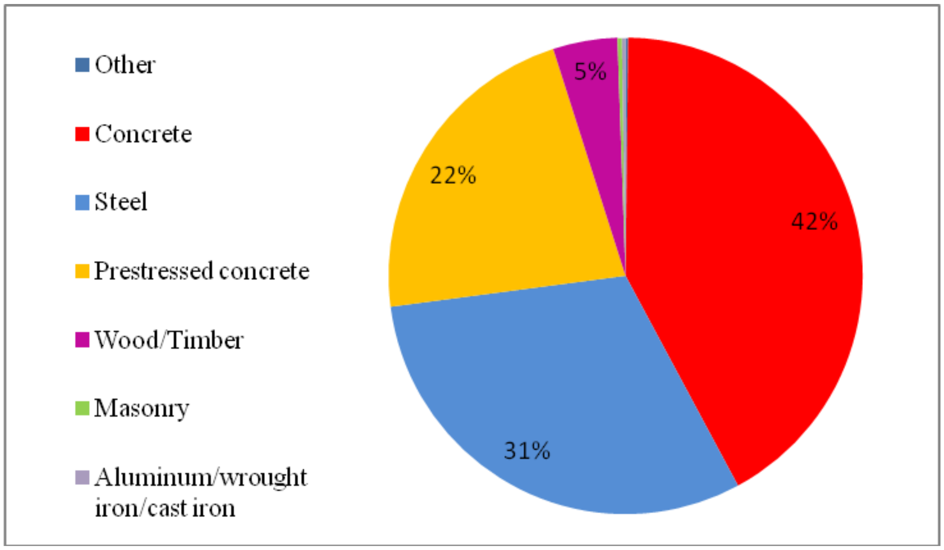

Figure 4 Distribution of Materials Used for Main Spans of US Highway Bridges by Number

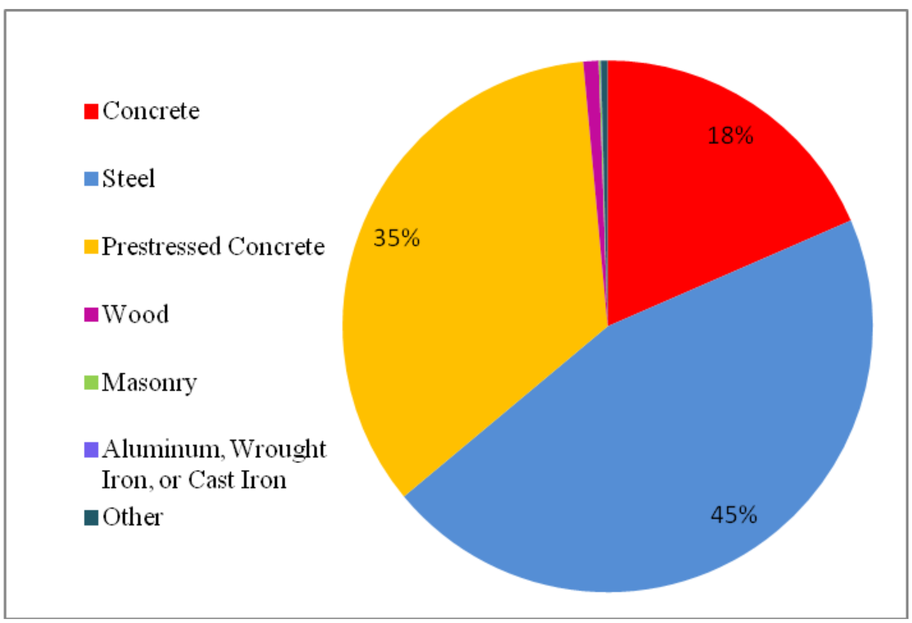

Figure 5 Distribution of Materials Used for Main Spans of US Highway Bridges, by Deck Area

Figure 4 and 5 depict the percentage of predominant structural materials used for the main spans of highway bridges in the United States. They are equally weighted by the number of the highway bridges and the ADT, respectively. The materials utilized include reinforced concrete, steel, prestressed concrete, timber, masonry and other materials (iron, aluminum, etc.). Reinforced concrete, which comprises 42 % of all of structural materials, is the most prevalent structural material used for main spans of highway bridges. The second and third most common structural materials are steel and prestressed concrete, which enjoy 31 % and 22% of the share respectively. From these figures, it can be inferred that timber, masonry and other materials tend to be utilized for smaller spans of bridges carrying low volume of traffic, which intuitively makes sense. Reinforced concrete, steel and prestressed concrete designs, on the other hand, are commonly utilized for larger spans of highway bridges carrying higher volume of traffic.

A sub query was done to classify the extracted data set by states and to count the number of bridges in each material category, and the result is shown in the table and the chart in the following.

State	Other	Conc.	Conc. Cont'	Steel	Steel Cont'	P.C.	P.C. Cont.	Timber	Masonry	Al/ iron
Alabama	21	9193	1187	1966	928	1079	432	932	165	6
Alaska	0	24	7	417	61	311	1	124	0	2
Arizona	0	522	4476	418	347	862	735	37	2	3

Arkansas	4	6968	208	3498	124	106	36	429	15	29
California	21	6344	9159	2462	346	2772	2543	708	38	4
Colorado	4	2088	472	2316	737	1492	716	432	30	73
Conn.	2	731	255	1826	442	785	37	42	50	4
Delaware	2	182	17	304	136	140	28	23	2	23
D. C.	0	39	25	119	34	16	1	0	1	0
Florida	1	3413	644	825	483	5556	214	491	0	25
Georgia	2	8174	111	2940	1146	1864	107	160	5	4
Hawaii	3	304	363	112	2	217	75	31	4	2
Idaho	1	1100	127	651	152	1581	61	471	0	5
Illinois	18	6857	1853	2956	4193	9756	296	110	9	26
Indiana	0	2973	2535	3202	2133	5062	1577	765	52	239
Iowa	0	3055	5759	6812	2021	3983	477	2664	11	13
Kansas	12	4257	10451	5444	2725	498	679	1242	183	13
Kentucky	7	5070	682	1794	680	4245	979	116	28	21
Louisiana	5	7839	136	1529	217	1146	251	2199	0	0
Maine	6	715	28	928	494	115	18	35	12	40
Maryland	9	1282	139	2219	929	294	39	183	41	32
Mass.	6	679	194	2542	464	844	69	65	154	23
Michigan	5	1333	313	4470	467	3684	43	591	4	31
Minnesota	0	5251	583	1537	1297	2862	4	1558	16	3
Mississippi	0	8967	452	1688	274	3386	992	1243	3	23
Missouri	3	3126	5243	9191	2912	1422	1993	186	15	30
Montana	0	279	263	950	312	1849	7	1307	0	6
Nebraska	0	3739	1290	6962	628	1363	70	1409	2	5
Nevada	1	844	262	129	100	195	158	23	0	1
New Hampshire	0	557	73	1033	398	146	2	120	32	9
New Jersey	10	1027	124	3208	359	1342	41	260	70	28
New Mexico	0	256	1794	337	246	728	273	210	1	22
New York	22	2552	610	9690	1289	2385	130	440	118	124
North Carolina	0	1100	2656	8055	1153	3882	110	794	0	140
North Dakota	1	1204	152	1128	218	743	478	523	0	0
Ohio	21	4823	2609	7220	5971	6422	626	122	95	121
Oklahoma	1	8902	923	7743	1004	3641	73	1281	15	6
Oregon	5	629	1512	903	194	3110	269	673	0	5
Pennsylvania	22	5815	1011	5866	1570	6881	482	218	349	88
Rhode Island	1	159	23	325	68	125	6	15	18	1
South Carolina	2	5167	511	978	383	1869	201	100	4	8
South Dakota	0	527	2280	1343	394	864	177	314	14	3
Tennessee	1	3444	8685	1836	968	2174	2478	261	11	5
Texas	327	26945	1868	4180	3365	12265	240	1186	142	70
Utah	2	612	322	544	297	819	159	90	2	7
Vermont	405	62135	24956	50148	17120	45908	5702	6227	769	600
Virginia	5	4623	291	5854	1253	1163	122	62	8	42
Washington	4	1417	1638	752	194	2227	845	560	0	14
West Virginia	3	1246	277	1867	1468	1948	89	88	11	38
Wisconsin	15	2948	2701	2511	1404	2150	1469	578	23	30
Wyoming	0	254	1010	539	796	216	15	199	0	6
Puerto Rico	0	676	345	303	31	798	9	0	5	4

Table 4 Number of Highway Bridges by Main Span Materials at State Level

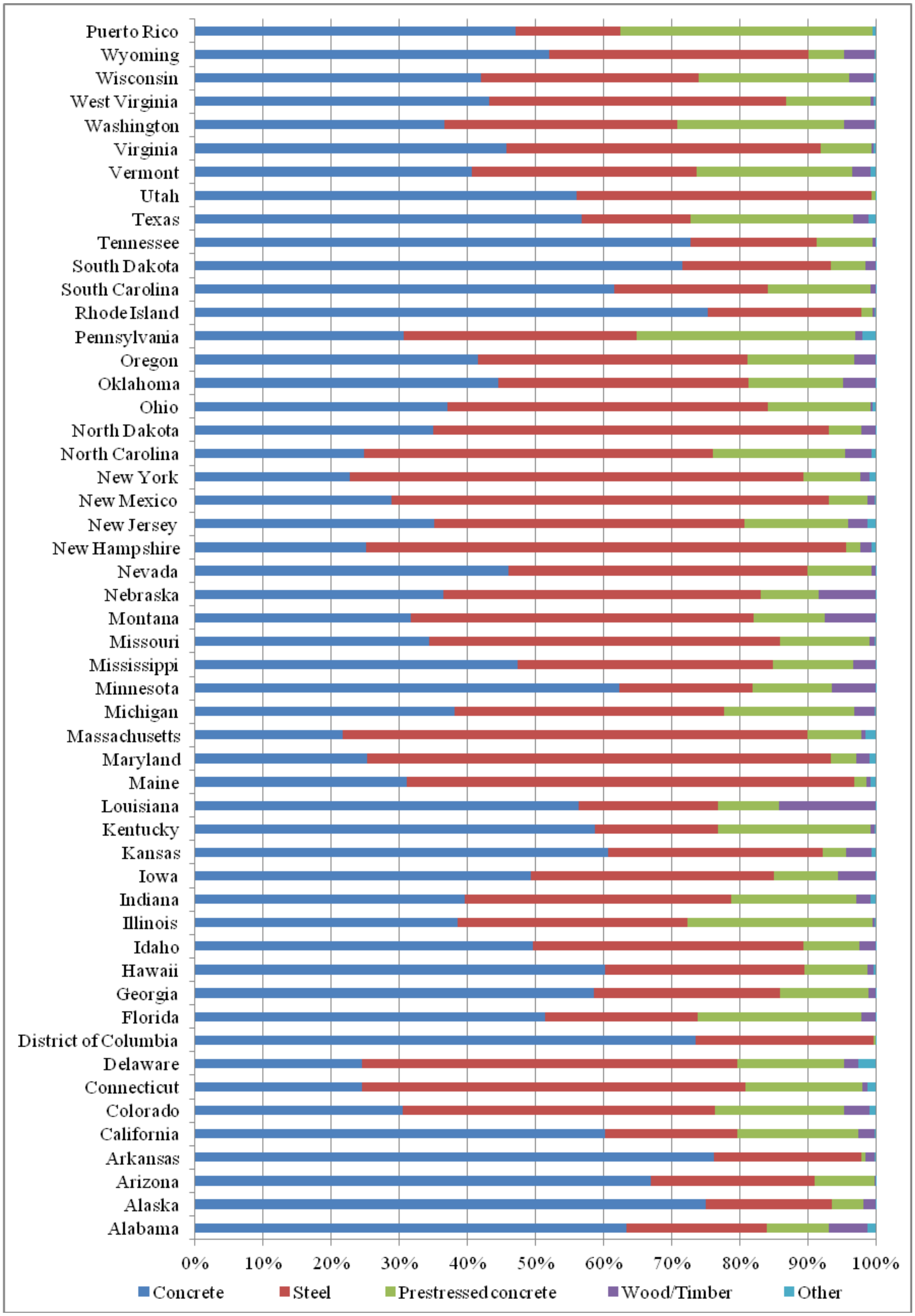

Figure 6 Distribution of Highway Bridge by Material at State Level

The results show that concrete is the most prevalent structural material choice among most states. Likewise, steel and prestressed concrete designs remain the same pattern as that shown previously. Compared to them, wood and other bridges only account for few percentages of highway bridges. Thus, it may be inferred that there exists no geographic criteria in the choice of structural materials used for the main spans of highway bridges in the United States.

2.3.2 Record Summary by Bridge Type

For examining the structure type of the bridge main spans, a similar query was done. The results are shown in the following charts.

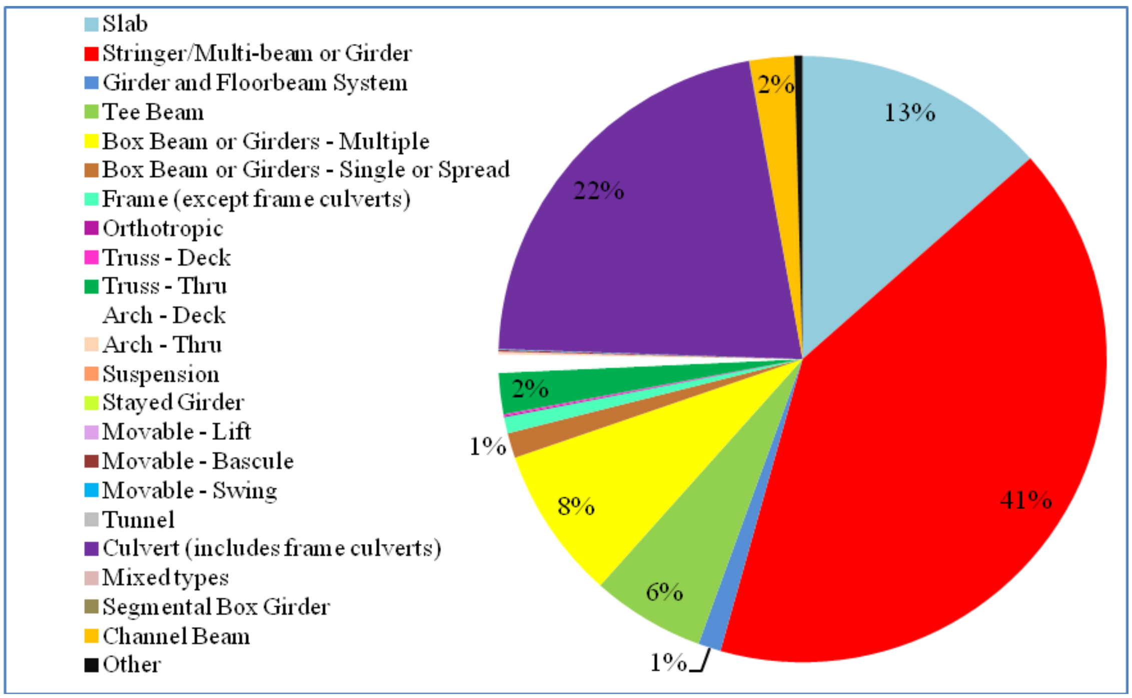

Figure 7 Distribution of Structure Types used for Main Spans of U.S. Highway Bridges, by number

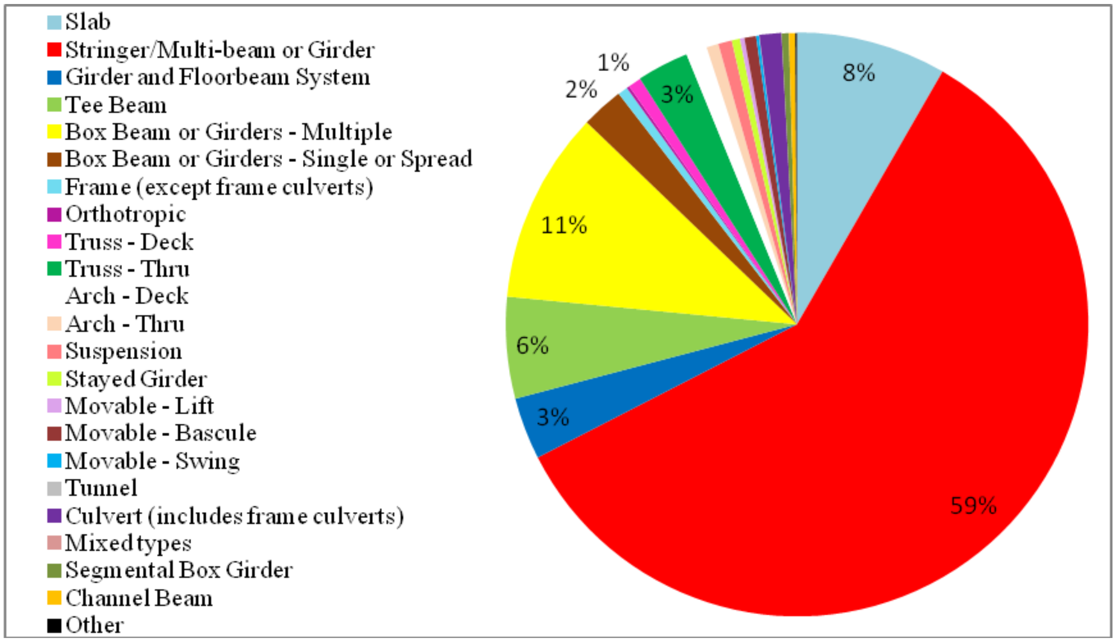

Figure 8 Distributions of Structure Types Used for Main Spans of U.S. Highway Bridges, by Deck Area

Figure 7 and 8 illustrate the distributions of structure types used for the main spans of U.S. highway bridges by number and ADT, respectively. They both show that stringer/multi-beam or girder structural designs make up almost half of existing highway bridges in the United States, and these bridges are mostly larger ones accounting for around 60% of total deck area in the United States. Other types of structure such as slab and truss make up less than 20% of the remaining share of bridges in terms of deck area and overall quantity. Although there are various new types of structure introduced, stringer/multi-beam or girder structure are still the predominant types of structure for national highway bridge.

This summary provides a better understanding of which types of structure are prevalent within national highway bridges and how these structural types compare with others in terms of popularity. Also, it serves as a base for further analysis such as temporal pattern discovery.

To further understand the prevalent combinations of material and structure type for national highway bridges, the query was then cross-classified by the combination of material and structure type. The results are listed in the following tables.

Structure Type	**Other**	**Conc.**	**Concrete Con't**	**Steel**	**Steel Con't**	**P.C**	**PC Con't**	**Timber**	**Masonry**	**Al/ Iron**
Slab	15	34011	30932	115	25	10569	322	3744	21	2
Stringer/Multi-beam or Girder	28	9976	2964	103205	63400	61525	12963	21223	3	22
Girder and Floor beam System	4	868	257	4449	1344	136	19	86	0	6
Tee Beam	3	21375	5809	12	71	7571	854	30	6	0
Box Beam/ Girders - Multiple	9	1682	4379	188	254	37890	3723	37	0	1
Box Beam/ Girders - Single or Spread	0	223	874	104	195	4155	2290	4	0	0
Frame	0	3846	816	111	147	71	7	114	0	1
Orthotropic	0	1	0	424	34	3	0	1	0	2
Truss - Deck	0	3	4	367	125	0	0	11	0	3
Truss - Thru	1	9	11	10788	268	0	0	381	0	235
Arch - Deck	17	4991	231	419	11	35	1	8	1236	59
Arch - Thru	2	137	11	166	26	4	0	33	6	0
Suspension	1	0	0	68	23	0	0	4	0	1
Stayed Girder	0	2	6	7	13	5	6	0	0	0
Movable - Lift	0	0	0	176	1	0	0	0	0	0
Movable - Bascule	0	0	0	456	3	0	0	1	0	0
Movable - Swing	1	0	0	198	17	1	1	0	0	0

Tunnel	4	51	7	6	0	0	0	0	3	0
Culvert	109	80629	31136	14124	79	173	2	127	498	1121
Mixed types	2	7	1	12	0	2	1	2	0	0
Segmental Box Girder	0	8	6	1	7	7	143	0	0	0
Channel Beam	1	12356	37	3	1	1584	10	1	0	0
Other	333	658	41	848	85	440	17	132	5	11

Table 5 Number of Bridges by Combination of Main Span Materials and Structure Type

Rank		**Count**	**% of total**	**Cumulative Percentage**
1	Steel Stringer	103205	17%	17%
2	Concrete Culvert (includes frame culverts)	80629	14%	31%
3	Prestressed Concrete Stringer	48180	8%	39%
4	Steel Continuous Stringer	43314	7%	47%
5	Prestressed Concrete Multiple Box Beam/Girder	37890	6%	53%
6	Concrete slab	34011	6%	59%
7	Concrete Continuous Culvert (includes frame culverts)	31136	5%	64%
8	Concrete Continuous slab	30932	5%	69%
9	Concrete Tee Beam	21375	4%	73%
10	Timber Stringer	21223	4%	76%
11	Steel culvert	14124	2%	79%
12	Concrete Continuous slab	12963	2%	81%
13	Concrete Channel Beam	12356	2%	83%
14	Steel Truss- Thru	10788	2%	85%
15	Prestressed Concrete Slab	10569	2%	87%
16	Concrete Stringer	9976	2%	88%
17	Prestressed Concrete Tee Beam	7571	1%	90%
18	Concrete Continuous Tee beam	5809	1%	91%
19	Concrete Arch-Deck	4991	1%	91%
20	Steel Girder and Floor beam System	4449	1%	92%
21	Concrete Continuous Multiple Box Beam/Girder	4379	1%	93%
22	Prestressed Concrete Spread Box Beam	4155	1%	94%
23	Concrete Frame (except frame culverts)	3846	1%	94%
24	Timber Slab	3744	1%	95%
25	Concrete Continuous Multiple Box Beam/Girder	3723	1%	96%
26	Concrete continuous Stringer	2964	1%	96%
27	Prestressed Concrete Continuous Spread Box	2290	0%	96%

28	Concrete Multiple box beam/girder	1682	0%	97%
29	Prestressed Concrete Channel Beam	1584	0%	97%
30	Steel Continuous Girder and Floor beam System	1344	0%	97%
31	Masonry Arch-Deck	1236	0%	97%
32	Aluminum/ wrought iron/cast iron Culvert (includes	1121	0%	98%
33	Concrete Continuous Spread Box Beam/Girder	874	0%	98%
34	Concrete Girder and Floor beam System	868	0%	98%
35	Concrete Continuous Tee beam	854	0%	98%
36	Other Steel Structural Bridge	848	0%	98%
37	Concrete continuous Frame (except frame culverts)	816	0%	98%
38	Other Concrete Structural Bridge	658	0%	98%
39	Masonry Culvert (includes frame culverts)	498	0%	99%
40	Steel Movable bascule bridge	456	0%	99%
41	Other Prestressed concrete bridge	440	0%	99%
42	Steel Orthotropic Bridge	424	0%	99%
43	Steel Arch-Deck	419	0%	99%
44	Timber Truss-Thru	381	0%	99%
45	Steel Truss - Deck	367	0%	99%
46	Other Material Structural Bridge	333	0%	99%
47	Prestressed concrete continuous Slab	322	0%	99%
48	Steel Continuous Truss-Thru	268	0%	99%
49	Concrete Continuous Girder and Floor beam System	257	0%	99%
50	Steel Continuous Multiple Box Beam/Girder	254	0%	100%
Total		586896		

Table 6 Rank of Highway Bridges by Material and Structure Type

Table 6 above shows 230 combinations of materials and structure type used for national highway bridges. Though there are numerous types of designs available for highway bridges, less than 10 types of design are commonly used for highway bridges in United States. Table 6 ranks various types of existing highway bridges by their share. Apparently, Steel Stringer, Concrete Culvert, Prestressed Concrete Stringer and Steel Continuous Stringer are the top four bridge material and structure combinations. They are followed by Steel Continuous Stringer, Prestressed Concrete Multiple Box Beam/Girder and Concrete slab. On the other hand, certain type of bridges such as Concrete Continuous Girder and Floor beam System and Steel Continuous Multiple Box Beam/Girder are far more seldom used for highway bridges. They rank 49th and 50th, respectively. Overall, stringer, multi-beam, girder and slab, account for more than half of national highway bridges in the United States. These structure types are most frequently implemented in steel and prestressed concrete.

The results seem reasonable. Although there are numerous structure types available, girder and slab, in terms of application, materials, cost, loading, durability and geographic features as well as requirements, seem to be the most practical options for designing highway bridges around the world, not just in the United States. In addition, these results serve as basis of further analysis for deficiency and possible bridge failures. For example, fracture critical bridges are typically associated with steel superstructures carrying tension members, so the number of fracture critical bridges should be smaller than that of steel superstructures.

2. 4 Record Summary of Scour Critical Bridges

Scour, defined as "*the erosion or removal of streambed or bank material form bridge foundations due to flowing water*" is the most prevalent factor of highway bridge failures in the United States [13]. According to the statistics compiled by the Structures Division of the New York State Department of Transportation, 58% of more than 1,502 documented bridge failures since 1966 have been result of hydraulic conditions. In response to several notable bridge failures, the Federal Highway Administration (FHWA) revised and included scour condition evaluation in the National Bridge Inspection Standards (NBIS). Thus, all the bridges over water need to be evaluated for their vulnerability to scour.

Scour Critical Bridge is coded as Item 113 in the National Bridge Inventory. Thirteen different codes are used to describe the status of bridges for its susceptibility to scour. For example, if the bridge is identified as scour critical bridge and required to be closed for the traffic, it is coded as 0 in the database.

The following graph indicates the percentage of highway bridges that are identified as scour critical in the United States. According to the coding code provided by FHWA, once the code is 4 or below, it would be identified and counted as a scour critical bridge.

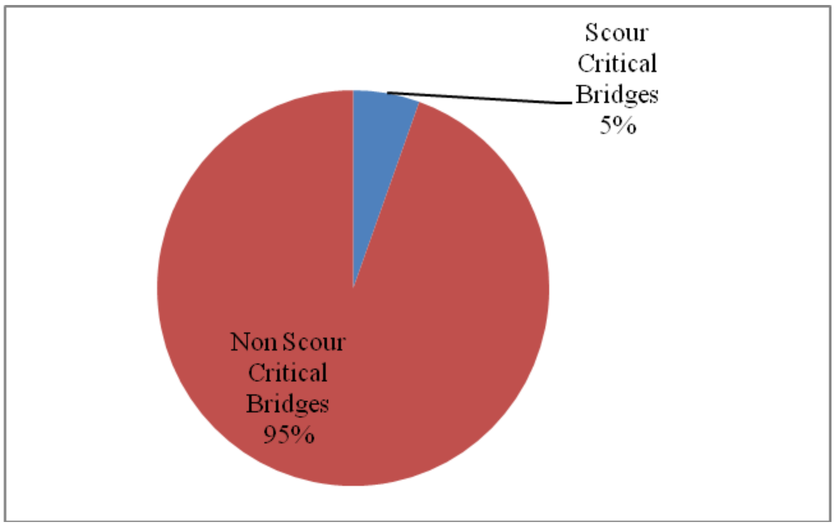

Figure 9 Percentages of Highway Bridges Identified as Scour Critical Bridge in the U.S.

The pie chart above shows that approximately 5% of 591,605 highway bridges in the United States are identified as scour critical. The percentage may seem small; however it means that more than 30,000 bridges people daily rely on are vulnerable to bridge failure.

In order to understand which states are most prone to a significant scour critical problem, the query then cross-classified the scour critical bridges by states and divided them by the total number of bridges in each state. The result is shown as table in the following.

Rank	States	# of Scour Critical Bridges	# of Highway Bridges	% of SC bridges in each States
1	Pennsylvania	6454	22042	29%
2	Oregon	1417	7187	20%
3	Massachusetts	875	5037	17%
4	Rhode Island	128	739	17%
5	Vermont	351	2717	13%
6	Alaska	156	1211	13%
7	Washington	920	7637	12%
8	Indiana	1923	18512	10%
9	Maine	245	2387	10%
10	Montana	472	4641	10%
11	Connecticut	415	4127	10%
12	New Jersey	617	6353	10%
13	Delaware	78	804	10%
14	Maryland	484	5163	9%
15	New York	1593	17344	9%
16	Utah	227	2517	9%
17	Idaho	332	3951	8%
18	Nebraska	1060	15240	7%
19	Puerto Rico	151	2171	7%
20	Oklahoma	1639	23578	7%
21	Michigan	687	10879	6%
22	Colorado	492	7861	6%
23	Nevada	101	1734	6%
24	Louisiana	723	13045	6%
25	Arizona	377	7038	5%
26	Kansas	1344	25517	5%
27	Tennessee	989	19865	5%
28	Hawaii	51	1114	5%
29	Minnesota	576	13132	4%
30	Kentucky	597	13632	4%
31	South Carolina	391	8991	4%
32	Virginia	504	13087	4%
33	Mississippi	646	17026	4%
34	Alabama	527	15598	3%
35	West Virginia	220	7041	3%
36	Missouri	752	24134	3%
37	Ohio	691	27661	2%
38	New Hampshire	57	2375	2%
39	Wisconsin	319	13796	2%
40	North Dakota	98	4281	2%
41	New Mexico	87	3858	2%
42	California	524	24275	2%
43	Illinois	542	25115	2%
44	Florida	220	11356	2%
45	Iowa	409	24322	2%
46	Texas	602	48887	1%
47	Wyoming	19	2717	1%
48	North Carolina	111	16772	1%
49	Arkansas	79	12378	1%
50	Georgia	78	14608	1%
51	District of Columbia	1	236	0%
52	South Dakota	5	5916	0%
Total		32356	591605	

Table 7 Summary and Descriptive Statistics of Scour Critical Bridges by State

The table reveals that, while the scour issue is experienced by each state, there is disparity among the incidence of this condition. Pennsylvania suffers the most significant issue of vulnerability to scour damage, at 29% of its highway bridges, which is equivalent to 6,454 bridges that are vulnerable to scour. Oregon brings in a far second where 20% of its highway bridges are susceptible to scour. Other states such as Massachusetts and Rhode Island also suffer commonness of the issue with up to 17% of their bridges susceptible to scour, On the other hand, very few bridges located in North Carolina, Arkansas and Georgia are classified as scour critical.

Naturally, the nominal number of highway bridges in each state can bias the strict percentage shares. However, states such as Texas, Illinois and California have far more highway bridges than states like Kansas and Indiana, yet they have fewer bridges identified as scour critical bridges. Further analysis for discovering temporal and spatial pattern of scour critical bridges is presented in the following chapter to investigate this interesting discovery.

2. 5 Record Summary of Fracture Critical Bridges

Three years ago, the I-35W Bridge, located near downtown Minneapolis and serving as a major link in the Interstate system, tragically collapsed in seconds and fell into the Mississippi River on August 1st, 2007, during the rush hour. The failure resulted in 13 deaths, more than 145 injuries, and over $300 million lost in damage and construction. After approximately one full year of investigation, the NTSB (National Transportation Safety Board) concluded that the "fracture-critical" design, compounded by the weight of extra lanes added over time as well as repaving equipment and materials gave rise to this tragedy. Explaining in detail, the bridge, which was constructed in the 1960, had undersized gusset plates connecting its steel segments. On the fatal day, the situation was exacerbated as the bridge was carrying newly constructed lanes, repaving equipments and materials which pushed it over its loading limits [17]. Following the tragedy, experts and observers have become significantly more concerned and are more aware of whether the highway bridges they rely on every day are sound enough to carry their expected loads.

In order to prevent such tragedies from occurring again, discovering unknown pattern and information regarding fracture critical bridges in the National Bridge Inventory is vitally important and essential. Bridges which are identified as fracture critical bridges are coded and recorded in Item 92A in the National Bridge Inventory. It is saved as a form of inspection required with 3-digit code. That is, once a bridge is identified as fracture critical and requiring special inspections, it will be coded as Y in the first digit and the following digits will record the inspection frequency. Otherwise, N will be used to code, and the following digits will be left as blank.

The following pie chart indicates the percentage of fracture critical bridges in the United State from the 2008 edition of NBI. The query was first used to extract the datasets from the NBI based on the criterion: valid highway bridge and the fracture critical inspection required. After that, the result was weighted to the total number of valid highway bridge and shown as a pie chart.

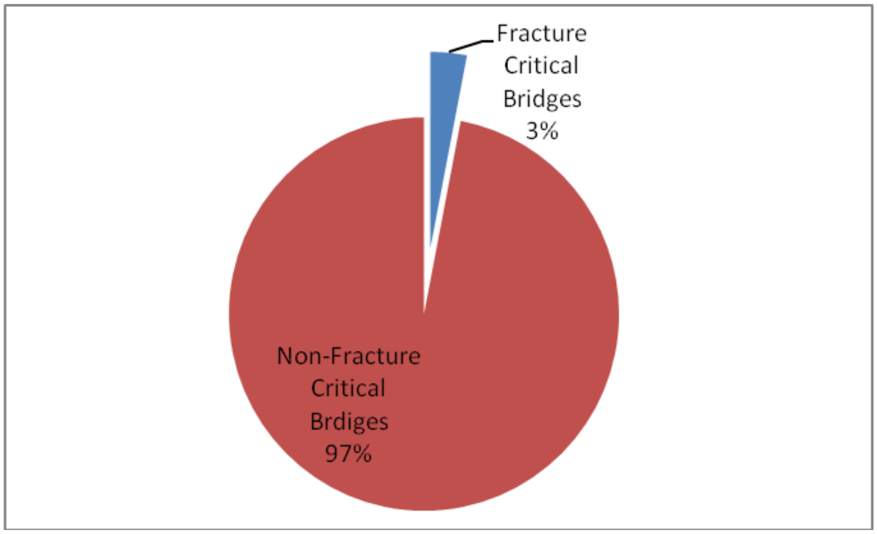

Figure 10 Percentage of Fracture Critical Bridge in the United States

The figure above shows that 3 % of existing highway bridges in the United States is associated with the fracture- critical issues. In other words, a least 18,330 highway bridges are required to have fracture critical inspection done in varying time intervals.

In order to understand which states have the most fracture critical bridges, the query then assigned the extracted datasets into different states and divided them by the total number of highway bridges in each state in order to rank the severity of the problem by area. The result is listed below.

Rank	States	# of Fracture Critical Bridges	# of Valid Highway Bridges	% of Fracture Critical Bridge in each State
1	District of Columbia	31	236	13%
2	Alaska	133	1211	11%
3	New York	1696	17344	10%
4	New Jersey	558	6353	9%
5	Nebraska	1298	15240	9%
6	West Virginia	526	7041	7%
7	Massachusetts	325	5037	6%
8	Montana	285	4641	6%
9	Iowa	1443	24322	6%
10	Maryland	292	5163	6%
11	Vermont	153	2717	6%
12	Missouri	1286	24134	5%
13	North Dakota	221	4281	5%
14	Washington	377	7637	5%
15	New Hampshire	108	2375	5%
16	Oregon	313	7187	4%
17	Rhode Island	32	739	4%
18	California	1024	24275	4%
19	Delaware	33	804	4%
20	Idaho	160	3951	4%
21	Connecticut	144	4127	3%
22	Kansas	876	25517	3%
23	Wyoming	91	2717	3%
24	South Dakota	193	5916	3%
25	Arkansas	389	12378	3%
26	Ohio	864	27661	3%
27	Hawaii	30	1114	3%
28	Indiana	491	18512	3%
29	Oklahoma	612	23578	3%
30	Florida	294	11356	3%
31	Kentucky	350	13632	3%
32	Maine	60	2387	3%
33	Virginia	326	13087	2%
34	Colorado	193	7861	2%
35	Pennsylvania	399	22042	2%
36	Illinois	451	25115	2%
37	Wisconsin	236	13796	2%
38	Minnesota	210	13132	2%
39	New Mexico	56	3858	1%
40	Alabama	223	15598	1%
41	Puerto Rico	31	2171	1%
42	Nevada	24	1734	1%
43	Tennessee	246	19865	1%
44	Mississippi	201	17026	1%
45	Utah	29	2517	1%
46	Arizona	75	7038	1%
47	Louisiana	123	13045	1%
48	Texas	450	48887	1%
49	Michigan	98	10879	1%
50	North Carolina	129	16772	1%

51	South Carolina	62	8991	1%
52	Georgia	80	14608	1%
Total		18330	591605	

Table 8 Summary and Descriptive Statistics of Fracture Critical Bridges by State

The table above describes the significance and influence of fracture-critical bridges in each state in the United States. Surprisingly, although D. C. area has relative small number of highway bridges, 13% of its bridges are associated with fracture-critical problem and required to have inspections done periodically. It is followed by Alaska, with 11 % of its bridges, equivalent to 133 bridges, identified having fracture-critical issue. New York, New Jersey and Nebraska have the 3rd, 4th, and 5th most oft checked bridges respectively.

On the other hand, Texas, Michigan, Georgia, North and South Carolina only have 1% of their highway bridges identified as fracture-critical, requiring fracture critical inspection regularly. In particular, though Texas has relatively many highway bridges, only a small portion of its bridges are associated with the fracture critical issue. As one may recall, this was also the case for its scour critical bridges.

In addition, according to the analysis result, Alaska and Massachusetts are most widely associated with both major causes of bridge failures, fracture and scour critical issues. Although the population and average daily traffic is greatly varied between the areas, they are both located around the shore and the weather in each is relatively cold. Especially, fracture critical bridges are sensitive to low temperature. The steel becomes more brittle and temperature induced stress can be very large. The large percentage in Alaska is an unexpected finding. It points to a future research area of using geospatial analysis to include additional data sets, such as climatic data, to study patterns and evaluate vulnerabilities in the NBI**.**

CHAPTER 3 TEMPEORAL PATTERN IN NATIONAL BRIDGE INVENTORY

It is well known that time plays an important role in the evolvement of bridges. Finding patterns among the evolvements is fundamental in bridge knowledge discovery. Especially, for certain database such as the NBI, the attributes generally list multiple versions of data as the data itself tends to evolve over time. Therefore, it is essential to identify patterns among these various versions as a mean of future trend projection or forecast.

In this chapter, the knowledge discovery process mainly focuses on the datasets that tend to change over time. Admittedly, it is challenging to discover such patterns in a very large database like the NBI. In order to efficiently discover frequent temporal pattern in the NBI, the core of the process mainly focuses on the objects that are related to specification changes or deterioration such as design load, load rating and ages of the bridges.

3.1 Temporal Pattern of Bridges by Material and Structure Type

Most people are aware that many of the bridges they daily rely on are constructed by strong materials such as concrete, steel and prestressed concrete. However, few people are aware that the prevalence of these materials has evolved over time. Meanwhile, interesting temporal puzzles have been left unsolved. For example, when did new bridge types come to dominate material use and design? When did those once-prevalent bridge types disappear? Is it possible that there still exist a small number of those bridges?

In order to answer these questions and identity temporal patterns among bridge types, queries were performed to extract datasets first by structure type and materials. After, the query cross-classified the data sets by year built and by the combination of materials and structure type, and then divided the result into 3 main time period groups as this eliminates noises to the broad pattern over time. The result is shown in the following stacked bar chart.

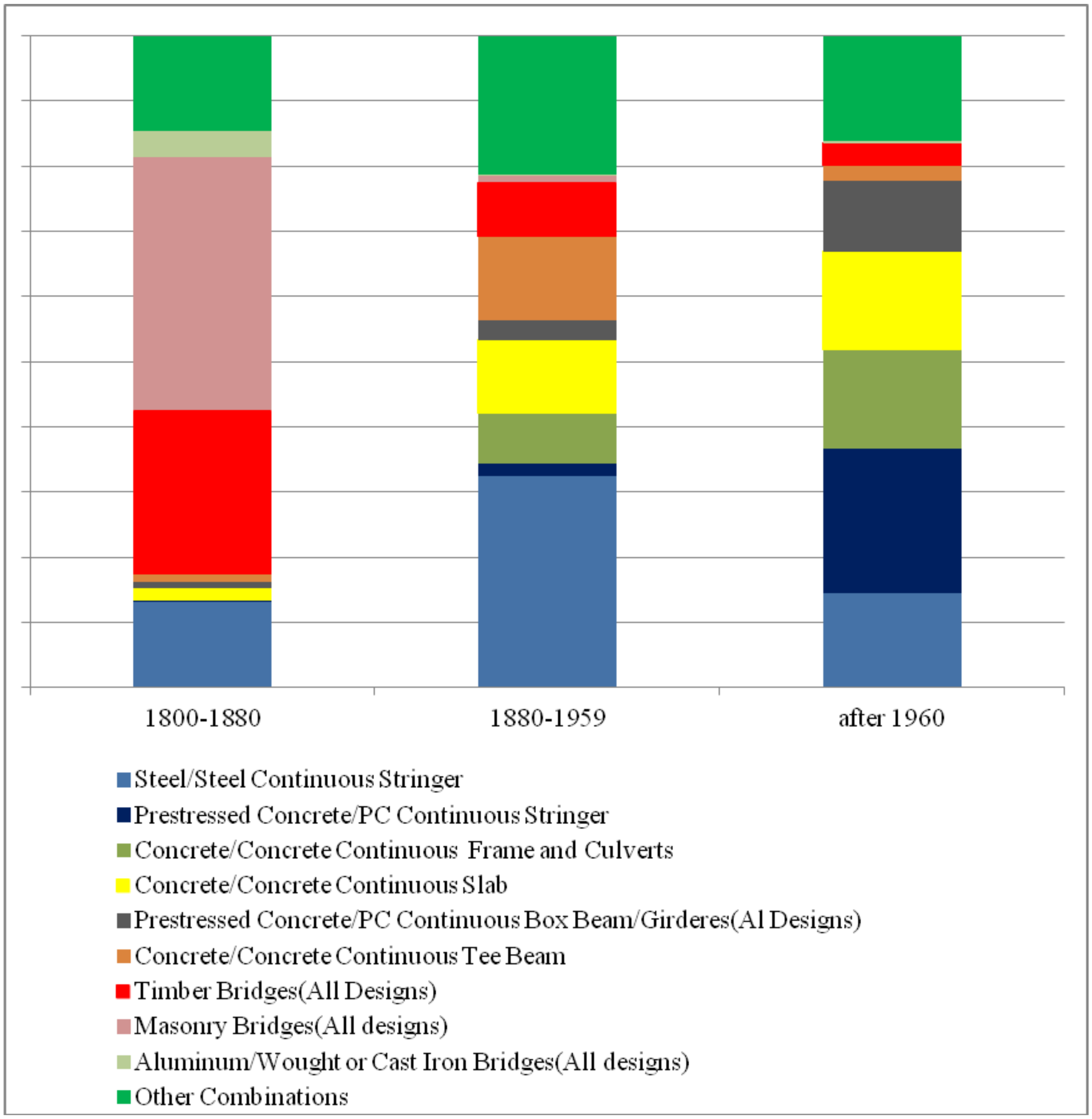

Figure 11 Percentages of Bridges Material and Structure Type Combinations, by Time Periods

Figure 11 illustrates the temporal pattern for types of highway bridges by year built. It appears that, before 1880, approximately 40 % of national highway bridges built were masonry bridges. However, in the following years, due to the fast growing population and the prevalence of vehicles, they were largely replaced by concrete/concrete continuous slab bridges and steel/steel continuous stringer bridges.

Since the mid19th century, steel has been widely available due to its mass production. Owing to its advantages in both tension and compression, bridges with longer major spans became possible. Before 1960, Steel and Steel Continuous Stringer were the predominant type of design for highway bridges. However, with the significant innovation of prestressed concrete, which uses high strength tendons to pre-compress concrete, the popularity of steel bridge has gradually been replaced since 1960. The innovation of prestressed concrete not only has propelled concrete to become the most popular construction material choice for highway bridges today, but also allowed us to build many types of short, median and long spans bridges. The bar chart above shows that after 1960 roughly, more than half of national highway bridges have been constructed by concrete and prestressed concrete. The popularity of prestressed concrete and prestressed concrete continuous stringer bridges has increased significantly since 1960, when it only enjoyed around 2% of national highway bridges, the shift has been phenomenal.

Regardless of materials, stringer bridges have been the most prevalent structure type ever since 1800. Its significance has not changed for over 200 years. In addition, after discovering the benefits of the design structures, the two structures, girder and slab has gradually become more common among other structure types since 1880. On the other hand, tee beam only enjoyed moderate significance between 1880 and 1959.

In other words, according to the historical trend, it may be inferred that the two structure types, stringer and slab will still remain significant in at least the near future. Tee beam, however, may possibly be fully replaced with other structural types in the future.

3.2 Temporal Pattern of Bridge by Scour Critical Rating

Nowadays people are aware that bridge scour, both at piers and abutment is one of leading causes of bridge failure. According to the estimation provided by numerous reports, 60% of highway bridge failures have been resulted from scour and other hydraulic related causes. The two major bridge failures caused by scour occurring in 1987 and 1989 emphasize the need and attention for advanced inspection and analysis for the condition.

On April 5th, 1987, due to the erosion and undermining of the piers, a bridge carrying I-87(the New York State Thruway) over Schoharie Creek collapsed and ten people died. Two years later, a section of the State Highway 51 Bridge over the Hatchie River in Tennessee was destroyed by lateral erosion during a moderate flood, resulting in eight deaths [13]. Due to these two closely timed tragedies, people and government officers identified the need for better bridge inspections and improved evaluation of potential scour situations for existing bridges.

In order to identify whether there are temporal patterns of scour condition among existing bridges, the query here extracted the datasets by year built and scour critical rating, and once the scour critical rating shows 4 or below for a bridge, it would be viewed and counted as a scour critical bridge. After that, the result is divided into 12 major time period groups and showed as proportions of the total number of bridges built at the same time period. Since there was no temporal pattern observed before 1900, the time period groups here focus only on the time since 1900. The result is shown in the following bar chart.

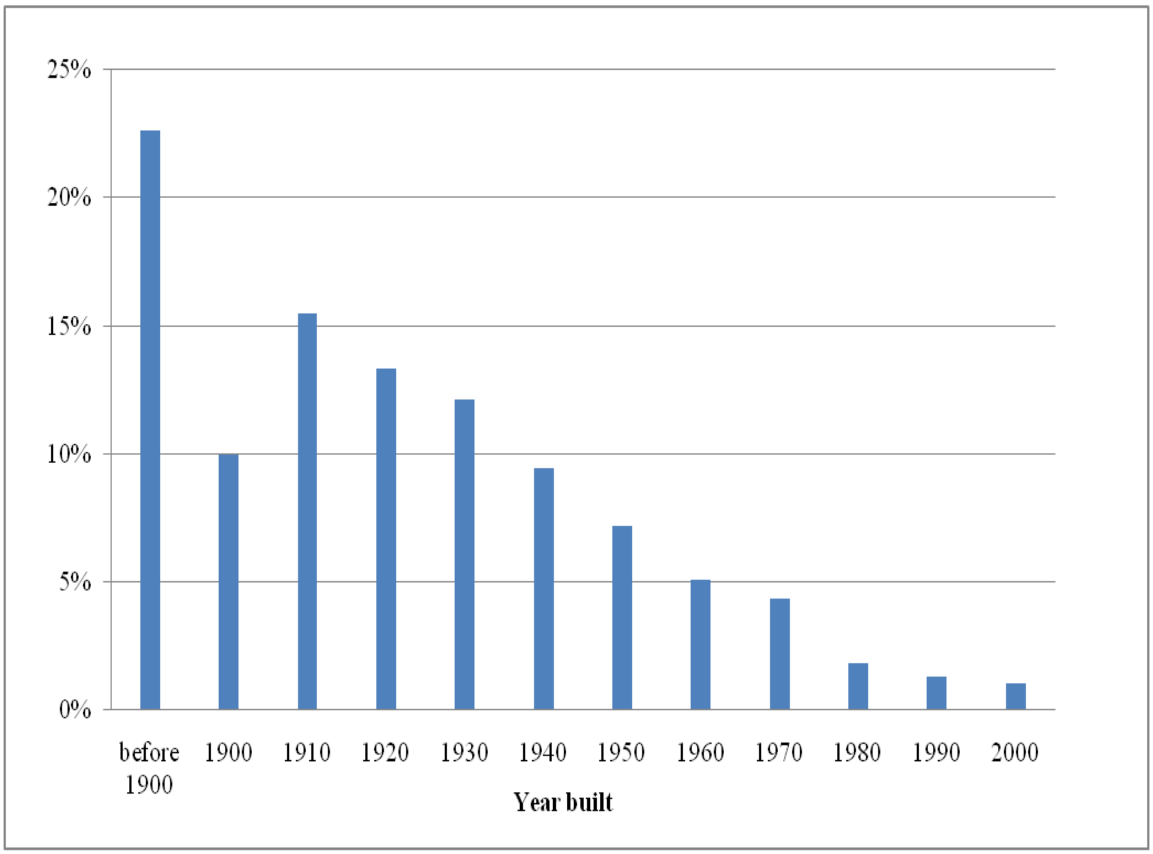

Figure 12 Percentage of Scour Critical Bridges by Bridge Year Built

This figure describes the share of scour critical bridges of a particular age, derived by year built, within the total share of scour critical bridges. Intuitively, older bridges might not have considered scour in the design and might have higher possibility to be scour critical. This hypothesis seems to be confirmed by the analysis. The portion of scour critical bridges relative to existing bridges deceases in all periods of year built except for the bridges built between the period of 1900 to 1910. The drop from 1900 to 1909 bridges is significantly higher than all of the subsequent drops in the same trend. As a matter of fact, the percentage of scour critical bridges built between 1900 and1909 is lower than half of those built before 1900. Even when compared with the following 3 groups, bridges built between 1900 and1909 still show a lower percentage of scour critical conditions. Since the exception is significant, a further analysis is worth conducting in the future.

In addition, according to the figure provided above, bridges built after 1979 are much less associated with scour, evident from a sharp drop in its share rather than the smooth decrease observed in prior years. The three groups shown consist of less than 5 % scour critical bridges in the United States. Although there is increasing erosion and other hydraulic-related issues occurring in the recent 20 years, much fewer bridges are at risk to get involved with scour issues. Further analysis toward what kinds of countermeasures are in place for theses bridges or their design types may be interesting and worth conducting in the future.

3.3 Temporal Pattern of Bridges by Design Load

Today there are numerous design vehicles available, but selecting the ideal design vehicle requires consideration of a variety of background information of the bridges such as heavy truck traffic and operational characteristics of bridge. For example, MS 18, a new standard design live load, is sufficient for all current loads. However, in a few situations such as high average daily truck traffic, the MS 18 needs to be increased to M 23. The choice is usually dictated by local policies, specifications and standards.

In order to better understand how the standards for design live load have changed over time, a data query was performed. Based on the criteria of highway bridge and design load, the datasets were extracted from the National Bridge Inventory (NBI). After that, a sub query cross-classified the datasets by year built. Since there are too many time periods to identify apparent patterns, the datasets then were divided into nine major time periods and weighted to the total number of bridges in the same period only. The result is shown in the following chart.

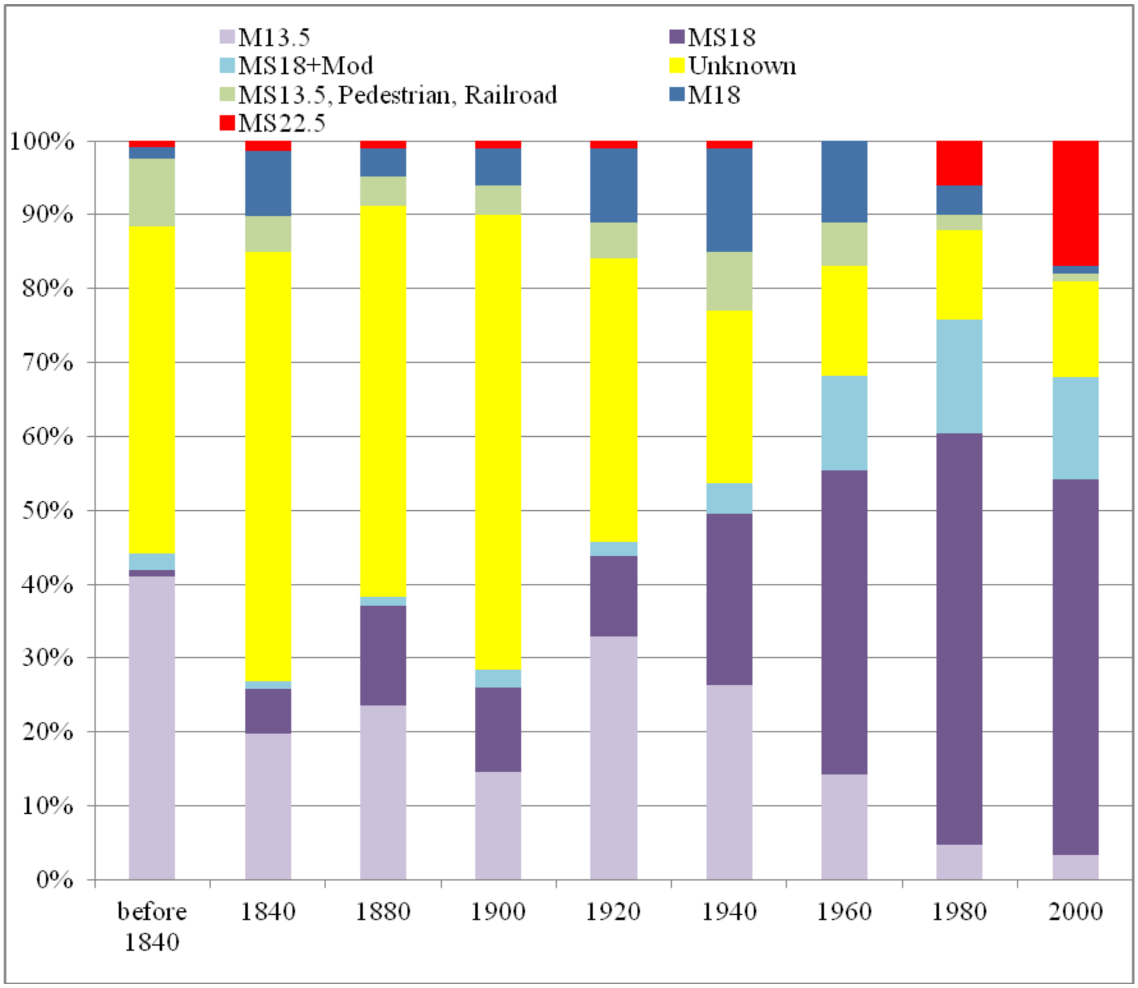

Figure 13 Numbers of Bridges by Year Built by Design Load as Percentage

The figure above illustrates the temporal pattern for design load of highway bridges by year built. In sum, except MS 13.5, pedestrian and railroad, each color represents one type of design live load. The yellow color denotes unknown information.

It appears that, before 1840, the smaller design vehicle, M13.5 (13.5 Metric Tons), was mainly utilized to design the live load of 40% of highway bridges at that time. However, with fast growing population and volume of traffic, such smaller design vehicles were no longer sufficient to meet the requirements. The M13.5 has been significantly replaced by the larger design vehicles, MS 18 (32.4 Metric Tons) and MS 22.5(40.5 Metric Tons).

Today, approximately 60% of the live loads of national highway bridges are designed by the MS 18 specification. Moreover, the smaller design live load, M18 (18 Metric Tons), was relative more widely used between 1920 and 1979.

Overall, it may be inferred that with fast increasing traffic volume and population, the live load of national highway bridges has been gradually increasing. Also, with advanced technology and information, bridges have evolved to have larger capacity.

3.4 Temporal Pattern of Bridges by Functional Classification

Functional classification, defined by FWHA, classifies streets and highways into systems or groups based on the operating characteristics and the traffic service they provide. There are generally three types of classification: arterials, collectors, and locals. Arterials, in terms of traffic mobility and land access, is a functional system providing the highest level of service at greatest speed with low degree of access. Collector is a functional system responsible for collecting traffic between local roads and arterials. Local is a functional system providing high degree access with little mobility.

Functional classification plays an important role in designing highways and bridges. For example, once a bridge is determined to be constructed at or around an arterial, its structure type, deck width, lane width, and other design features would vary with highway bridges on other systems.

In addition, since traffic service patterns and bridge functions can change over time, the functional classification system has been called for reevaluation on a relatively regular basis. As to better understand how the systems of highway bridges can change over time, data query was utilized here.

Firstly, datasets were extracted from the National Bridge Inventory based on the criteria of valid highway bridge and functional classification of highway bridges. After that, a sub query cross-classifies the datasets by year built. Since the result showed implicit patterns, it was then grouped into eight major time periods and three major functional systems without considering whether bridges are located in rural or urban area. The final result is shown in the following bar chart.

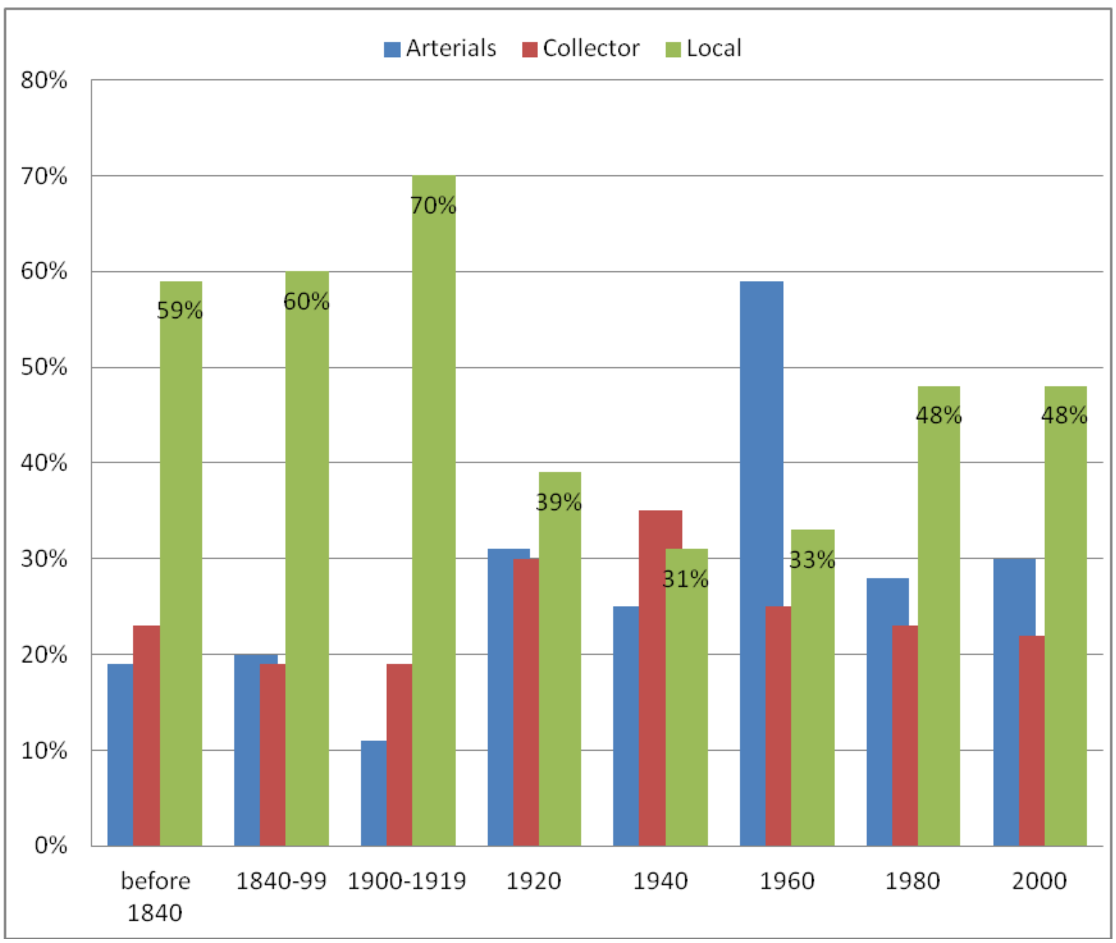

Figure 14 Percentage of Bridges by Functional Classification and Year Built

The chart above illustrates temporal pattern for functional classification of highway bridges by year built. In sum, regardless of rural or urban area, each color represents one of functional systems. Arterial is shown in blue bar. Collector is indicated by red bar, and local is shown as green bar.

Apparently, except for the period between 1940 and 1979, local function systems account for the highest percentages of highway systems throughout the years. Before 1920, with smaller bridges, low volume of traffic and smaller population, local functional systems consistently enjoyed more than half of percentages. However, from 1920 to 1979, the share significantly dropped to 33%. Although arterials and collectors share relatively smaller portions of highway systems for almost 200 years, the percentage of arterials between 1960 and 1979 suddenly jumped to around 60%. This was probably due to the construction of the Interstate System.

Overall, it may be inferred that a larger proportion of newer bridges are on the higher classes of roadway. Locals, on the other hand, are seeing smaller portions in the highway systems compared to pre and early 1900s.

In the following section, further analysis looks at the load rating of highway bridges. In particular, the distribution of the load ratings of highway bridges varies with the type of highway system was studied.

3.5 Temporal Pattern of Bridges by Load Rating

Load rating, defined by FWHA, is a component of inspection process that is used to determine the safe load carrying capacity of the existing bridges [19]. In other words, it is a process determining if specific legal or overweight vehicles can safely cross the bridge. In general, loading rating is conducted every two years. Once a bridge has a condition warrant, then an updated load rating tests will be performed.

Load rating is coded and recorded in Item 66 of the National Bridge Inventory. It is coded with a 3-digit number, which can be converted to XX.X metric tons.

In order to understand how the load levels of existing bridges change over time, queries were performed here. First, based on the criteria of valid highway bridge and load rating, the datasets were extracted from the National Bridge Inventory. After that, a sub query was performed to convert the datasets to into units of XX.X metric tons. Then, the datasets were cross-classified by year built. Because the result contains temporal patterns, the datasets were then grouped into seven categories of load rating with major time periods. Lastly, the result was weighted by the total number of bridge built in each time period. The result is shown below.

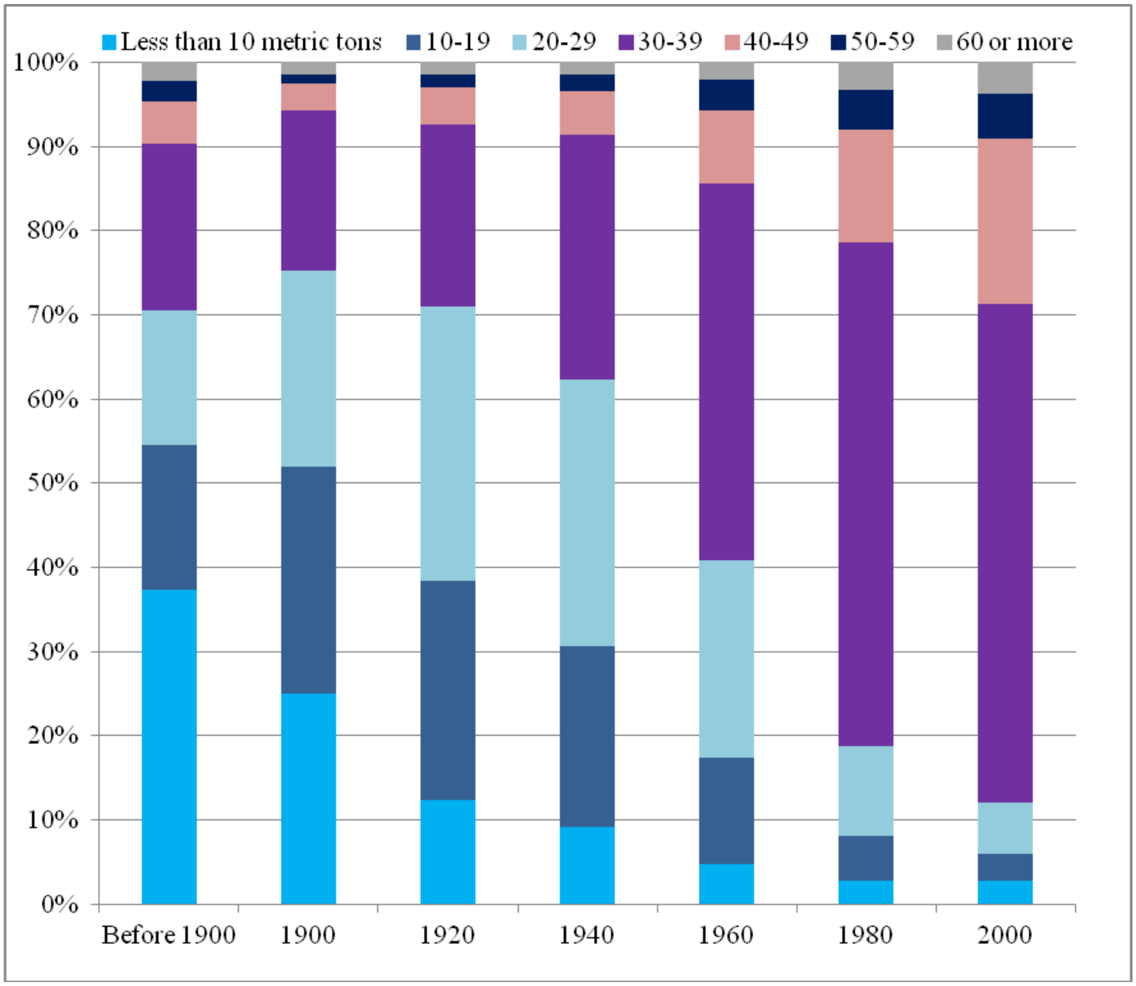

Figure 15 Percentage of Bridges by Load Rating and Year Built

The bar chart above illustrates the temporal pattern for the load ratings of existing U.S. highway bridges by year built. Apparently, except load rating of 30 metric tons or above, the percentages for smaller load-carrying capacity bridges have been shown decreasing for more than 100 years. For example, the percentage for the 10-19 metric tons category has been decreased since 1900. It means that the existing newer or nearly new bridge have higher load- carrying capacity. This is probably due to the combined effects of changing design standards and bridge deterioration.

Existing highway bridges identified as having more than 60 metric tons load capacity, on the other hand, continue to only account for a small percentage of all of highway bridges throughout all time periods. It may be inferred that in spite of advanced technology and information available, highway bridges nowadays tend to be designed more economically to meet the current demands. For example, after 1979, the load level of 30-39 metric tons has the highest percentage among others.

Overall, with fast growing population and traffic volumes, bridges nowadays tend to be constructed with larger load capacity to meet the current demand. Although certain bridges are identified with more than 60 metric tons load-carrying capacity, the majority of highway bridges are identified as having load capacity between 30 to 49 metric tons. Comparing with older bridges, bridges built before 1900 have much less ability to safely carry large volumes of heavy trucks and to meet the demands observed today.

3.6 Temporal Pattern of Bridges by Deficiency Type

Most of highway bridges in the United States are inspected every two years. The inspections are performed to determine if the structure meets the current demands for structural and functional purposes. Factors considered in the inspection process include load-carrying capacity, clearances, waterway adequacy, and approach roadway alignment. They are recorded in the condition and appraisal ratings of NBI, respectively. The rating scale both range from 0 being bridge closure is required, to 9, indicating a new or nearly-new bridge state.

In general, condition ratings are used to classify and evaluate structural deficiency of a bridge. The three primary factors are deck, superstructure and substructure. The deck of a bridge, defined as the primary surface, is mainly used for transportation. It is supported by the superstructure such as girders and stringers. The substructure, defined as the foundation of the bridge, is utilized to transfers the loads of the structure to the ground. Besides these factors, condition ratings are also assigned for the structures, which don't have distinct bridge components.

Different from conditional ratings, appraisal ratings consider the field condition such as waterway adequacy, deck geometry, structural evaluation, approach roadway alignment and under-clearance. According to the Bridge Inspection Manual, deck geometry inspection mainly considers the width of the bridge deck, ADT and the number of lanes carried by the bridge for functional purposes. Underclearance ratings are based on the vertical and horizontal underclearance measured from the through roadway to the nearest bridge component. The structural evaluation and waterway adequacy are generally used as factors to determine if a bridge is classified as structural deficiency or functional obsolescence. For example, if the rating of a bridge is shown as 2 or below for either the structural evaluation or the waterway adequacy, it is classified as a structural deficient bridge. However, if it is shown as 3, the bridge is then classified as functionally obsolete.

In order to better understand if there are significant temporal patterns among these types of deficiency and the age of bridges. Matlab codes were utilized to perform a query. Datasets were extracted from the National Bridge Inventory based on the preliminary criteria of valid highway bridges that are identified as having deficiency issues. After that, the datasets were further classified by year built. As there are possible temporal patterns, the datasets were grouped into major time periods. The results are listed in the following table and subsequent horizontal bar chart.

Deficiency Type	Before 1880	1880	1900	1920	1940	1960	1980	2000	Total
Deck	73	200	2530	7423	6840	7287	1044	122	25519
Superstructure	161	437	4091	9081	6615	5130	915	100	26530
Substructure	12	299	3944	9252	9452	8213	1569	103	32844
Structural Evaluation	277	540	5174	11646	11113	9685	3451	910	42796
Deck Geometry	479	760	6200	19995	21346	20143	10709	3114	82746
Underclearance	41	142	867	1419	5462	10481	3037	1308	22757
Waterway Adequacy	8	35	396	1256	1115	1137	896	166	5009
Approach Roadway Alignment	84	206	1433	2390	1798	2093	1516	339	9859
Total	1135	2619	24635	62462	63741	64169	23137	6162	248060

Table 9 Summarization of Bridge Deficiency Type by Year Built

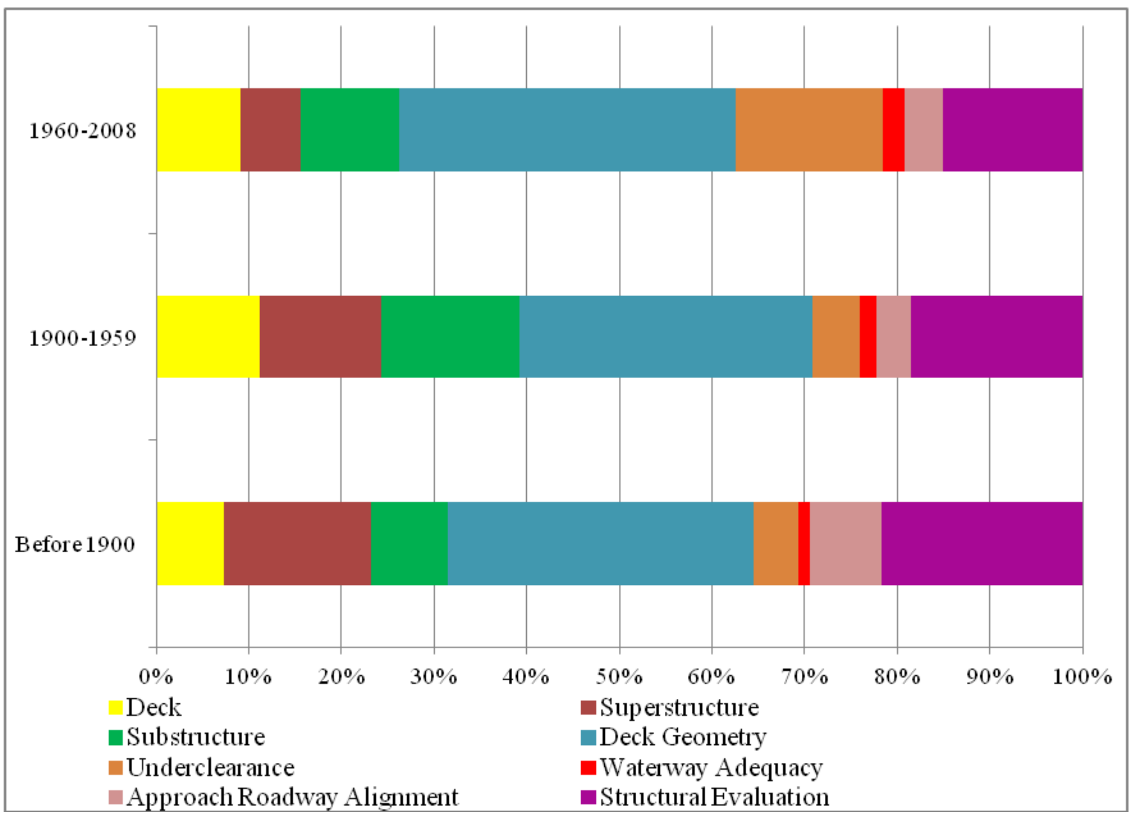

Figure 16 Distribution of Bridge by Deficiency Type and Year built

The data illustrations summarize U.S. highway bridges by deficiency types and by year built. Evidently, deck geometry is the most prevalent type of deficiency among U.S. highway bridges. It is followed by Structural Evaluation, Substructure, Superstructure, Deck and Underclearance. Only relatively small number of deficient bridges is associated with waterway adequacy and approach roadway alignment.

Except approach roadway alignment and substructure, highway bridges built before 1960 tend to have relatively similar temporal pattern among other deficiency types such as deck geometry, deck and super structure. In addition, bridges built after 1960 are more strongly associated with the deficiency issue, underclearance. However, within more than 100 years, the percentages of superstructure and structural evaluation significantly decrease to approximately 5% and 15 %, respectively. It might be inferred that newer and nearly new highway bridges tend to have sound superstructures and better structure performance than older bridges.

Another query was performed to get more understanding of the conditional and appraisal ratings of the bridges. Based on the criteria of highway bridge and deficiency type, the datasets were extracted from the National Bridge Inventory, and then shown as bar chart in the following.

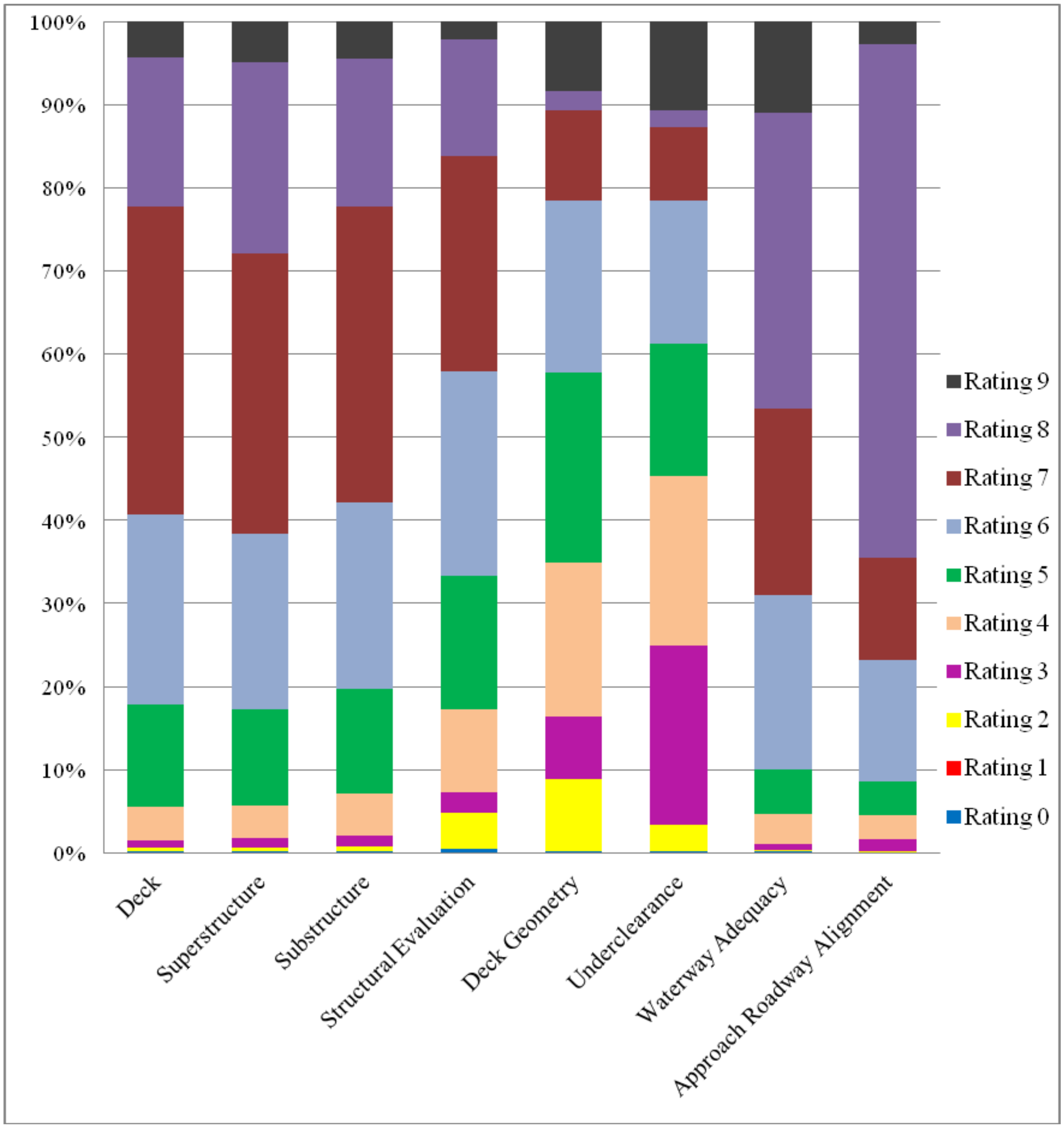

Figure 17 Distributions for Condition and Appraisal Ratings of Bridges

The figure above illustrates the condition and appraisal ratings of highway bridges in the United States. Apparently, very few bridges are identified in a failed status and required to be closed for traffic. Except underclearance and deck geometry, other deficiency types tend to have higher percentage in the rating of 6 or above. In addition, structural evaluation, deck geometry and underclearance have higher percentage in the rating of 2 or below.

It may be inferred that the highway bridges, identified as deficient, tend to be more likely associated with deck geometry, structural evaluation and underclearance. Highway bridges indentified with excellent performance enjoy relatively lower percentages among condition and appraisal ratings.

CHAPTER 4 SPATIAL PATTERN IN NATIONAL BRIDGE INVENTORY

People have become gradually aware that spatial distribution of data plays an important and essential role in understanding and discovering various geographically related knowledge such as environmental impacts on bridge deterioration. Due to the availability of the user friendly tool, Geographical Information System (GIS), spatial analysis and discovery can be interpreted through data visualization. With spatial or related datasets available, colored maps provided by GIS, enables significant spatial relationships, patterns or trends hidden inside the data to be discovered via human eyes. In this research, GIS and Matlab queries were utilized in the spatial pattern discovery process.

This chapter focuses on the datasets of the specific phenomena that are associated with geographical locations. Admittedly, it is a great challenge to identify and discover spatial patterns in a very large geo-related dataset such as the NBI. In order to efficiently discover significant spatial patterns in the NBI, the knowledge discovery process l only emphasized deterioration related factors or issues such as design load, condition and appraisal ratings of the bridges, as well as scour critical bridge and fracture critical bridge.

4.1 Spatial Pattern of Bridge by Design Load

Basically, design load was set at the time when a bridge was designed. In order to protect users' safety and prevent bridges from failure, the standard for the design live load of traffic-carrying bridges nowadays requires consideration of a variety of background information of the bridges such as heavy truck traffic and ADT. With fast growing population and traffic volume, design loads generally have increased over time. As to investigate if there is an unexpected spatial pattern in the design load of the bridges, the spatial pattern discovery process is performed here.

First, the datasets were extracted from the National Bridge Inventory (NBI) based on the criteria of highway bridge and design load. Next, a sub query cross-classified the datasets by county. The datasets selected only focus on three main categories, M13.5, MS18 and MS22.5, and then were re-classified by state. After outputting the result to spreadsheet, it was converted and saved as a "dbf" file to ensure the data is linkable to GIS. At the final step, map function provided by GIS was used to visualize patterns found during the knowledge discovery process. The results are shown in the following figure.

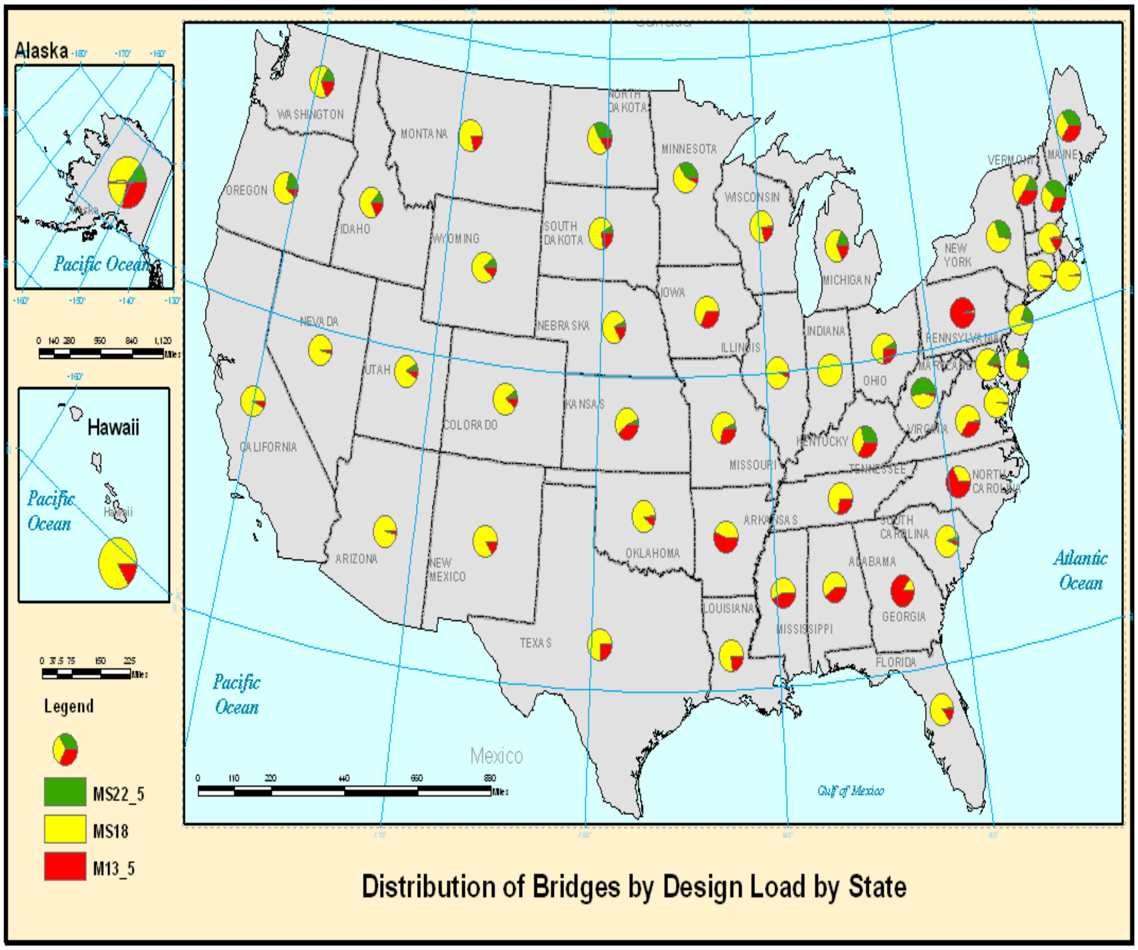

Figure 18 Spatial Distribution of Design Load of Bridge by States (Based on template from ArcGIS)

The map shown above illustrates the spatial distribution of design load of U.S. Highway bridges. The spatial data shown on the map is represented by pie chart. The red portion denotes the live load of the bridges designed with smaller design vehicles, MS13.5. The yellow one indicates the live load of the bridge designed with relatively larger vehicles, MS18. The green one denotes the live load of the bridges designed with the heaviest and largest vehicle, MS22.5.

Compared to the red and green, most of the largest portions of the pie charts shown on the map are yellow. It appears equally distributed amongst the United States. This means that the majority of the existing highway bridges were designed with relatively larger live load standard. On the other hand, compared to MS22.5, MS13.5 denoted by the red enjoys relatively higher prevalence among the states. In particular, almost all highway bridges located in Pennsylvania were designed with lower live load standard, (MS 13.5). Other states such as Georgia, Mississippi, Alabama and South Carolina also have higher percentages of the bridges designed with the lower live load standard, (MS13.5).

The red (MS 22.5) only represent a relatively smaller percentage of highway bridges. Some states such as New York and Vermont have more bridges designed with much higher live load standard, MS22.5.

In sum, with the exception of Pennsylvania, it might be inferred that there are not significant spatial patterns for the design load of U.S. highway bridges. Existing bridges in the United States are mostly designed with the middle live load standard, MS18. In addition, it is unusual to find that most bridges located in Pennsylvania are designed with lower live load standard, MS13.5. It points to further research needing to be conducted in regard to this finding.

4.2 Spatial Pattern of Bridges by Load Rating

As mentioned previously, load rating is a component of inspection process used to determine the safe load-carrying capacity of the bridges. In order to protect users' safety, load rating is generally conducted every two years. If a bridge has a condition warrant, additional load rating will also be performed.

With the intent to discover how the safe load levels of the existing bridges change across various locations, the spatial pattern discovery process was performed here. First, based on the criteria of valid highway bridges and load ratings, the datasets were extracted from the National Bridge Inventory. Next, a sub query was used to cross-classify the datasets by state. As to get average load rating for each state, the datasets were calculated by another sub query. After outputting the result to Excel spreadsheet, the datasets were converted and saved as a "dbf" file. Finally, the dbf file was linked to GIS to create a colored map with the extracted datasets.

The results are shown in the following figure.

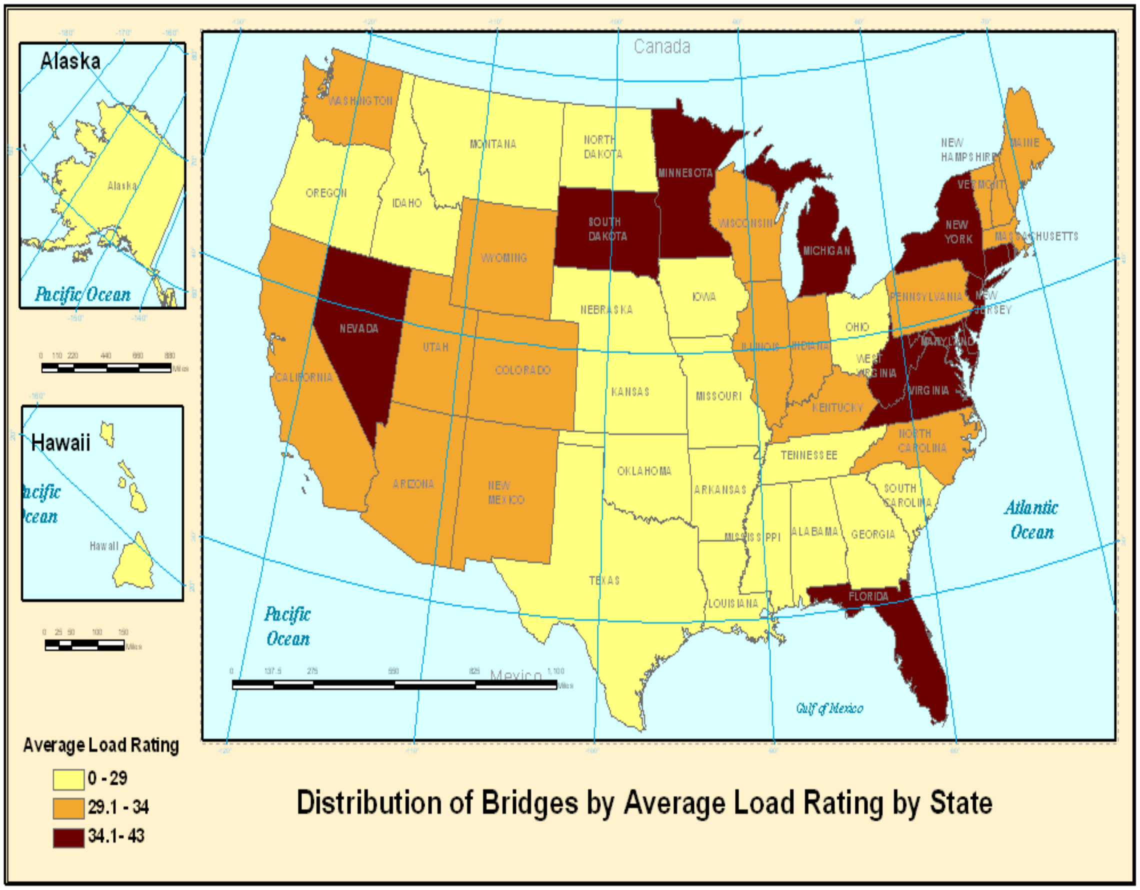

Figure 19 Spatial Distribution of U.S. Highway Bridges by Average Load Rating (Based on template from ArcGIS)

The 3-quantiles colored map shown above displays the spatial patterns for the load levels of existing U.S. highway bridges. The spatial data shown on the map is represented by graduated colors. The lightest one denotes the existing bridges in a state were identified having much smaller load-carrying capacity. The darkest one denotes that bridges in a state were indentified having much higher load-carrying capacity.

Apparently, with the exception for Texas, Florida and Washington, the darker colors are mostly distributed among Northeast and Southwest of United States such as New York and California. It may be inferred that the highway bridges with larger load capacity tend to be constructed and located in relatively high demanding areas such as areas with higher traffic volumes and populations. On the other hand, existing bridges with smaller load carrying-capacities are mostly located in relatively low population and traffic volume areas such as Missouri, Iowa and Arkansas.

Overall, existing bridges indentified with the highest load capacity tend to be located in the highest demanding areas such as New York, New Jersey, Florida and Northern Virginia. Bridges with the smallest load-carrying capacity tend to be located in lower population and traffic volume areas.

4.3 Spatial Pattern of Bridge by Score Critical Ratings

Scour is the primary cause of bridge failures in the United States. As NCHRP 396 mentioned, that more than 20,904 highway bridges were identified as scour critical bridges in the United States before 2005. In other words, a least 4 % of U.S. highway bridges are vulnerable to failure due to scour.

In the previous chapters, both the summary statistics and the temporal pattern analysis for scour critical bridge were presented. However, an analysis of the spatial patterns of scour critical bridges has not been conducted. Although experts and academic researchers have found that scour severity is significantly associated with specific site conditions and factors such as high velocity flows, debris, ice forces, sediment loading and severe water temperature, the severity of scour critical bridges in each state still remains a question.

As to answer the question and understand if there exists an unknown spatial pattern toward scour critical issue, spatial pattern knowledge discovery process was performed.

First, based on the criteria of valid highway bridge and scour critical bridge, the datasets were extracted from the database (NBI). Next, it was cross-classified by states. After outputting the result to Excel spreadsheet, the content and its file format was converted to make it linkable to GIS. Finally, a colored map was created with the extracted datasets. The result is shown in the following.

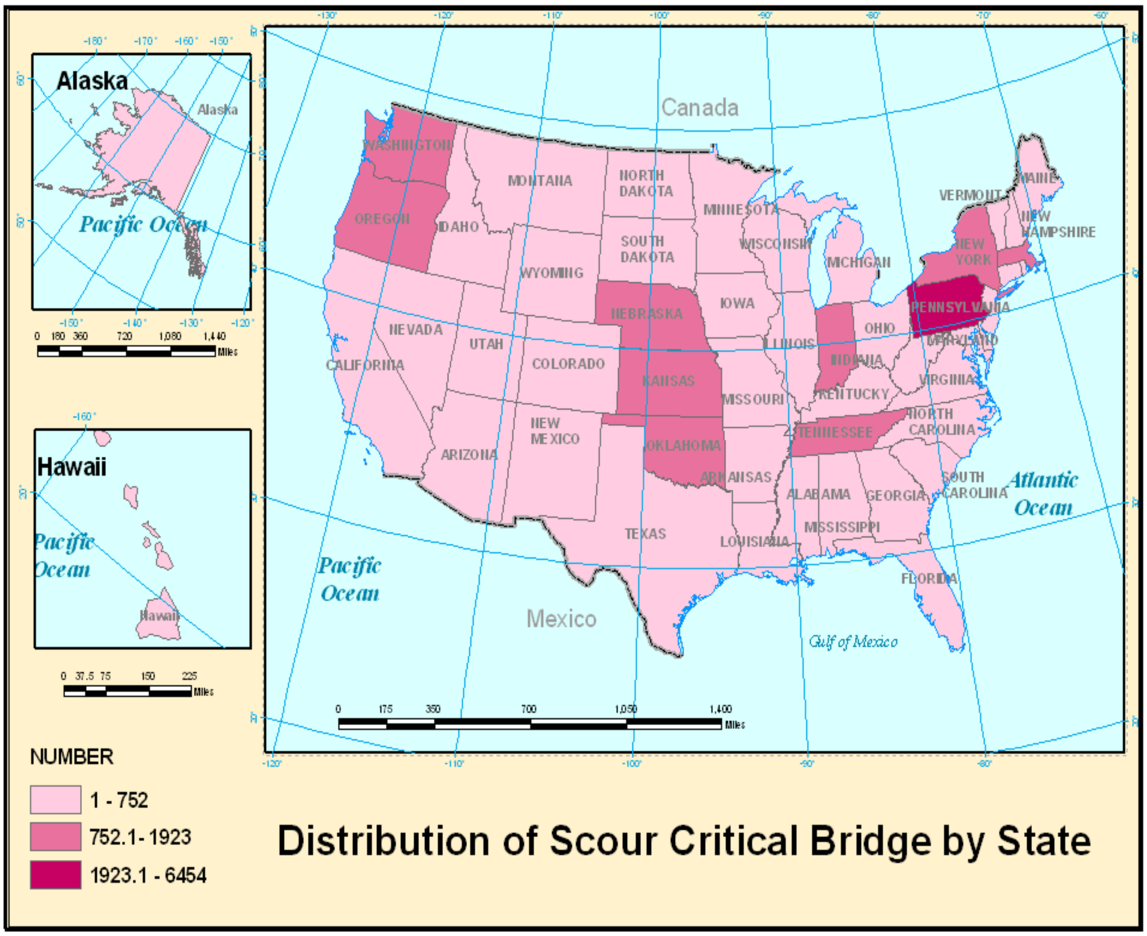

Figure 20 Distribution for Scour Critical Bridge by State (Based on template from ArcGIS)

The 3-quintiles colored map above illustrates the spatial pattern for scour critical bridges in the United States. It is represented by graduated colors. The lightest pink denotes less than 753 highway bridges are indentified as a scour critical bridge. The baby pink denotes a least 753 but less than 1923 highway bridges are indentified as scour critical bridges. The dark pink denote that more than 1923 highway bridges are indentified as scour critical bridges in a state.

With the exceptions of Washington, Oregon, Nebraska, Kansas, Oklahoma, Tennessee, Indiana, Pennsylvania, New York and New Hampshire, there are relatively fewer scour critical bridges in other states. Compared to states facing relatively more sever scour critical issue, Pennsylvania has the largest number of scour critical bridges.

As to get a greater understanding of the scour critical issue experienced by each state, a sub query was performed. The extracted datasets were proportional to the total number of highway bridges in each state. The result then was linked to GIS and shown in the following map.

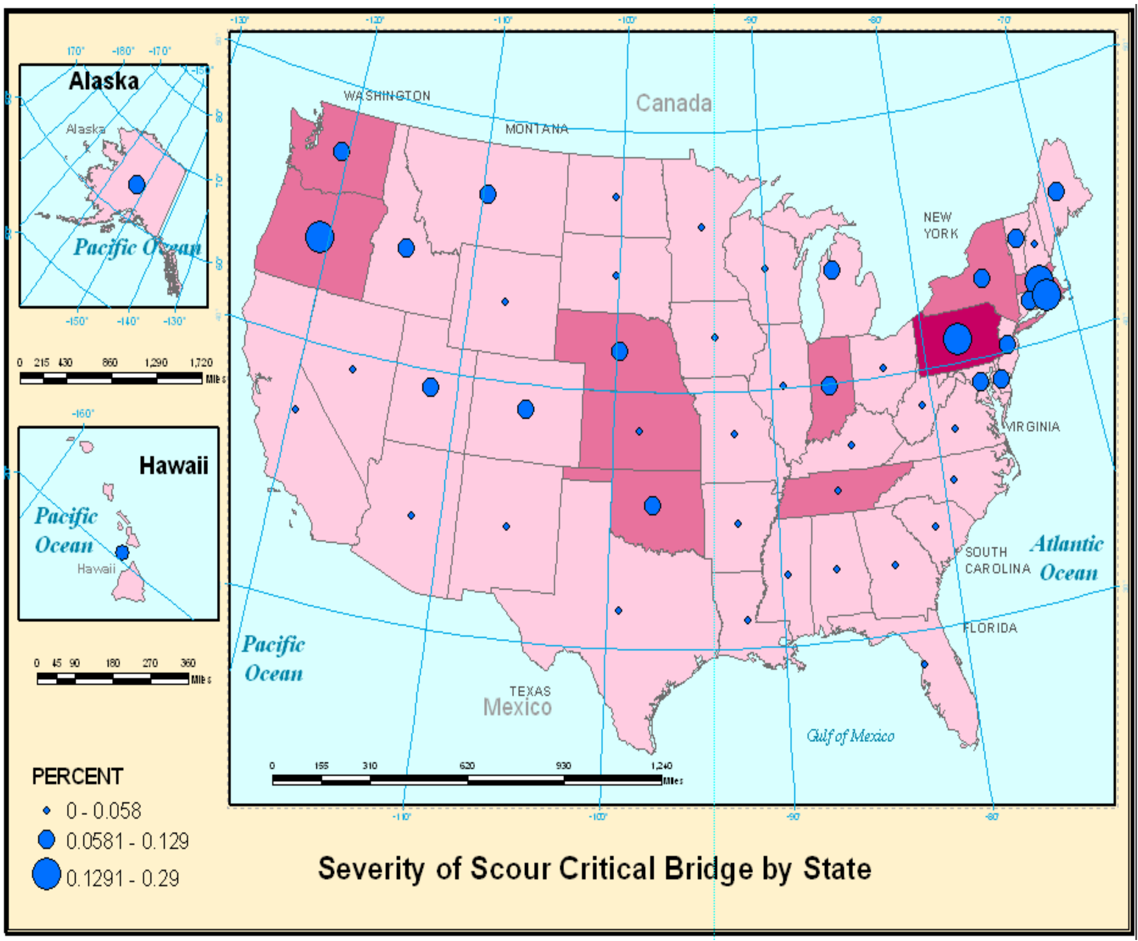

Figure 21 Distribution for the Severity of Scour Critical Bridge by State (Based on template from ArcGIS)

The map above shows the severity of scour critical issue experienced by each state. The spatial patterns shown on the map are illustrated by three quintiles graduated circle. The smallest circle denotes the scour critical issue experienced by a state is of the least severity. The average sized circle describes the scour critical issue experienced by a state is relatively more serious. The biggest circle denotes that a state is experiencing the most serious scour critical issue.

Compared to other states in The United States, Pennsylvania experiences the most serious scour critical issue. Not only is the number of scour critical bridges in Pennsylvania the highest, but it also has the largest percentage of highway bridges indentified as scour critical bridge. In other words, in order to protect users' safety, highway bridges located in Pennsylvania must be monitored, maintained and inspected more frequently than bridges in other states in The United Sates. Funds spent on these expenditures are also higher than other states. This justifies more funding being necessary to mitigate this issue.

In addition, with the exception of the northeastern United States, the scour critical issues on the East coast are far less serious. The northeastern United States in places such as New York and New Hampshire there is a higher percentage of highway bridges indentified as scour critical bridges. Likewise, the West Coast follows the same pattern. Only Washington and Oregon experience a more serious scour critical issue. Although other States such as Tennessee and Kansas have a much higher number of scour critical bridges, the scour critical issue they experience is the least serious. The main reason is compared to the total number of highway bridges, much fewer highway bridges located in these two states are indentified as scour critical bridges. Evidently, although Tennessee and Kansas enjoy a relatively lower percentage of scour critical bridges, the bridges there still need to be inspected, monitored and maintained more often due to the large number of scour critical bridges.

Overall, since a large number of scour critical bridges are located around higher population and ADT areas, people and agencies responsible for maintaining these bridges must maintain them carefully.

4.4 Spatial pattern of Bridge by Fracture Critical Ratings

Due to historical accidents, people nowadays have been becoming more aware of the significance of fracture critical issue. Fracture critical member, defined by LRFD Specifications, is a “component in tension whose failure is expected to result in the collapse of the bridge or the inability of the bridge to perform its function.” According to the previous summary statistics, 18,330 of highway bridges in the United States have been identified and required to conduct fracture critical inspections in varying timeframes.

Although experts and researchers have developed ways and approaches to inspect and manage the bridges that are identified as having fracture critical issue, it is still not clear that how the significance and influence of the fracture critical issue vary by locations. In order to better understand the phenomena and provide more related information to the maintenance agencies as well the local users, spatial pattern knowledge discovery was performed.

First, based on the criteria of valid highway bridges and bridges required fracture critical inspections, queries were used via Matlab to extract the datasets from the database. Then, a sub query further grouped the datasets by states, and exported the result to the Excel spreadsheet. To make the extracted datasets linkable to the GIS attributes, the datasets were converted and saved as dbf files. After successfully linking the datasets to GIS, GIS mapping tools was utilized to visualize patterns found for knowledge discovery. The results are presented in the following.

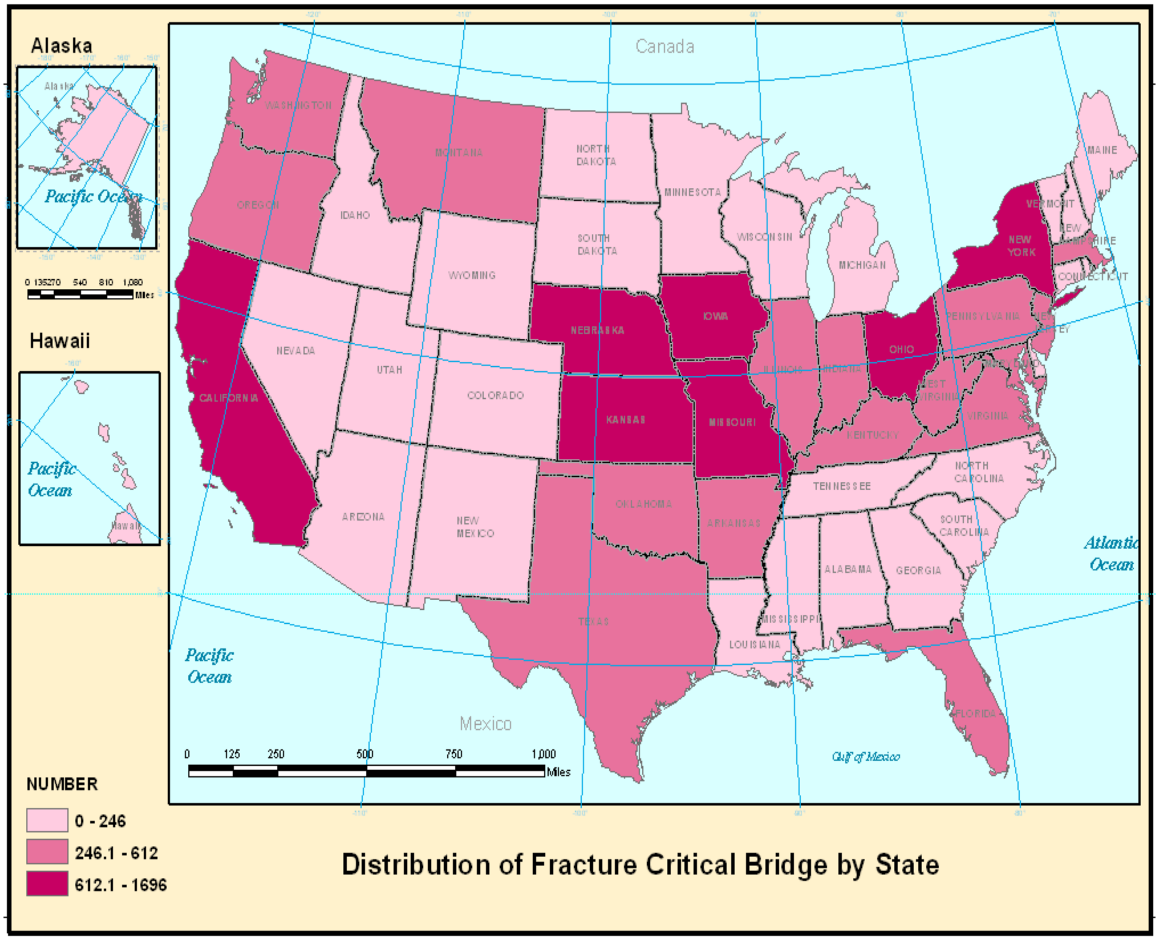

Figure 22 Distribution for Fracture Critical Bridge by State (Based on template from ArcGIS)

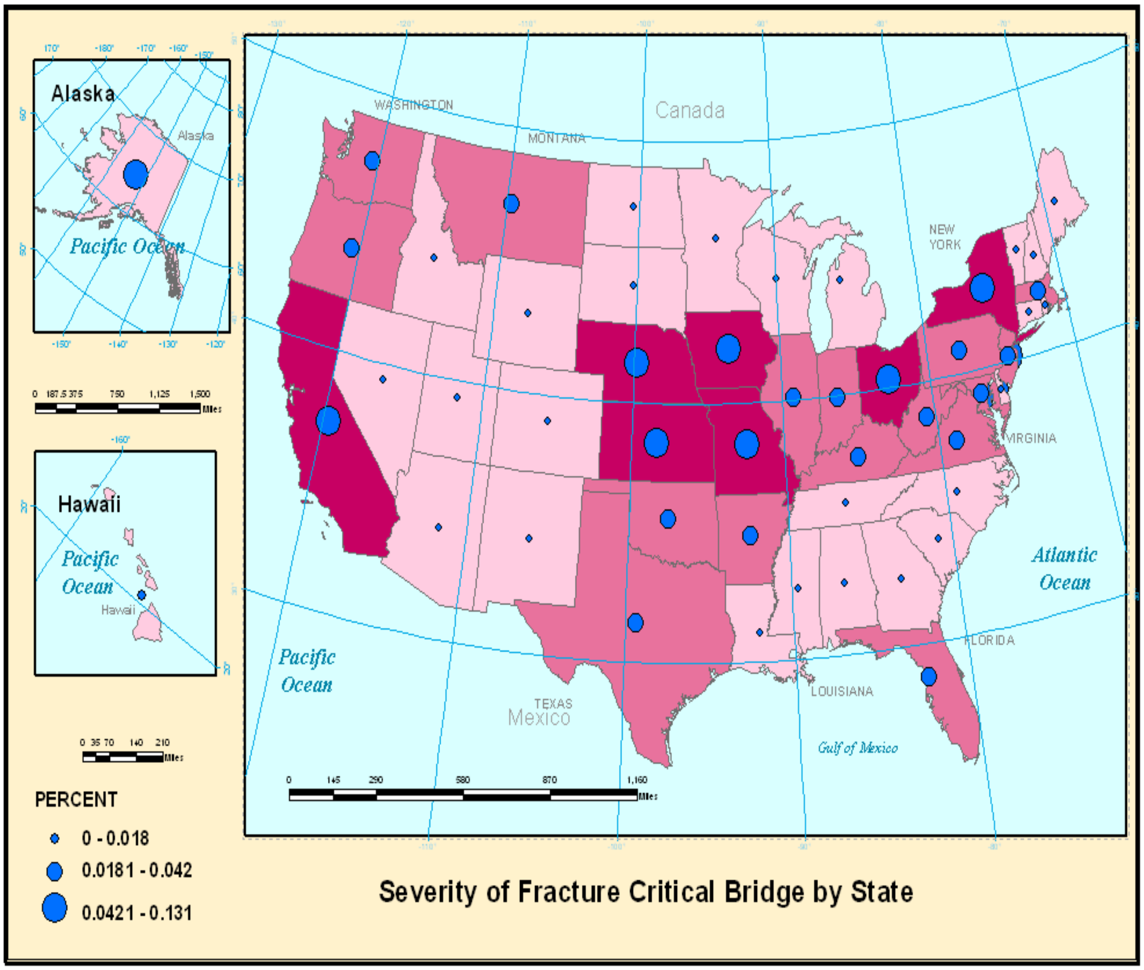

Figure 23 Distribution for the Severity of Fracture Critical Bridge by State (Based on template from ArcGIS)

The maps above illustrate the spatial pattern for fracture critical bridges located in the US. Figure 22 denotes the spatial distribution for fracture critical bridge. Figure 23 shows the distribution for the severity of fracture critical bridge in each state. The severity of fracture critical issue suffered by each state is classified by three levels. The lightest pink denotes states experiencing the least severe fracture critical issue. The darker pink shows state suffering more severe fracture critical issue. The darkest pink indicates state experiencing the most severe fracture critical issue.

Apparently, there are two major patterns shown on the map. The first one is that states located in West Coast, Northwest and the middle of United States experience relatively more severe fracture critical issues in their bridges. In other words, not only do the inspection and maintenance have to be done at these places more frequently, engineers and decision makers there also need to pay attention to the bridge designs when repairing old bridges and constructing new bridges.

The other pattern is that except for Texas and Florida, states located in low latitude suffer less fracture critical issue; these states include Arizona, Louisiana, Georgia, South Carolina, Alabama and others. Although there are lots of variations and factors that could result in this phenomenon, it at least points to a new direction or confirms the importance for researchers and experts to explore in weather and temperature related analysis. In addition, though there are lots of variations among New Jersey, New York and Alaska in population, ADT, bridge designs and age of the bridges, they all suffer the most serious fracture critical issue and all happen to locate in higher latitudes.

Overall, though there are spatial patterns found during this knowledge discovery process, further detailed analysis toward environmental factors appears to be promising in terms of minimizing the risks of fracture critical bridges in the US.

4.5 Spatial Pattern of Bridge by Deficiency Type

The National Bridge Inspection Standard requires bridges longer than 20 feet in total length to conduct safety inspection every two years. The information then is collected and documented in the condition and appraisal ratings of National Bridge Inventory database.

Through periodic inspections of the primary components and the field conditions of bridges such as deck, super structure, substructure, deck geometry and underclearance, experts, engineers and decision makers are able to get more understanding of the performance and condition of the bridges directly, and then develop ways and policy to maintain and manage highway bridges in the United States. In the previous chapter, the knowledge discovery process was performed toward the temporal patterns of the deficiency types. However, it is still not clear whether these deficiency types would evolve over certain places at fixed patterns. In order to understand how these deficiency types change over geographical locations, the spatial pattern discovery process is performed in the following sections.

4.5.1 Spatial Pattern of Bridge by Condition Ratings

The bridge component condition ratings are the primary considerations in classifying a bridge as structural deficient. Once a bridge is classified as “structural deficient”, the bridge the bridge might need further analysis for maintenance, rehabilitation, replacement, closure or load posting. In order to identify any unknown spatial patterns or trends hidden inside the datasets, condition ratings, a knowledge discovery process was performed of the three primary condition ratings, deck, superstructure and substructure.

Based on the preliminary criteria of valid highway bridges and the bridges having 4 or below ratings for deck, superstructure or substructure, the datasets were extracted from the database. Then, the datasets were cross-classified by counties. Since there are too many implicit patterns to identify, the datasets then grouped into states. After that, the datasets were proportional to total number of highway bridges in each state. After the result outputting to the Excel spread sheet, it was then converted to text and saved as dbf file to make it linkable to the GIS attributes. Finally, the map function embedded in the GIS was used to visualize the pattern found during knowledge process. The results are presented as follows.

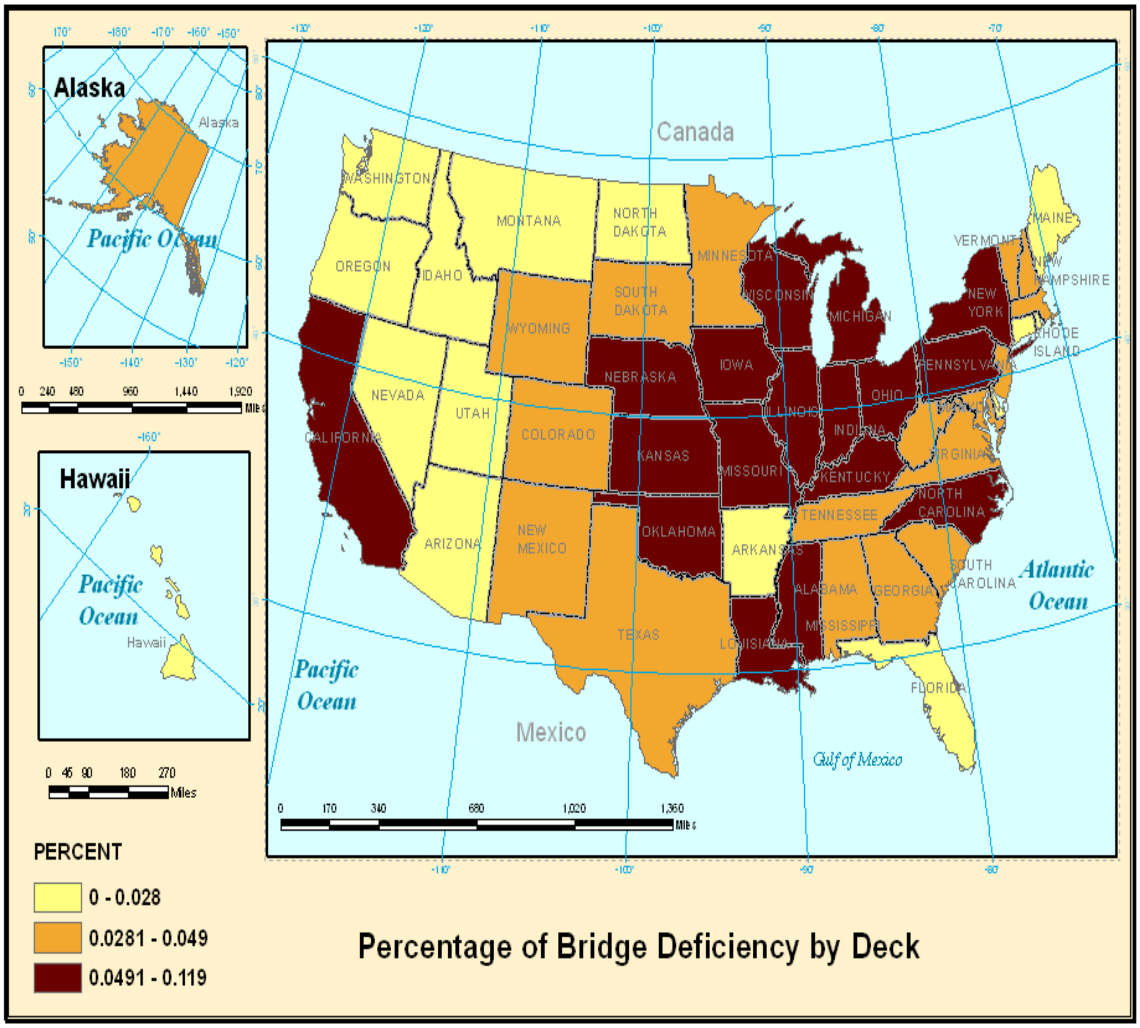

Figure 24 Distribution for Percentage of Bridge Deficiency by Deck (Based on template from ArcGIS)

The 3-quantiles colored map above illustrates the spatial distribution found for the deck deficiency at the state level and is represented by the percentage of deck deficient bridges. The yellow represents the smallest percentage of highway bridges involving deck deficiency. The orange denotes higher percentage of the bridges in that area having deck deficiency issue. The dark crimson color indicates the highest percentage of deck deficient highway bridges.

Most of the states experiencing highest and second highest percentage of deck deficiency, are distributed in eastern United States such as New York, Pennsylvania, Ohio, Indiana, Illinois, Michigan, North Carolina and Wisconsin. Based on the previous summary, these states have more bridges and larger bridges as well bridges with higher ADT. These factors make the deck deficiency issue more significant there. On the other hand, California is the only state in the western U.S. identified as having the most serious deck deficiency issue.

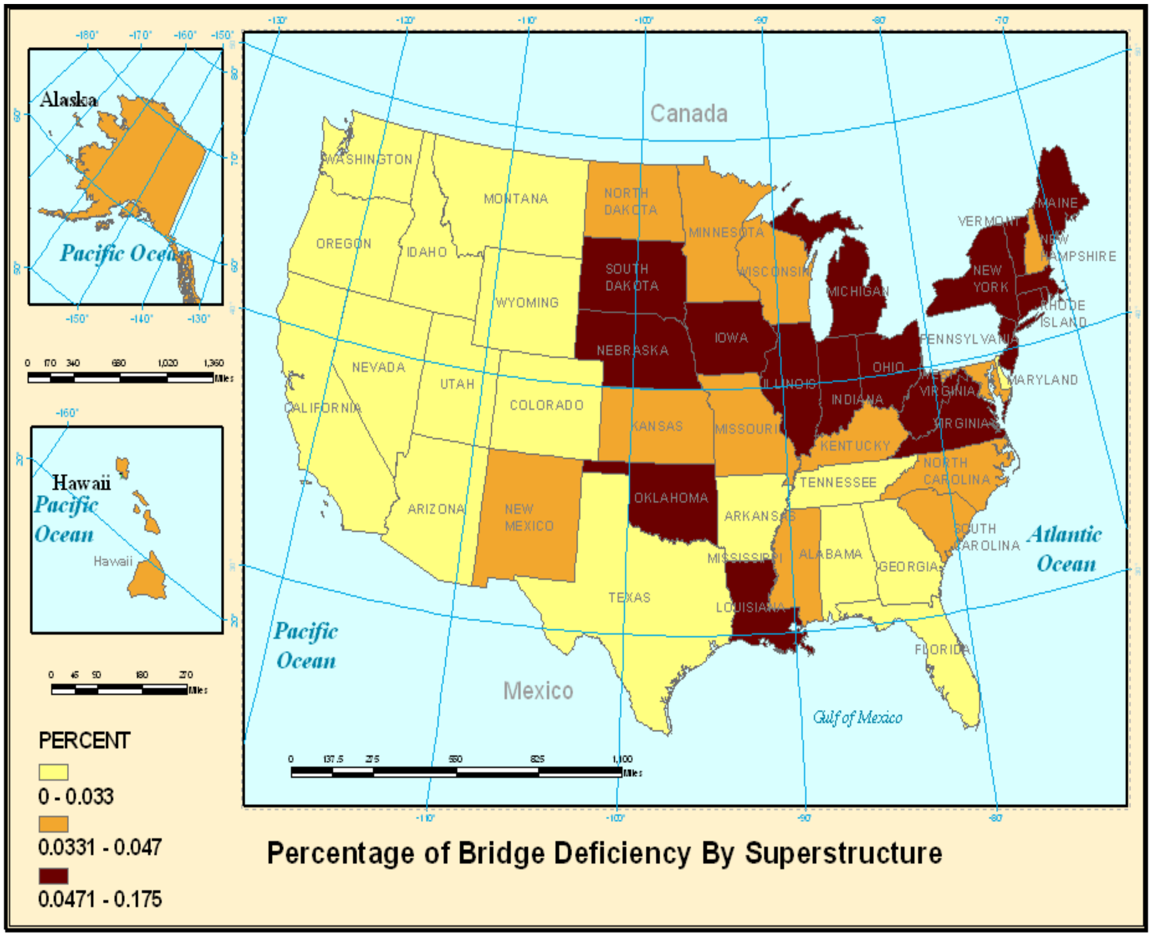

Figure 25 Distribution for Percentage of Bridge Deficiency by Superstructure (Based on template from ArcGIS)

The 3-quantiles colored map above describes the spatial pattern for the structural deficiency by superstructure at the state level. The light yellow represents the smallest percentage of highway bridges in that area involving superstructure deficiency. The dark crimson color indicates the highest percentage of the highway bridges in that area having superstructure deficiency issue.

As contrasted with deck deficiency, the states with more severe superstructure deficiency issues are mostly distributed in states near Great Lakes. These states, such as New York and Pennsylvania, not only have large number of highway bridges involving the deck deficiency issue, but also superstructure deficiency. Particularly, Pennsylvania has been shown as the area having the largest percentage of deficient highway bridges. In addition, it is interesting to find Alaska and Hawaii having higher percentage of superstructure deficient highway bridges. Since there are fewer bridges located there, the larger percentage numbers may be a result of small sample size.

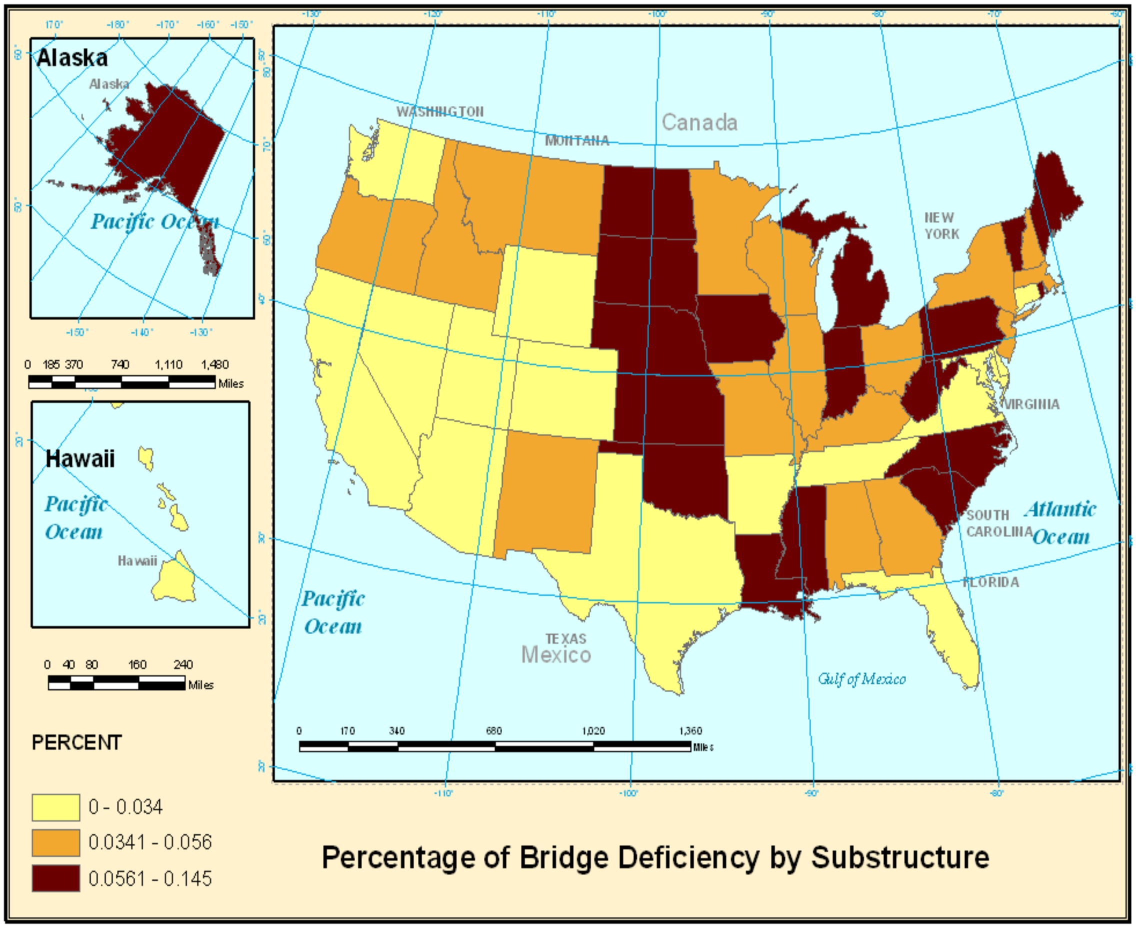

Figure 26 Distribution for Percentage of Bridge Deficiency by Substructure (Based on template from ArcGIS)

The 3-quantiles colored map below illustrates the spatial distribution for substructure deficiency. The distribution appears random and no significant spatial pattern is seen here. Comparing with other states, Pennsylvania still has the largest percentage of deficient highway bridges.

Furthermore, all of the three maps above indicate Ohio, Michigan, Louisiana, New York, North Carolina, Alabama, Oklahoma, Iowa, Kansas and Alaska have relatively higher percentage of structurally deficient highway bridges. Further analysis might be needed for bridges there.

4.5.2 Spatial Pattern of Bridge by Appraisal Ratings

Appraisal ratings are primarily used to classify functionally obsolete bridges. While structural deficiency is generally associated with the deterioration of the bridge components such as deck and superstructure, functional obsolescence is associated with the change of traffic demand on the bridges. For example, bridges with too narrow lanes, no shoulders or poor approach alignment failing to meet current design and safety standards as well as demands are considered as functional obsolete. In addition, structural deficiency and functional obsolescence are not mutually exclusive since two appraisal ratings, structural evaluation and waterway adequacy, are also used to determine structural deficiency. Once either of the ratings shows a 2 or below for a bridge, then a bridge is considered as structurally deficient. Only when either of the criteria shows a 3 will a bridge is determined as functionally obsolete. In this section, the knowledge discovery process focused on all the appraisal ratings shown as 3 or below for both of structural deficiency and functional obsolescence.

To understand how these ratings change over geographical locations, firstly, based on the preliminary criteria of valid highway bridges and the bridges having appraisal ratings as 3 or below, Matlab queries were run to extract the corresponding datasets from the NBI database. Then, a sub query dissected the datasets by state, and the datasets were proportioned to the total number of highway bridges in each state. After that, the result was converted and linked to the GIS attributes. Finally, the GIS map function was used to classify and visualize the spatial patterns found. The results are shown in the following section.

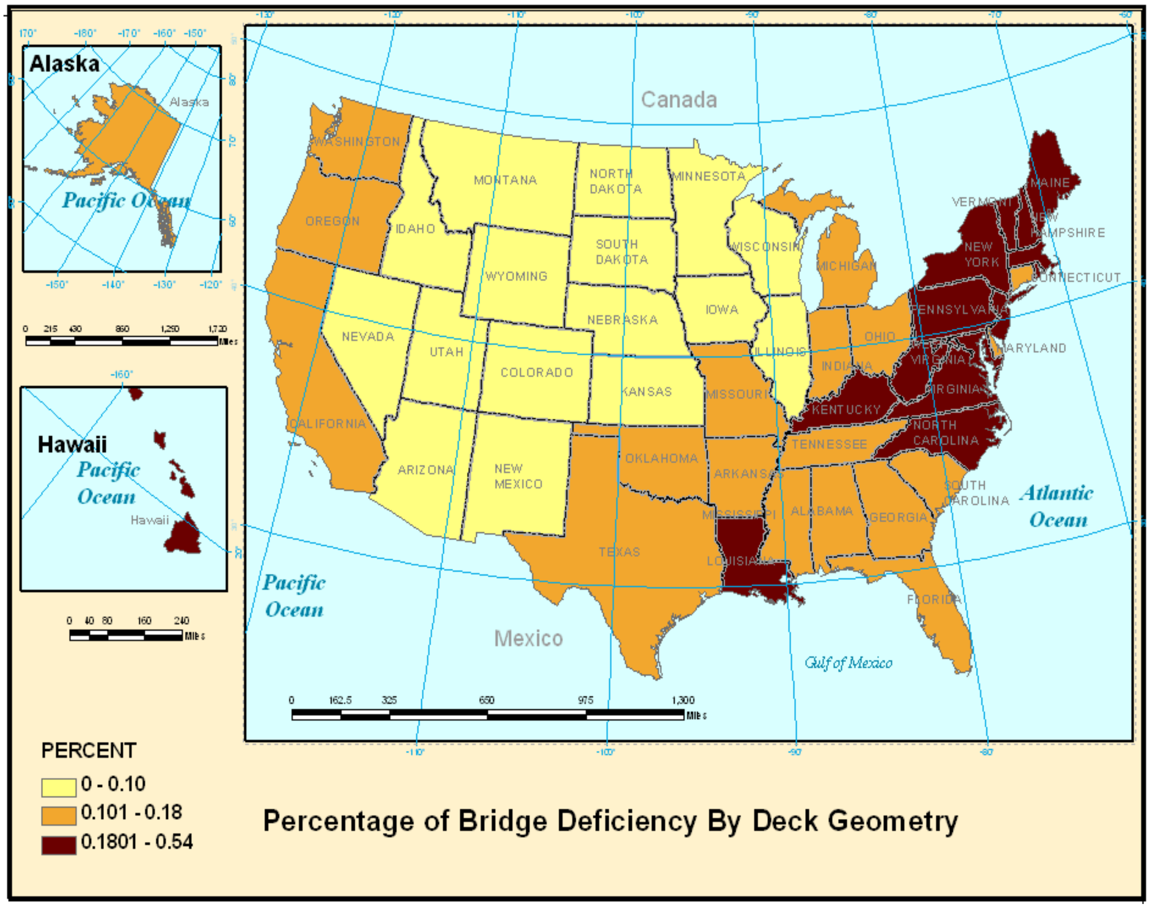

Figure 27 Distribution for Percentage of Bridge Deficiency by Deck Geometry (Based on template from ArcGIS)

The 3-quantiles colored map above describes the spatial distribution for deck geometry. The lightest color shows area with the smallest percentage of the bridges having low ratings for deck geometry. The darkest color denotes an area with the largest percentage of the bridges there having the low rating. In sum, the lightest color is mostly distributed in central United States. It was identified in the previous chapter that deck geometry is the most common type of deficiency in United States. States such as Texas and New York have much larger number of bridges and deck area, yet also have relatively more bridges associated with poor deck geometry. On the other hand, although Hawaii has relatively fewer bridges, it is also the state with largest percentage of its bridges having a deck geometry issue. Further analysis is needed to better understand this observation.

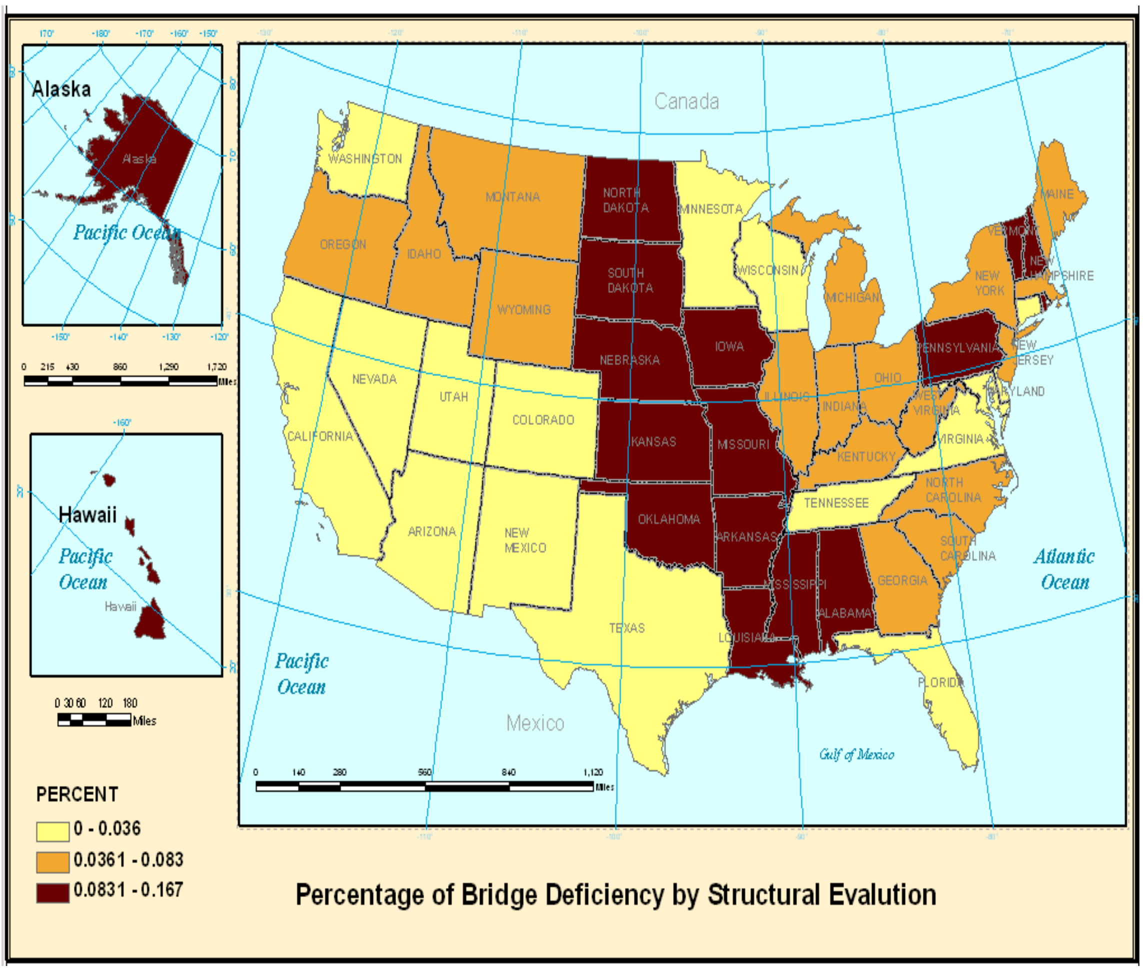

Figure 28 Distribution for Percentage of Bridge Deficiency by Structural Evaluation (Based on template from ArcGIS)

The 3-quantile colored map above describes the spatial distribution for structural evaluation. The lightest color shows that the area has the smallest percentage of the bridges having lower structural evaluation ratings. Likewise, the darkest color denotes an area with the largest percentage of the bridges with the lower rating. In sum, except for Hawaii, Alaska and Pennsylvania, states located in central United States tend to have higher percentage of the bridges with lower rating for structural evaluation.

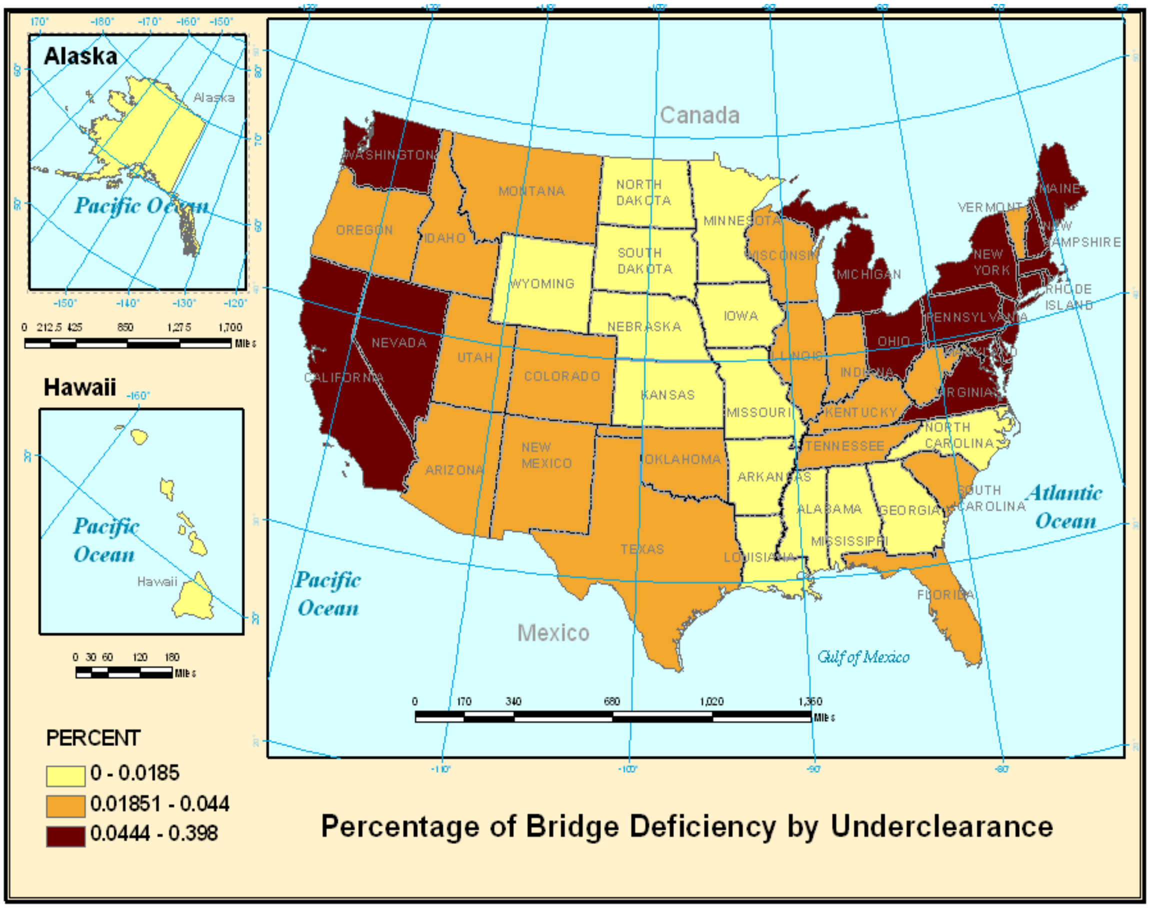

Figure 29 Distribution for Percentage of Bridge Deficiency by Underclearance (Based on template from ArcGIS)

The 3-quantiles colored map above illustrates the spatial distribution for poor underclearance. Likewise, the dark color denotes an area with higher percentage of the bridges having lower ratings for underclearance. Differing with the spatial pattern shown on the previous maps, the darker colors are distributed in northeast of United States, in

California, and in Nevada. Other places, on the other hand, have relatively fewer percentages of the low ratings bridges.

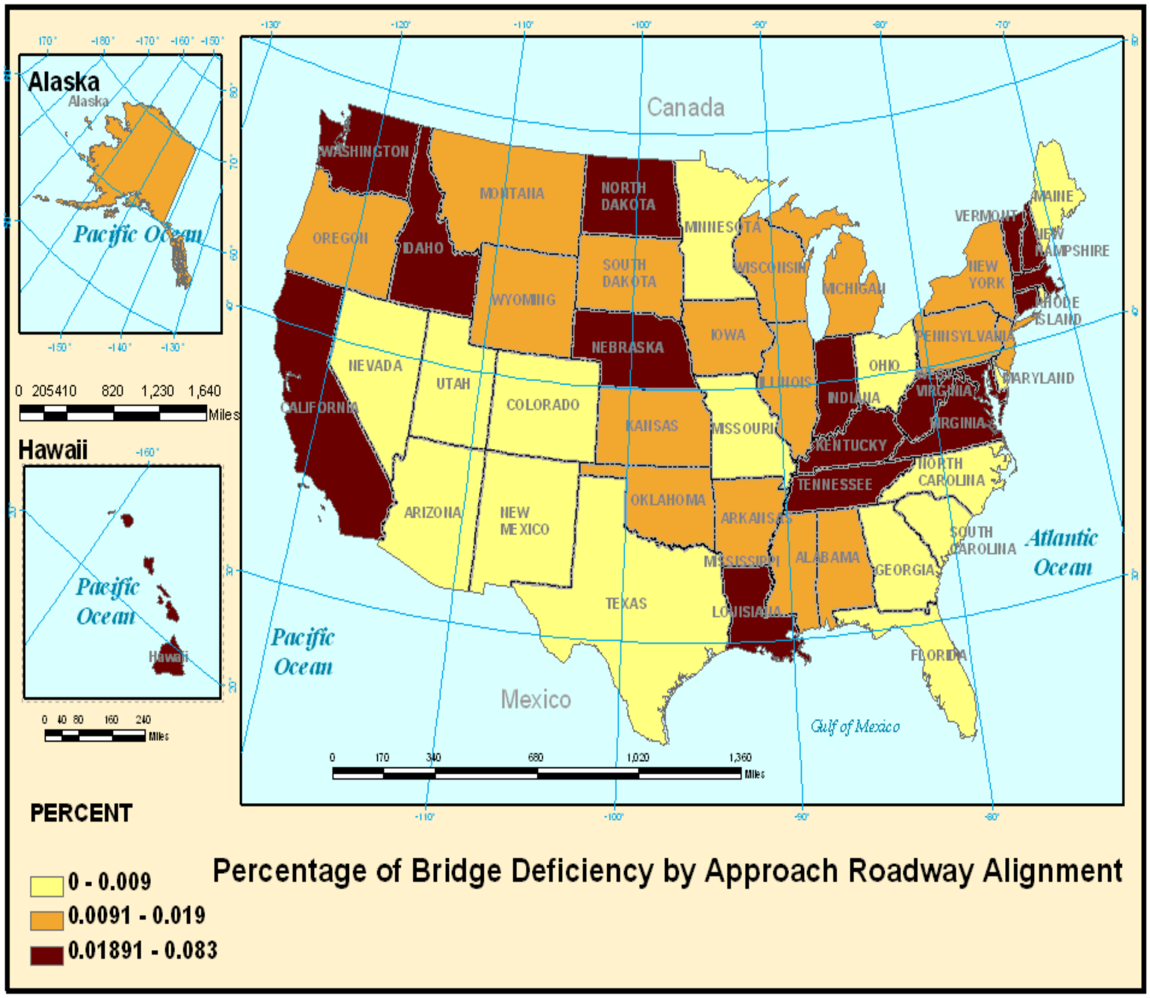

Figure 30 Distribution for Percentage of Bridge Deficiency by Approach Roadway Alignment (Based on template from ArcGIS)

The 3-quantiles colored map above illustrates the spatial distribution for approach roadway alignment. There is no significant spatial trend or pattern found for approach roadway alignment. The darker color does not distribute systematically on the map. For example, states such as Kentucky, Washington and Hawaii have been shown with higher percentages of its bridges associate with the low ratings. Other states around them, on the other hand, have the relatively low percentages.

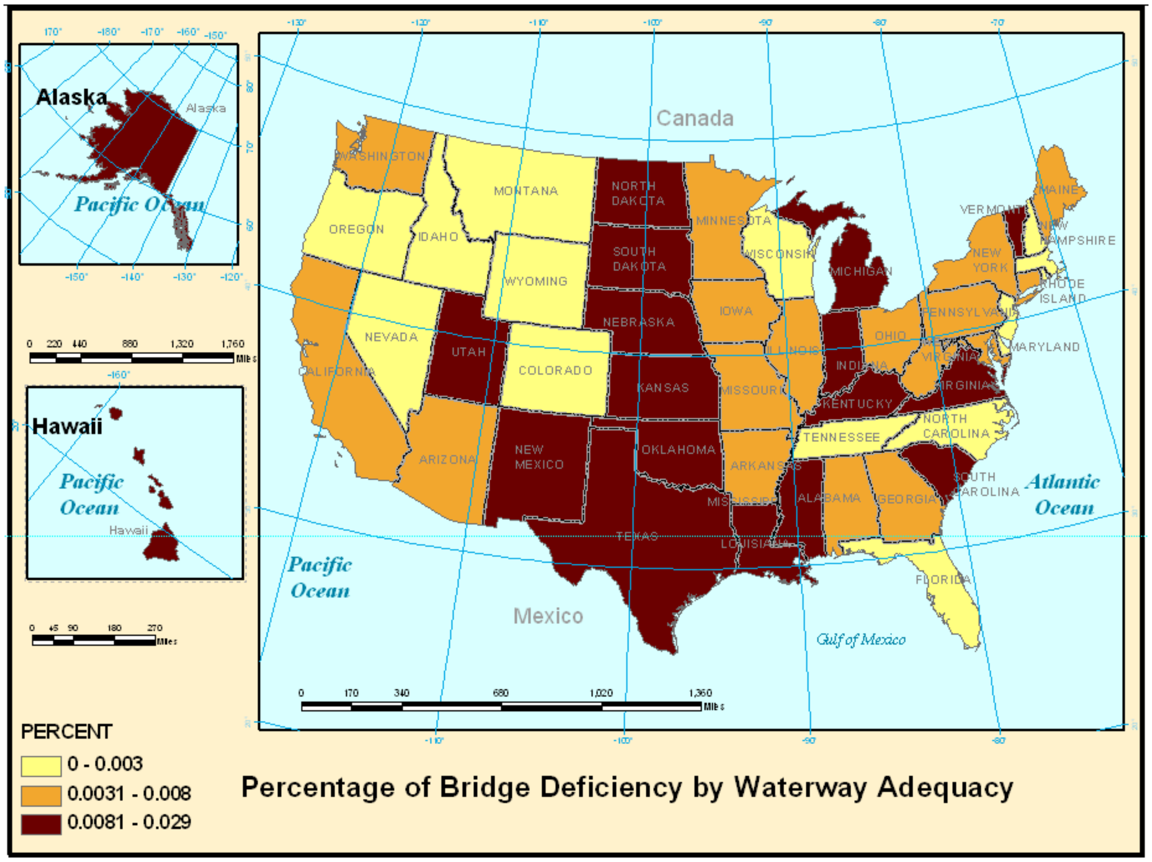

Figure 31 Distribution for Percentage of Bridge Deficiency by Waterway Adequacy (Based on template from ArcGIS)

The 3-quantiles colored map above indicates the spatial distribution for water adequacy. There is no significant pattern shown for waterway adequacy. The darker colors spread around United States. States such as Texas, Louisiana, Kansas, Vermont, Virginia, Alaska, Utah and Mississippi are shown to have a higher percentage of bridges having lower ratings for waterway adequacy

Overall, there were no consistent spatial patterns found for appraisal ratings. The trends shown on the maps are mostly random.

CHAPTER 5 CONCLUSIONS

5.1 Conclusion

This study aimed to investigate the utility of exploratory data analysis methods to provide valuable insights toward better informing the public, decision makers, and other stakeholders on the condition and safety risk of bridges in the United States listed in the National Bridge Inventory. The analysis was implemented with a knowledge discovery process to achieve the objectives of the study while utilizing all available information resources. Further, the study demonstrated the potentiality and efficiency of exploratory data analysis when they are used for discovering unknown patterns and relationships embedded inside large datasets. The knowledge discovered in this research include summary and descriptive statistics of National Bridge Inventory (NBI), temporal and spatial patterns for types of bridge deficiency, load rating, design load, functional classification, bridge design, scour conditions, as well as fractural critical bridges.

The findings reported in this study are significant and useful to local users, bridge owners as well as consulting engineers engaged in the design, inspection and management of highway bridges in the United States. The summary and descriptive statistics of NBI provide significant information on the distribution of highway bridges with certain characteristics and operational conditions in the United States, in terms of number, deck area and average daily traffic at the national and state level. These specific metrics were chosen to summarize the data in the NBI because absolute and relative numbers are the most frequently cited statistics, deck area is directly proportional to asset value and ADT is a measure of user cost. The results are presented in tables and graphs to better highlight the historical and geographical trends. The temporal patterns found in NBI shed light on the characteristics, operational conditions, condition and appraisal ratings of U. S. highway bridges in terms of time differentiation and evolution at the national level. The spatial patterns, on the other hand, provide important knowledge on operational condition, condition and appraisal ratings of the bridge in terms of geo-variation at the national level.

Moreover, the National Bridge Inventory has proven to have great potential as a learning tool for revealing and illuminating important knowledge regarding the nation's highway bridges. This study has successfully utilized the database and extracted previously unknown knowledge via the current technique of EDA, data visualization, on the National Bridge Inventory. Further, this study points out that more hidden knowledge can be discovered if the current National Bridge Inventory is combined with all of the previous data to form into a time-series database. With such a database, not only temporally contiguous datasets can be created to analyze more accurate and reliable trends in the NBI, but additional spatial/temporal patterns are also possible for discovery.

Lastly, since the study largely relies on many queries to extract and generate the datasets from National Bridge Inventory, an example of the Matlab queries is included in the appendixes so that future researches can benefit from utilizing an identical methodology. In fact, the queries, based on the preliminary criteria, are unique in representing a variety of summary and descriptive statistics and preparing and generating the datasets for temporal and spatial patterns. Besides Matlab, future researchers may still want to consider other possible analysis tools such as data mining to efficiently prepare the datasets for knowledge discovery process if the current NBI edition is to be combined with all of its previous data.

5.2 Summary of the Significant Finding

The followings are summarizations of the findings for this research.

1. Significant temporal patterns were found for bridges material and structure type combinations.
2. Significant temporal patterns found for design load indicate that the design load of bridges tend to increase over time. In addition, more than 10 % of US highway bridges have either been designed by a design load standard not specified in the database or have not been designed with any design load standards at all.
3. Significant temporal patterns were found for deficiency types.
4. Through spatial exploratory data analysis, bridges located in Eastern United Sates, especially bridges in Pennsylvania, were found to tend to be designed with lower design load standards.
5. Spatial patterns found for design load and average load rating were not consistent. Future research is needed to investigate these patterns further.
6. Except for substructure, significant spatial patterns were identified for deficiency types.
7. Through spatial exploratory data analysis, bridges in Pennsylvania have been identified for having much higher percentages of scour critical bridge and deficient bridges by deck, superstructure, substructure, deck geometry, structural evaluation or underclearance than the rest of the states. Future research is needed to investigate this discovery.

5.3 Recommendations

In addition to the above insights, the following recommendations were made for future research.

1) Combining the current National Bridge Inventory with its previous editions to form into a time-series database. With such a database, temporally contiguous datasets can be created for advanced time series analysis.

2) Future investigations in the National Bridge Inventory can be directed toward the discovery of temporal and spatial patterns. For example, it is still not clear how the spatial patterns of bridges' conditional and appraisal ratings change over time.

3) More special studies can be conducted further. Since there are several interesting patterns discovered and identified in the previous works, further analysis might be needed to investigate them more detail. For example, in chapter 2.5, it states the unexpected finding that the large percentage of bridges in Alaska was identified as fracture critical bridge.

4) Further analysis or case studies can be conducted toward vulnerabilities with more additional data sets added such as climatic data.

5) Special exploratory studies, focused on some of the more important aspects the Nation's highway bridges could be performed. A few examples are: a detailed

study of the factors resulting in a bridge being classified as structurally deficient, a detailed study of the factors results in a bridge being classified as functionally obsolete, and a detailed study of the association between deck condition and possible explanatory factors, and an investigation of models predicting condition deterioration over time.

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Appendix A: Recording and Coding Guide for the National Bridge Inventory

Data Item 1: States Code 3 digits

The first 2 digits are the same as the Federal Information Processing Standards (FIPS) code for the States, and the third digit is the Federal Highway Administration region code. Although the 3 digits are composed of numbers, they are stored as character in the database.

Code	State	Code	State
014	Alabama	308	Montana
020	Alaska	317	Nebraska
049	Arizona	329	Nevada
056	Arkansas	331	New Hampshire
069	California	342	New Jersey
088	Colorado	356	New Mexico
091	Connecticut	362	New York
103	Delaware	374	North Carolina
113	District of Columbia	388	North Dakota
124	Florida	395	Ohio
134	Georgia	406	Oklahoma
159	Hawaii	410	Oregon
160	Idaho	423	Pennsylvania
175	Illinois	441	Rhode Island
185	Indiana	454	South Carolina
197	Iowa	468	South Dakota
207	Kansas	474	Tennessee
214	Kentucky	486	Texas
226	Louisiana	498	Utah
231	Maine	501	Vermont
243	Maryland	513	Virginia
251	Massachusetts	530	Washington
265	Michigan	543	West Virginia
275	Minnesota	555	Wisconsin
284	Mississippi	568	Wyoming
297	Missouri	721	Puerto Rico

Data Item 2: Highway Agency District 2 digits

The highway agency district represents the highway agency district within which the bridge is located. It is shown by 2- digit code number.

Data Item 3: County (Parish) Code 3 digits

Counties are shown as 3-digit code number, which is identified by the Federal Information Processing Standards (FIPS) codes for the counties.

Data Item 4: Place Code 5 digits

Place code represents census-designated places such as cities, towns and villages. It is identified by the Federal Information Processing Standards (FIPS) codes for place. In addition, if the place code shows all zeros, it means that there is no FIPS place code for it.

Data Item 5: Inventory Route 9 digits

The inventory route consists of 5segments. They are Record Type, Route Signing Prefix, Designated Level of Service, Route Number and Directional Suffix, respectively. The followings list the data information of these 5 segments.

Segm ent			Description		Length
5A	Record Type	There are two types of National Bridge Inventory records," on" and "under". "On" represents the inventory route is carried on the structure. 'Under" means that that the inventory route goes under the structure.	Code		1 digit
			1	Route carried on the structure	
			2	Single route goes "under" the structure	
			A - Z	Multiple routes go "under" the structure	
5B	Route Signing Prefix	Route Signing Prefix represents the class of route. When two or more routes concurrent, the highest class of route is chosen to use.	Code		1digit
			1	Interstate highway	
			2	U.S. numbered highway	
			3	State highway	
			4	County highway	
			5	City street	
			6	Federal lands road	
			7	State land road	
			8	Other	

5C	Designated Level of Service	It is the designated level of service for inventory route	Code		1 digit
			0	None of the below	
			1	Mainline	
			2	Alternate	
			3	Bypass	
			4	Spur	
			6	Business	
			7	Ramp, Wyes, Connector	
			8	Service or unclassified frontage road	
5D	Route Number	It is the route number of the inventory route.			5 digits
5E	Directional Suffix	It is the directional suffix of the inventory route	Code		1 digit
			0	Not applicable	
			1	North	
			2	East	
			3	South	
			4	West	

Data Item 6: Features Intersected 25 digits

It describes the features intersected by the structure and a critical facility indicator. The following lists 2 segments of features intersected.

Segment	Description	Length
6A	Features intersected	24 digits
6B	No Longer Coded (blank)	1 digit

Data Item 7: Facility Carried by Structure 18 digits

It is identified as the facility being carried by the structure, and it only describes the use on the structure.

Data Item 8: Structure Number 15 digits

The structure number is unique for each bridge within the State. Once it is established, it should never be changed during the life time of bridges. If it is essential that the structure number must be changed, all 15 digits are needed to be filled. For any change of structure number, a complete cross reference of corresponding "old" and "new" numbers must be provided to the FHWA Bridge Division.

Data Item 9: Location 25 digits

This item is a narrative description of the locations of bridge within the State.

Data Item 10: Inventory Route, Minimum Vertical Clearance 4 digits

This item codes the minimum vertical clearance over the inventory route, regardless if the route is on the structure or under the structure. Only the greatest of the minimum clearances of two or more openings are coded in a form of XXXX. There is an implied decimal point yielding a measurement in hundredths of a meter in the form of XX.XX meter.

Data Item 11: Kilometer Point 7 digits

The linear referencing system (LRS) kilometer point is used to establish the location of the bridges on the Base Highway Network, and it should come from the same LRS Inventory Route and kilometer point system.

All of the structures located on or overpassing the Base Highway Network should be coded. A 7-digit number is used to represent the LRS kilometer point distance in kilometers to the nearest thousandth of a meter with an assumed decimal point. For structures carrying the LRS Inventory Route, the kilometer point at the beginning of the structure is coded. If the LRS Inventory Route goes under the structure, then the kilometer point on the underpassing route where the structure is first encountered is coded.

Data Item 12: Base Highway Network 1 digit

The Base Highway Network includes the through lane portions of the National Highway System (NHS), rural/urban principal arterial system and rural minor arterial system. R ramps, frontage roads and other roadways are not included. The following list details the data.

Code	Description	
0	If Inventory Route "is not" on the Base Network	Categorical type
1	If Inventory Route "is" on the Base Network	Categorical type

Data Item 13: LRS Inventory Route, Sub-route Number 12 digits

The LRS Inventory Route and Sub-route numbers recorded in this item have to correspond to the LRS Inventory Route and Sub-route numbers reported by the States for the Highway Performance Monitoring System (HPMS).

If data item 12, Base Highway Network, is coded as 1, the information for this item is coded and recorded. If not, then the entire item 13 is left blank. The following 2 segments contain the details of data item 13.

Segment	Description	Length
13A	LRS Inventory Route	10 digits
13B	Sub-route number	2 digits

Data Item 14 and Data Item 15 (Reserved)

Data Item 16: Latitude 8 digits

For bridges on the Strategic Highway Network (STRAHNET) and STRAHNET Connector highways and on the NHS, the latitude of each is coded in degrees, minutes and seconds to the nearest hundredth of a second (with an assumed decimal point). If not, use all zero to code. The following is an example of code for this data item.

Latitude		Code
35□27'18.55"	GPS reading	35271855

Data Item 17: Longitude 9 digits

For bridges on STRAHNET and STRAHNET Connector highways and on the NHS, record and code the longitude of each in degrees, minutes and seconds to the nearest hundredth of a second (with an assumed decimal point). If not, use all zero to code. The following is an example of code for this data item.

Longitude		Code
81□5'50.65"	GPS reading	081055065

Data Item 18 (Reserved)

Data Item 19: Bypass, Detour Length 3 digits

This item indicates the actual length to the nearest kilometer of the detour length. The detour length represents the total additional travel for a vehicle which would result from closing of the bridge. The factor considered when determining if a bypass is available at the site is the potential for moving vehicles, including military vehicles, around the structure. If a ground level bypass is available at the structure site for the inventory route, the detour length is coded as 000. If the detour length exceeds 199 kilometers, it is coded as 199. The following are examples of the coding for detour length.

Example:	Code:
Structure over river; 121-kilometer detour	121
Structure on the dead end road	199

Data Item 20: Toll 1 digit

This item indicates the toll status of the structure. The following codes are used for this data item.

Code	Description
1	Toll bridge. Tolls are paid specifically to use the structure
2	On toll road. The structure carries a toll road. That is, tolls are paid to use the facility, which includes both the highway and the structure.
3	On free road. The structure is toll-free and carries a toll-free highway
4	On Interstate toll segment under Secretarial Agreement. Structure functions as a part of the toll segment
5	Agreement. Structure is separate agreement from highway segment

Data Item 21: Maintenance Responsibility 2 digits

This item indicates the agency that has primary responsibility for maintaining the structure. The following codes are used for this data item.

Code	Description
01	State Highway Agency
02	County Highway Agency
03	Town or Township Highway Agency
04	City or Municipal Highway Agency
11	State Park, Forest, or Reservation Agency
12	Local Park, Forest, or Reservation Agency
21	Other State Agencies
25	Other Local Agencies
26	Private (other than railroad)
27	Railroad
31	State Toll Authority
32	Local Toll Authority
60	Other Federal Agencies (not listed below)
61	Indian Tribal Government
62	Bureau of Indian Affairs
63	Bureau of Fish and Wildlife
64	U.S. Forest Service
66	National Park Service
67	Tennessee Valley Authority
68	Bureau of Land Management
69	Bureau of Reclamation
70	Corps of Engineers (Civil)
71	Corps of Engineers (Military)
72	Air Force
73	Navy/Marines

74	Army
75	NASA
76	Metropolitan Washington Airports Service
80	Unknown

Data Item 22: Owner 2 digits

The codes used in data item 21, maintenance responsibility, are also used to represent the agency that is the primary owner of the structure.

Data Item 23 through Data Item 25 (Reserved)

Data Item 26: Functional Classification of Inventory Route 2 digits

This item indicates the functional classification for Inventory Route. The codes used for this item are listed below.

Code		
01	Rural	Principal Arterial - Interstate
02		Principal Arterial – Other
06		Minor Arterial
07		Major Collector
08		Minor Collector
09		Local
11	Urban	Principal Arterial - Interstate
12		Principal Arterial – Other Freeway or Expressways
14		Other Principal Arterial
16		Minor Arterial
17		Collector
19		Local

The urban or rural designation is determined by the bridge location instead of the character of the roadway.

Data Item 27: Year Built 4 digits

This item indicates the year of construction of the structure. If the year built is unknown, a best estimate is being provided.

Data Item 28: Lanes On and Under the Structure 4 digits

This item indicates the number of lanes being carried by and crossed over by the structure. For example, if the inventory route is on the bridge, the sum of the total number of lances on the inventory route should be coded. The followings 2 segments comprise item 28.

Segment	Description	Length
28A	Lanes on the structure	2 digit
28B	Lanes under the structure	2 digit

Data Item 29: Average Daily Traffic 6 digits

This item shows the average daily traffic volume for the inventory route identified in item 5. It is represented by 6-digit code number. The followings are examples for this item.

Average Daily Traffic	Code
540	000540
15,662	015662

Data Item 30: Year of Average Daily Traffic 4 digits

This item indicates the year of the ADT volume that recorded in Data Item 29.

Data Item 31: Design Load 1 digit

This item indicates the live load for which the structure was designed. The following codes are used for this item.

Code	Metric Description	or	English Description
1	M 9		H 10
2	M 13.5		H 15
3	MS 13.5		HS 15
4	M 18		H 20
5	MS 18		HS 20
6	MS 18+Mod		HS 20+Mod
7	Pedestrian		Pedestrian
8	Railroad		Railroad
9	MS 22.5		HS 25
0	Other or Unknown (describe on inspection reporting form)		Other or Unknown (describe on inspection reporting form)

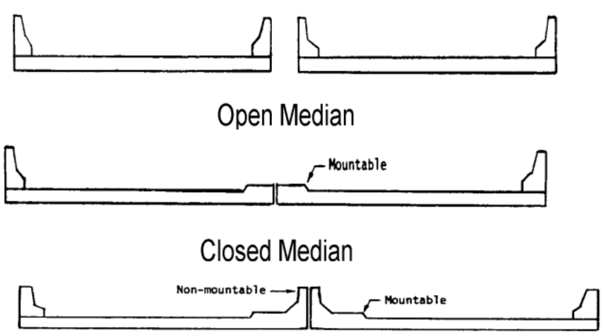
Data Item 32: Approach Roadway Width 4 digits

This item indicates the most restrictive width of usable roadway approaching the structure. The usable roadway width includes the width of traffic lanes and the width of shoulders. For certain situation, if structures with medians of any type or double-decked structure, this item should be coded as the sum of the usable roadway width for the approach roadways. The approach roadway width is coded and recorded as a 4-digit number, interpreted as XXX.X (meters).

Data Item 33: Bridge Median 1digit

The followings are information of codes used in this item.

Code	Description
0	No median
1	Open median
2	Closed median (no barrier)
3	Closed median with non-mountable barriers



Closed Median with Non-mountable Barrier

Data Item 34: Skew 2 digits

The skew is the angle between the centerline of a píer and a line normal to the roadway sentirem. The followings are the example of codes used to represent skew.

Skew angle	Code
8°	08
29°	29

Data Item 35: Structure Flared 1 digit

This item indicates if the structure is flared or not. The codes used in this item are shown below.

Code	Description
0	No flare
1	Yes, flared

Data Item 36: Traffic Safety Features 4 digits

This item records information of traffic safety features. The following codes are for the 4 segments of the traffic safety features item.

Segment	Description	Length
36A	Bridge railings	1 digit
36B	Transitions	1 digit
36C	Approach guardrail	1 digit
36D	Approach guardrail ends	1 digit

Code	Description
0	Inspected feature does not meet currently acceptable standards, or a safety feature is required and none is provided
1	Inspected feature meets currently acceptable standards
N	Not applicable or a safety feature is not required

For example, if all features meet currently acceptable standards except transition, then it is coded as 1011.

Data Item 37: Historical Significance 1 digit

The historical significance of a bridge involves a variety of characteristics: the bridge may be a particularly unique example of the history of engineering; the crossing might be significant; the bridge might be associated with a historical property or area; or historical significance could be derived from the fact the bridge was associated with significant events or circumstances. The followings codes are used in this data item.

Code	Description
1	Bridge is on the National Register of Historic Places
2	Bridge is eligible for the National Register of Historic Places
3	Bridge is possibly eligible for the National Register of Historic Places (requires further investigation before determination can be made) or bridge is on a State or local historic register
4	Historical significance is not determinable at this time
5	Bridge is not eligible for the National Register of Historic Places

Data Item 38: Navigation Control 1 digit

The followings codes as used for this item.

Code	Description
N	No applicable, no waterway
0	No navigation control on waterway (bridge permit not required)
1	Navigation Control on waterway (bridge permit required)

Data Item 39: Navigation Vertical Clearance 4 digits

If item 38 (Navigation Control) is coded as 1, this item will code and record the minimum vertical clearance imposed at the site. The measurement represents the clearance that is allowable for navigational purposes. It is coded as 4-digit number, and can be interpreted as XXX.X (meters). If the Item 38 (Navigation Control) is coded as 0 or N, then 000 is used to indicate not applicable.

Data Item 40: Navigation Horizontal Clearance 5 digits

If the item 38 (Navigation Control) is coded as 1, this item will code and record the horizontal clearance imposed at the site. However, if the item 38(Navigation Control) is coded as o or N, then 0000 is used to indicate not applicable.

The navigation horizontal clearance is coded and recorded as a 5-digit number, interpreted as XXXX.X (meters).

Data Item 41: Structure Open, Posted, or Closed to Traffic 1 digit

This item codes information about the actual operational status of a structure. The following codes are used for this item.

Code	Description
A	Open, no restriction
B	Open, posting recommended but not legally implemented (all signs not in place or not correctly implemented)
D	Open, would be posted or closed except for temporary shoring, etc. to allow for unrestricted traffic
E	Open, temporary structure in place to carry legal loads while original structure is closed and awaiting replacement or rehabilitation
G	New structure not yet open to traffic
K	Bridge closed to all traffic
P	Posted for load (may include other restrictions such as temporary bridges which are load posted)
R	Posted for other load-capacity restriction (speed, number of vehicles on bridge, etc.)

Data Item 42: Type of Service 2 digits

This item indicates the type of service on the bridge and under the bridges, respectively. The following codes are used for the 2 segments of this item.

Segment		Code	Description
42 A	Type of service on bridge	1	Highway
		2	Railroad
		3	Pedestrian-bicycle
		4	Highway-railroad
		5	Highway-pedestrian
		6	Overpass structure at an interchange or second level of a multilevel interchange
		7	Third level (Interchange)
		8	Fourth level (Interchange)
		9	Building or plaza
		0	Other

42 B	Type of service under bridge	1	Highway, with or without pedestrian
		2	Railroad
		3	Pedestrian-bicycle
		4	Highway-railroad
		5	Waterway
		6	Highway-waterway
		7	Railroad-waterway
		8	Highway-waterway-railroad
		9	Relief for waterway
		0	Other

Data Item 43: Structure Type, Main 3 digits

This item codes the type of structure for the main span(s) with a 3-digit code composed of 2 segments.

Segment		Code	Description
43 A	Kind of material and/or design	1	Concrete
		2	Concrete continuous
		3	Steel
		4	Steel continuous
		5	Pre-stressed concrete
		6	Pre-stressed concrete continuous
		7	Wood or Timber
		8	Masonry
		9	Aluminum, Wrought Iron, or Cast Iron
		0	Other
43 B	Type of design and/or construction	01	Slab
		02	Stringer/Multi-beam or Girder
		03	Girder and Floor beam System
		04	Tee Beam
		05	Box Beam or Girders - Multiple
		06	Box Beam or Girders - Single or Spread
		07	Frame (except frame culverts)
		08	Orthotropic
		09	Truss - Deck
		10	Truss - Thru
		11	Arch - Deck
		12	Arch - Thru
		13	Suspension
		14	Stayed Girder
		15	Movable-Lift
		16	Movable-Bascule
		17	Movable-Swing
		18	Tunnel
		19	Culvert (includes frame culverts)

		20	Mixed types
		21	Segmental Box Girder
		22	Channel Beam
		00	Other

Data Item 44: Structure Type, Approach Spans 3 digits

This item indicates the type of structure for the approach spans to a major bridge or for the spans where the structural material is different.

The codes used for this item is the same as the codes for item 43. Yet, if this item is not applicable, code 000 will be used instead. The followings are descriptions of 2 segments of this item.

Segment	Description	Length
44A	Kind of material and/or design	1 digit
44B	Type of design and/or construction	2 digits

Data Item 45: Number of Spans in Main Unit 3 digits

This item shows the number of spans in the main or major unit.

Data Item 46: Number of Approach Spans 4 digits

If applicable, this item provides the number of spans in the approach to the major bridge, or the number of spans, which are constructed of a different material from that of the major bridge.

Data Item 47: Inventory Route, Total Horizontal Clearance 3 digits

The total horizontal clearance for the inventory route identified in Item 5 is measured and recorded. The total horizontal clearance is coded and recorded as a 3-digit number, interpreted as XX.X (meters).

Data Item 48: Length of Maximum Span 5 digits

This item records the length of the maximum span. It is coded as a 5-digit number, which can be interpreted as XXXX.X (meters).

The followings are examples of the coding format used in this item.

Length of Maximum Span	Code
37.5 meters	00375
1219.2 meters	12192

Data Item 49: Structure Length 6 digits

This item records the length of roadway that is supported on the bridge structure. It is coded as a 6-digit number, which can be interpreted as XXX XX.X (meters). For culvert length, it is measured along the centerline of roadway regardless of the depth below grade, and the measurement is also made between inside faces of exterior walls. For tunnel length, it is measured along the centerline of the roadway. The followings are examples of the coding format used in this item.

Structure length	Code
542.1 meters	005421
10123.1 meters	101231

Data Item 50: Curb or Sidewalk Widths 6 digits

This item is composed of 2 segments, each recorded as a 3-digit number to indicate the widths of the left and right curbs or sidewalks to nearest tenth of a meter (with assumed decimal points). The descriptions of the 2 segments are shown below.

Segment			Length
50A	Left curb or sidewalk width		3 digits
50B	Right curb or sidewalk width		3 digits
Example:	XX.X meters	XX.X meters	
Curb or sidewalk	Left Side	Right Side	Code
	None	2.3 meters	000023
	12.1 meters	11.5 meters	121115

	3.3 meters	None	033000

Data Item 51: Bridge Roadway Width, Curb-to-Curb 4 digits

This item records the most restrictive minimum distance between curbs or rails on the structure roadway. For certain situation, such as double decked structures and structures with closed medians, this item records the sum of the most restrictive minimum distances for all roadways carried by the structure. Flared areas for ramps are excluded in this item. The bridge roadway width is coded as a 4-digit number, which can be interpreted as XXX.X (meters). The followings are examples of data recorded in this item.

Bridge Roadway Width	Code
16.00 meters wide	0160
33.07 meters wide	0331

Data Item 52: Deck Width, Out-to-Out 4 digits

This item is recorded as a form of 4-digit number, which can be interpreted as XXX.X (meters), to show the out-to-out width to the nearest tenth of a meter (with an assumed decimal point).

Data Item 53: Minimum Vertical Clearance Over Bridge Roadway 4 digits

This item records the actual minimum vertical clearance over the bridge roadway, including shoulders, to any superstructure restriction, rounded down to the nearest hundredth of a meter.

If no superstructure restriction exists above the bridge roadway, or the restriction is 30 meters or greater, then the code, 9999, should be used in this item.

The minimum vertical clearance over bridge roadway is coded as a 4-digit number, which can be interpreted as XXX.X (meters). The followings are examples of codes recorded in this item.

Minimum Vertical Clearance	Code
No restriction	9999
5.25 meters	0525
23.00 meters	2300
38.50 meters	9999

<u>Data Item 54: Minimum Vertical Under-clearance 5 digits</u>

This item records the minimum vertical clearance from the roadway (travel lanes only) or railroad track beneath the structure to the underside of the superstructure. If railroad and highway are both under the structure, the most critical dimension should be recorded in this item.

This item is composed of 2 segments. The followings are detailed information and examples of the segments.

<table>
<tr><th>Segment</th><th></th><th colspan="2"></th><th>Length</th></tr>
<tr><td rowspan="4">54A</td><td rowspan="4">Reference feature</td><td>Code</td><td>Description</td><td rowspan="4">1 digit</td></tr>
<tr><td>H</td><td>Highway beneath structure</td></tr>
<tr><td>R</td><td>Railroad beneath structure</td></tr>
<tr><td>N</td><td>Feature not a highway or railroad</td></tr>
<tr><td>54B</td><td>Minimum Vertical Under-clearance</td><td colspan="2">It is coded as a 4-digit number, which can be interpreted as XXX.X (meters)</td><td>4 digits</td></tr>
</table>

Example	Code
River beneath structure	N0000
Railroad 9.529 meters beneath structure	R0952
Highway 10.464 meters beneath structure	H1046

Data Item 55: Minimum Lateral Under-clearance on Right 4 digits

This item describes the minimum lateral under-clearance on the right to the nearest tenth of a meter (with an assumed decimal point). If railroad and highway are both under the structure, the most critical dimension is coded and recorded is this item.

This item is composed of 2 segments. The followings are detailed information and examples of the 2 segments.

Segment				Length
55A	Reference feature	Code	Description	1 digit
		H	Highway beneath structure	
		R	Railroad beneath structure	
		N	Feature not a highway or railroad	
55B	Minimum Lateral Under-clearance			3 digits

Example	Code
Railroad 6.22 meters centerline to pier	R062
Highway 6.16 meters edge of pavement to pier	H062

Data Item 56: Minimum Lateral Under-clearance on Left 4 digits

The lateral clearance recorded in this item should be measured from the left edge of the roadway (excluding shoulders) to the nearest substructure unit, to a rigid barrier, or to the toe of slope steeper than 1 to 3.

If there is no obstruction in the median area, a notation of "open" should be recorded and coded as 999. For clearances greater than 30 meters, it should be coded as 998. For railroad, 000 is used to indicate not applicable.

In addition, the information is coded and recorded as a form of 3-digit numbers here, and can be easily interpreted as XX.X (meters).

Data Item: 57 (Reserved)

Data Item: 58 Decks - (Condition Rating) 1digit

This item describes the overall condition rating of the deck. The following codes are used for the condition rating of the deck.

Code	Description
N	NOT APPLICABLE
9	EXCELLENT CONDITION
8	VERY GOOD CONDITION - no problems noted
7	GOOD CONDITION - some minor problems
6	SATISFACTORY CONDITION - structural elements show some minor deterioration
5	FAIR CONDITION - all primary structural elements are sound but may have minor section loss, cracking, spalling or scour
4	POOR CONDITION - advanced section loss, deterioration, spalling or scour
3	SERIOUS CONDITION - loss of section, deterioration, spalling or scour have seriously affected primary structural components. Local failures are possible. Fatigue cracks in steel or shear cracks in concrete may be present
2	CRITICAL CONDITION - advanced deterioration of primary structural elements. Fatigue cracks in steel or shear cracks in concrete may be present or scour may have removed substructure support. Unless closely monitored it may be necessary to close the bridge until corrective action is taken
1	"IMMINENT" FAILURE CONDITION - major deterioration or section loss present in critical structural components or obvious vertical or horizontal movement affecting structure stability. Bridge is closed to traffic but corrective action may put back in light service.
0	FAILED CONDITION - out of service - beyond corrective action

Data Item 59: Superstructure - (Condition Rating) 1digit

This item describes the physical condition rating of all structural members. The following codes are used for the condition rating of the structural members.

Code	Description
N	NOT APPLICABLE
9	EXCELLENT CONDITION
8	VERY GOOD CONDITION - no problems noted
7	GOOD CONDITION - some minor problems
6	SATISFACTORY CONDITION - structural elements show some minor deterioration
5	FAIR CONDITION - all primary structural elements are sound but may have minor section loss, cracking, spalling or scour
4	POOR CONDITION - advanced section loss, deterioration, spalling or scour
3	SERIOUS CONDITION - loss of section, deterioration, spalling or scour have seriously affected primary structural components. Local failures are possible. Fatigue cracks in steel or shear cracks in concrete may be present
2	CRITICAL CONDITION - advanced deterioration of primary structural elements. Fatigue cracks in steel or shear cracks in concrete may be present or scour may have removed substructure support. Unless closely monitored it may be necessary to close the bridge until corrective action is taken
1	"IMMINENT" FAILURE CONDITION - major deterioration or section loss present in critical structural components or obvious vertical or horizontal movement affecting structure stability. Bridge is closed to traffic but corrective action may put back in light service.
0	FAILED CONDITION - out of service - beyond corrective action

Data Item 60 Substructure- (Condition Rating) 1digit

This item describes the physical condition of piers, abutments, piles, fenders, footings, or other components. The following codes are used for the condition rating of the substructure.

Code	Description
N	NOT APPLICABLE
9	EXCELLENT CONDITION

8	VERY GOOD CONDITION - no problems noted
7	GOOD CONDITION - some minor problems
6	SATISFACTORY CONDITION - structural elements show some minor deterioration
5	FAIR CONDITION - all primary structural elements are sound but may have minor section loss, cracking, spalling or scour
4	POOR CONDITION - advanced section loss, deterioration, spalling or scour
3	SERIOUS CONDITION - loss of section, deterioration, spalling or scour have seriously affected primary structural components. Local failures are possible. Fatigue cracks in steel or shear cracks in concrete may be present
2	CRITICAL CONDITION - advanced deterioration of primary structural elements. Fatigue cracks in steel or shear cracks in concrete may be present or scour may have removed substructure support. Unless closely monitored it may be necessary to close the bridge until corrective action is taken
1	"IMMINENT" FAILURE CONDITION - major deterioration or section loss present in critical structural components or obvious vertical or horizontal movement affecting structure stability. Bridge is closed to traffic but corrective action may put back in light service.
0	FAILED CONDITION - out of service - beyond corrective action

Data Item 61: Channel and Channel Protection-(Condition Rating) 1digit

This item describes the physical conditions associated with the flow of water through the bridge and includes factors such as stream stability and the condition of the channel, riprap, slope protection, or stream control devices including spur dikes.

The following codes are used for the condition rating of channel and channel protection.

Code	Description
N	Not applicable. Use when bridge is not over a waterway (channel)
9	There are no noticeable or noteworthy deficiencies which affect the condition of the channel
8	Banks are protected or well vegetated. River control devices such as spur dikes and embankment protection are not required or are in a stable condition
7	Bank protection is in need of minor repairs. River control devices and embankment protection have a little minor damage. Banks and/or channel have minor amounts of drift
6	Bank is beginning to slump. River control devices and embankment protection have

	widespread minor damage. There is minor stream bed movement evident. Debris is restricting the channel slightly
5	Bank protection is being eroded. River control devices and/or embankment have major damage. Trees and brush restrict the channel
4	Bank and embankment protection is severely undermined. River control devices have severe damage. Large deposits of debris are in the channel.
3	Bank protection has failed. River control devices have been destroyed. Stream bed aggradations, degradation or lateral movement has changed the channel to now threaten the bridge and/or approach roadway
2	The channel has changed to the extent the bridge is near a state of collapse
1	Bridge closed because of channel failure. Corrective action may put back in light service
0	Bridge closed because of channel failure. Replacement necessary

Data Item 62 Culverts-(Condition Rating) 1 digit

This item evaluates the alignment, settlement, joints, structural condition, scour, and other items associated with culverts. The rating code is intended to be an overall condition evaluation of the culvert.

The following codes are used for the condition rating of culverts.

Code	Description
N	Not applicable. Use if structure is not a culvert
9	No deficiencies
8	No noticeable or noteworthy deficiencies which affect the condition of the culvert. Insignificant scrape marks caused by drift
7	Shrinkage cracks, light scaling, and insignificant spalling which does not expose reinforcing steel. Insignificant damage caused by drift with no misalignment and not requiring corrective action. Some minor scouring has occurred near curtain walls, wingwalls, or pipes. Metal culverts have a smooth symmetrical curvature with superficial corrosion and no pitting
6	Deterioration or initial disintegration, minor chloride contamination, cracking with some leaching, or spalls on concrete or masonry walls and slabs. Local minor scouring at curtain walls, wingwalls, or pipes. Metal culverts have a smooth curvature, non-symmetrical shape, significant corrosion or moderate pitting
5	Moderate to major deterioration or disintegration, extensive cracking and leaching, or spalls on concrete or masonry walls and slabs. Minor settlement or misalignment. Noticeable scouring or erosion at curtain walls, wingwalls, or pipes. Metal culverts have significant distortion and deflection in one section, significant corrosion or deep pitting

4	Large spalls, heavy scaling, wide cracks, considerable efflorescence, or opened construction joint permitting loss of backfill. Considerable settlement or misalignment. Considerable scouring or erosion at curtain walls, wingwalls or pipes. Metal culverts have significant distortion and deflection throughout, extensive corrosion or deep pitting
3	Any condition described in Code 4 but which is excessive in scope. Severe movement or differential settlement of the segments, or loss of fill. Holes may exist in walls or slabs. Integral wing walls nearly severed from culvert. Severe scour or erosion at curtain walls, wing walls or pipes. Metal culverts have extreme distortion and deflection in one section, extensive corrosion, or deep pitting with scattered perforations.
2	Integral wing walls collapsed severe settlement of roadway due to loss of fill. Section of culvert may have failed and can no longer support embankment. Complete undermining at curtain walls and pipes. Corrective action required to maintain traffic. Metal culverts have extreme distortion and deflection throughout with extensive perforations due to corrosion
1	Bridge closed. Corrective action may put back in light service
0	Bridge closed. Replacement necessary

Data Item 63: Method Used to Determine Operating Rating 1digit

This item indicates which load rating method was used to determine the Operating Rating coded in Item 64 for this structure.

The following codes are used for this item.

Code	Description
1	Load Factor (LF)
2	Allowable Stress (AS)
3	Load and Resistance Factor (LRFR)
4	Load Testing
5	No rating analysis performed

Data Item 64: Operating Rating 3digits

This capacity rating, referred to as the operating rating, results in the absolute maximum permissible load level to which the structure may be subjected for the vehicle type used in the rating.

The operating rating is coded as a 3-digit number to represent the total mass in metric tons of the entire vehicle measured to the nearest tenth of a metric ton (with an assumed decimal point). For a structure unaffected by live load, code 999 is used to record the data.

The use or presence of a temporary bridge or shoring requires special consideration in the coding. In such cases, since there is no permanent bridge, this item is coded as 000 even though the temporary structure is rated for as much as full legal load

The followings are examples of the operating rating recorded in this item.

Examples	Code
MS27	486
Temporary bridge	000
Shored-up bridge	030

Data Item 65: Method Used to Determine Inventory Rating 1digit

This item indicates which load rating method was used to determine the Inventory Rating coded in Item 66 for this structure.

The following codes are used for this item.

Code	Description
1	Load Factor (LF)
2	Allowable Stress (AS)
3	Load and Resistance Factor (LRFR)
4	Load Testing
5	No rating analysis performed

Data Item 66: Inventory Rating 3 digits

This capacity rating, referred to as the inventory rating, will result in a load level which can safely utilize an existing structure for an indefinite period of time. Only the MS loading is used to determine the inventory rating.

The inventory rating is coded as a 3-digit number to represent the total mass in metric tons of the entire vehicle measured to the nearest tenth of a metric ton (with an assumed decimal point). For a structure unaffected by live load, code 999 is used to record the data.

Appraisal Ratings

Items 67, 68, 69, 71, and 72 - indicate the Appraisal Ratings. The items in the Appraisal Section are used to evaluate a bridge in relation to the level of service which it provides on the highway system of which it is a part. The structure will be compared to a new one which is built to current standards for that particular type of road as further defined in this section except for Item 72 - Approach Roadway Alignment.

Items 67, 68, 69, 71, and 72 will be coded with a 1-digit code that indicates the appraisal rating for the item. The ratings and codes are shown in the followings:

Code	Description
N	Not applicable
9	Superior to present desirable criteria
8	Equal to present desirable criteria
7	Better than present minimum criteria
6	Equal to present minimum criteria
5	Somewhat better than minimum adequacy to tolerate being left in place as is
4	Meets minimum tolerable limits to be left in place as is
3	Basically intolerable requiring high priority of corrective action
2	Basically intolerable requiring high priority of replacement
1	This value of rating code not used
0	Bridge closed

Data Item 67: Structural Evaluation 1 digit

This item is calculated by the Edit/Update Program based on table below, and need not be coded by the bridge inspector.

Structural Evaluation Rating Code	Inventory Rating		
	Average Daily Traffic (ADT)		
	0-500	501-5000	>5000
9	>32.4 (MS18)	>32.4 (MS18)	>32.4 (MS18)
8	32.4 (MS18)	32.4 (MS18)	32.4 (MS18)
7	27.9 (MS15.5)	27.9 (MS15.5)	27.9 (MS15.5)
6	20.7 (MS11.5)	22.5 (MS12.5)	24.3 (MS13.5)
5	16.2 (MS9)	18.0 (MS10)	19.8 (MS11)
4	10.8 (MS6)	12.6 (MS7)	16.2 (MS9)
3	Inventory rating less than value in rating code of 4 and requiring corrective action		
2	Inventory rating less than value in rating code of 4 and requiring replacement		
1	Bridge closed due to structural condition		

Data Item 68: Deck Geometry 1 digit

The overall rating for deck geometry is a two step evaluation. Bothe the curb-to-curb or face-to-face of rail bridge width and the minimum vertical clearance over the bridge roadway are considered in assigning the appraisal rating.

Data Item 69: Under-clearances, Vertical and Horizontal 1digit

Vertical and horizontal under-clearances as coded in Items 54, 55 and 56 are used to assign this appraisal rating.

Data Item: 70 Bridge Posting 1digit

The National Bridge Inspection Standards require the posting of load limits only if the maximum legal load configurations in the State exceed the load permitted under the operating rating. If the load capacity at the operating rating is such that posting is required, this item should be coded 4 or less. If no posting is required at the operating rating, this item should be coded 5. The following codes are used for this item.

Code	Relationship of Operating Rating to Maximum Legal Load
5	Equal to or above legal loads
4	0.1 - 9.9% below
3	10.0 - 19.9% below
2	20.0 - 29.9% below
1	30.0 - 39.9% below
0	> 39.9% below

Data Item 71: Waterway Adequacy 1digit

This item appraises the waterway opening with respect to passage of flow through the bridge. The following codes are used in evaluating waterway adequacy (interpolate where appropriate).

Principal Arterials-Interstates, Freeways, or Expressways	Other Principal and Minor Arterials and Major Collectors	Minor Collectors, Local	Code Description
N	N	N	Bridge not over a waterway
9	9	9	Bridge deck and roadway approaches above flood water elevations (high water). Chance of overtopping is remote
8	8	8	Bridge deck above roadway approaches. Slight chance of overtopping roadway approaches
6	6	7	Slight chance of overtopping bridge deck and roadway approaches
4	5	6	Bridge deck above roadway approaches. Occasional overtopping of roadway approaches with insignificant traffic delays
3	4	5	Bridge deck above roadway approaches. Occasional

			overtopping of roadway approaches with significant traffic delays
2	3	4	Occasional overtopping of bridge deck and roadway approaches with significant traffic delays
2	2	3	Frequent overtopping of bridge deck and roadway approaches with significant traffic delays
2	2	2	Occasional or frequent overtopping of bridge deck and roadway approaches with severe traffic delays
0	0	0	Bridge closed

Data Item 72: Approach Roadway Alignment 1 digit

This item identifies those bridges which do not function properly or adequately due to the alignment of the approaches. The approach roadway alignment does not be compared to current standards but rather to the existing highway alignment.

The approach roadway alignment will be rated intolerable (a code of 3 or less) if the horizontal or vertical curvature requires a substantial reduction in the vehicle operating speed from that on the highway section. A very minor speed reduction will be rated a 6, and when a speed reduction is not required, the appraisal code will be an 8.

Data Item 73 and 74 (Reserved)

Data Item 75: Type of Work 3digits

The information recorded in this item is the type of work proposed to be accomplished on the structure, and whether the work is to be done by contract or force account. The followings are descriptions of the 2 segments.

Segment	Description	Length	Code	

75A	Type of Work Proposed	2 digits	31	Replacement of bridge or other structure because of substandard load carrying capacity or substandard bridge roadway geometry
			32	Replacement of bridge or other structure because of relocation of road
			33	Widening of existing bridge or other major structure without deck rehabilitation or replacement; includes culvert lengthening.
			34	Widening of existing bridge with deck rehabilitation or replacement
			35	Bridge rehabilitation because of general structure deterioration or inadequate strength
			36	Bridge deck rehabilitation with only incidental widening
			37	Bridge deck replacement with only incidental widening
			38	Other structural work, including hydraulic replacements
75B	Work Done by	1 digit	1	Work to be done by contract
			2	Work to be done by owner's forces

(If segment A is blank, leave segment B blank)

<u>Data Item 76: Length of Structure Improvement 6 digits</u>

This item represents the length of the proposed bridge improvement to the nearest tenth of a meter (with an assumed decimal point).

This item only records bridges that are eligible for the Highway Bridge Replacement and Rehabilitation Program. Other bridges at the option of the highway agency might possibly be coded here. The followings are examples of coding format used in this item.

Length of Structure Improvement (XXXXX.X meters)	Code
76.2 meters	000762
1200 meters	012000
12,345 meters	12345

<u>Data Item 77 through Data Item 89 (Reserved)</u>

<u>Data Item 90: Inspection Date 4 digits</u>

This item represents the month and year that the last routine inspection of the structure was performed. This inspection date may be different from those recorded in Item 93 - Critical Feature Inspection Date.

The number of the month should be coded in the first 2 digits with a leading zero as required and the last 2 digits of the year coded as the third and fourth digits of the field

Data Item 91: Designated Inspection Frequency 2 digits

This item represents the number of months between designated inspections of the structure.

The designated inspection interval could vary from inspection to inspection depending on the condition of the bridge at the time of inspection.

The followings are examples of codes recorded in this item.

Examples	Code
Posted bridge with heavy truck traffic and questionable structural details which is designated to be inspected each month	01
Bridge is scheduled to be inspected every 24 months	24

Data Item 92: Critical Feature Inspection 9 digits

This item describes critical features that need special inspections or special emphasis during inspections and the designated inspection interval in months are determined by the individual in charge of the inspection program.

Segment		Length
92A	Fracture Critical Details	3 digits

92B	Underwater Inspection	3 digits
92C	Other Special Inspection	3 digits

For each segment of Item 92A, B, and C, code the first digit Y for special inspection or emphasis needed and code N for not needed. The first digit of Item 92A, B, and C must be coded for all structures to designate either a yes or no answer.

Data Item 93: Critical Feature Inspection Date 12 digits

If the first digit of Item 92A, B, or C is coded Y for yes, this item will be used for recording. In other words, if the first digit of any part of Item 92 is coded N, then the corresponding part of this item should be blank.

This item is composed of 3 segments. Each segment, when applicable, use 4-digit number to represent the month and year. The number of the month is coded in the first 2 digits with a leading zero as required and the last 2 digits of the year are coded as the third and fourth digits of the field.

Data Item 94: Bridge Improvement Cost 6 digits

This item indicates the estimated cost of the proposed bridge or major structure improvements in thousands of dollars. The cost only includes bridge construction costs. Roadway, right of way, detour, demolition and preliminary engineering are excluded here.

Data Item 95: Roadway Improvement Cost 6 digits

This item represents the cost of the proposed roadway improvement in thousands of dollars. The cost should only include roadway construction costs. Bridge, right-of-way, detour, extensive roadway realignment costs and preliminary engineering are excluded here.

Data Item 96: Total Project Cost 6 digits

This item represents the total project cost in thousands of dollars including incidental costs, but the item 94 and 95 are excluded here. Since this item includes all costs associated with the proposed bridge improvement project, this data item, The Total Project Cost, will therefore be greater than the sum of Items 94 and 95.

Data Item 97: Year of Improvement Cost Estimate 4 digits

This item shows the year that the costs of work estimated in Item 94, 95 and 96.

Data Item 98: Border Bridge 5 digits

This item indicates structures crossing borders of States.

The followings are descriptions of two segments of this item.

Segment	Description	Length
98A	Neighboring State Code	3 digits
98B	Percent Responsibility	2 digits

Data Item 99: Border Bridge Structure Number 15 digits

This item shows the neighboring State's 15-digit National Bridge Inventory structure number for any structure noted in Item 98. This number must match exactly the neighboring State's submitted NBI structure number, and the entire 15-digit field must be accounted for zeros and blank spaces whether they are leading, trailing, or embedded in the 15-digit field. If Item 98 is blank, then this item is blank.

Data Item 100: STRAHNET Highway Designation 1digit

The following codes are used in this item.

Code	Description
0	The inventory route is not a STRAHNET route
1	The inventory route is on a Interstate STRAHNET route
2	The inventory route is on a Non-Interstate STRAHNET route
3	The inventory route is on a STRAHNET connector route

Data Item 101: Parallel Structure Designation 1digit

This item indicates situations where separate structures carry the inventory route in opposite directions of travel over the same feature. The followings are descriptions of codes used in this item.

Code	Description
R	The right structure of parallel bridges carrying the roadway in the direction of the inventory. (For a STRAHNET highway, this is west to east and south to north.)
L	The left structure of parallel bridges. This structure carries traffic in the opposite direction
N	No parallel structure exists

Data Item 102: Direction of Traffic 1digit

This item represents the direction of traffic of the inventory route identified in Item 5. Codes recorded in this item are shown as followings.

Code	Description
0	Highway traffic not carried
1	1-way traffic
2	2-way traffic
3	One lane bridge for 2-way traffic

Data Item 103: Temporary Structure Designation 1digit

This item indicates situations where temporary structures or conditions exist. If not applicable, this item should be blank.

Code	Description
T	Temporary structure(s) or conditions exist

Data Item 104: Highway System of the Inventory Route 1 digit

Codes used in this item to represent the information about highway system of the inventory route are shown as followings.

Code	Description
0	Inventory Route is not on the NHS
1	Inventory Route is on the NHS

Data Item 105: Federal Lands Highways 1digit

Codes used in this item to describe the information about federal lands highway are shown as followings.

Code	Description
0	Not applicable
1	Indian Reservation Road (IRR)
2	Forest Highway (FH)
3	Land Management Highway System (LMHS)
4	Both IRR and FH
5	Both IRR and LMHS
6	Both FH and LMHS
9	Combined IRR, FH and LMHS

Data Item 106: Year Reconstructed 4 digits

This item describes the year of most recent reconstruction of the structure.

Data Item 107: Deck Structure Type 1 digit

This item indicates the type of deck system on the bridge. If there is more than one type of deck system on the bridge, the most predominant is coded. The followings are descriptions of codes used in this item.

Code	
1	Concrete Cast-in-Place
2	Concrete Precast Panels
3	Open Grating
4	Closed Grating

5	Steel plate (includes orthotropic)
6	Corrugated Steel
7	Aluminum
8	Wood or Timber
9	Other
N	Not applicable

Data Item 108: Wearing Surface/Protective System
3 digits

This item describes the information on the wearing surface and protective system of the bridge deck.

Segment		Length	Code	Description
108A	Type of Wearing Surface	1 digit	1	Monolithic Concrete (concurrently placed with structural deck)
			2	Integral Concrete (separate non-modified layer of concrete added to structural deck)
			3	Latex Concrete or similar additive
			4	Low Slump Concrete
			5	Epoxy Overlay
			6	Bituminous
			7	Wood or Timber
			8	Gravel
			9	Other
			0	None (no additional concrete thickness or wearing surface is included in the bridge deck)
			N	Not Applicable (applies only to structures with no deck)
108B	Type of Membrane	1 digit	1	Built-up
			2	Preformed Fabric
			3	Epoxy
			8	Unknown
			9	Other
			0	None
			N	Not Applicable (applies only to structures with no deck)
108C	Deck Protection	1 digit	1	Epoxy Coated Reinforcing
			2	Galvanized Reinforcing
			3	Other Coated Reinforcing
			4	Cathodic Protection
			6	Polymer Impregnated
			7	Internally Sealed
			8	Unknown

			9	Other
			0	None
			N	Not Applicable (applies only to structures with no deck)

Data Item 109: Average Daily Truck Traffic 2 digits

This item represents the percentage of Item 29 – Average Daily Traffic that is truck traffic. It is codes as a form of 2-digit number, which is converted from XX percent.

Data Item 110: Designated National Network 1digit

Codes used in this item to show the information about designated national network are shown as followings.

Code	Description
0	The inventory route is not part of the national network for trucks
1	The inventory route is part of the national network for trucks

Data Item 111: Pier or Abutment Protection (for Navigation) 1 digit

If Item 38 - Navigation Control is coded as 1, then use the codes below to indicate the presence and adequacy of pier or abutment protection features such as fenders, dolphins, etc.

Code	Description
1	Navigation protection not required
2	In place and functioning
3	In place but in a deteriorated condition
4	In place but reevaluation of design suggested
5	None present but reevaluation suggested

Data Item 112: NBIS Bridge Length 1digit

This item describes the structure meets or exceeds the minimum length specified to be designated as a bridge for National Bridge Inspection Standards purposes. Codes used in this item are shown as followings.

Code	Description
Y	Yes
N	No

Data Item 113: Scour Critical Bridges 1digit

This item identifies the current status of the bridge regarding its vulnerability to scour.

Code	Description
N	Bridge not over waterway
U	Bridge with "unknown" foundation that has not been evaluated for scour. Since risk cannot be determined, flag for monitoring during flood events and, if appropriate, closure
T	Bridge over "tidal" water that has not been evaluated for scour, but considered low risk. Bridge will be monitored with regular inspection cycle and with appropriate underwater inspections. ("Unknown" foundations in "tidal" waters should be coded U.)
9	Bridge foundations (including piles) on dry land well above flood water elevations
8	Bridge foundations determined to be stable for assessed or calculated scour conditions; calculated scour is above top of footing
7	Countermeasures have been installed to correct a previously existing problem with scour. Bridge is no longer scour critical
6	Scour calculation/evaluation has not been made
5	Bridge foundations determined to be stable for calculated scour conditions; scour within limits of footing or piles.
4	Bridge foundations determined to be stable for calculated scour conditions; field review indicates action is required to protect exposed foundations from effects of additional erosion and corrosion
3	Bridge is scour critical
2	Bridge is scour critical; field review indicates that extensive scour has occurred at bridge foundations. Immediate action is required to provide scour countermeasures
1	Bridge is scour critical; field review indicates that failure of piers/abutments is imminent. Bridge is closed to traffic
0	Bridge is scour critical. Bridge has failed and is closed to traffic

Data Item 114: Future Average Daily Traffic 6 digits

This item shows the forecasted average daily traffic for the inventory route identified in Item5. The data recorded here is projected at least 17 years but no more than 22 years from the year of inspection, and it also must be compatible with the other items coded for the bridge. The followings are examples of codes recorded here.

Future ADT	Code
540	000540
1,245	001245
240,000	240000

Data Item 115: Year of Future Average Daily Traffic 4 digits

This item shows the year of the future ADT represented in Item 114.

Data Item 116: Minimum Navigation Vertical Clearance 4 digits

This item represents the minimum navigation vertical clearance by a 4-digit number code. It is can be interpreted as a form of" XXX.X" (meters). This item only codes and records vertical lift bridges in the dropped or closed position. Otherwise, just leave blank for the data.

Appendix B: National Bridge Inventory Record Format

Item No.	Data Items	Item Position	Item Length/Type
1	State Code	1-3	3/ String
8	Structure Number	4-18	15/String
5A	Record Type	19	1/Nominal
5B	Route Signing Prefix	20	1/Ordinal
5C	Designated Level of Service	21	1/Ordinal
5D	Route Number	22-26	5/String
5E	Directional Suffix	27	1/String
2	Highway Agency District	28-29	2/String
3	County (Parish) Code	30-32	3/String
4	Place Code	33-37	5/String
6A	Features Intersected	38-61	24/String
7	Facility Carried by Structure	63-80	18/String
9	Location	81-105	25/String
10	Inventory Route, Minimum Vertical Clearance	106-109	4/Real
11	Kilometer Point	110-116	7/Real
12	Base Highway Network	117	1/Nominal
13A	LRS Inventory Route	118-127	10/String
13B	Sub route Number	128-129	2/String
16	Latitude	130-137	8/Real
17	Longitude	138-146	9/Real
19	Bypass/Detour Length	147-149	3/Real
20	Toll	150	1/Nominal
21	Maintenance Responsibility	151-152	2/ Nominal
22	Owner	153-154	2/ Nominal
26	Functional Classification of Inventory Route	155-156	2/Ordinal
27	Year Built	157-160	4/Integer
28A	Lanes On Structure	161-162	2/Integer
28B	Lanes Under Structure	163-164	2/Integer
29	Average Daily Traffic	165-170	6/Integer
30	Year of Average Daily Traffic	171-174	4/Integer
31	Design Load	175	1/Ordinal
32	Approach Roadway Width	176-179	4/Real
33	Bridge Median	180	1/Nominal
34	Skew	181-182	2/Real
35	Structure Flared	183	1/Nominal
36A	Bridge Railings	184	1/ Nominal
36B	Transitions	185	1/ Nominal
36C	Approach Guardrail	186	1/ Nominal
36D	Approach Guardrail Ends	187	1/ Nominal
37	Historical Significance	188	1/ Ordinal
38	Navigation Control	189	1/ Nominal
39	Navigation Vertical Clearance	190-193	4/ Real
40	Navigation Horizontal Clearance	194-198	5/ Real

41	Structure Open/ Posted/ Closed /Traffic	199	1/ Ordinal
42A	Type of Service on Bridge	200	1/ Nominal
42B	Type of Bridge Under Bridge	201	1/ Nominal
43A	Kind of Material/Design	202	1/ Nominal
43B	Type of Design/Construction	203-204	2/ Nominal
44A	Kind of Material/Design	205	1/ Nominal
44B	Type of Design/Construction	206-207	2/ Nominal
45	Number of Spans In Main Unit	208-210	3/ Integer
46	Number of Approach Spans	211-214	4/ Integer
47	Inventory Route Total Horizontal Clearance	215-217	3/ Real
48	Length of Maximum Span	218-222	5/ Real
49	Structure Length	223-228	6/ Real
50A	Left Curb/Sidewalk Width	229-231	3/ Real
50B	Right Curb/Sidewalk Width	232-234	3/ Real
51	Bridge Roadway Width Curb-To-Curb	235-238	4/ Real
52	Deck Width, Out-to-Out	239-242	4/ Real
53	Minimum Vertical Clearance Over Bridge Roadway	243-246	4/ Real
54A	Reference Feature	247	1/ Nominal
54B	Minimum Vertical Underclearance	248-251	4/ Real
55A	Reference Feature	252	1/ Nominal
55B	Minimum Lateral Underclearance	253-255	3/ Real
56	Minimum Lateral Underclearance On Left	256-258	3/ Real
58	Deck	259	1/ Ordinal
59	Superstructure	260	1/ Ordinal
60	Substructure	261	1/ Ordinal
61	Channel/Channel Protection	262	1/ Ordinal
62	Culverts	263	1/ Ordinal
63	Method Used To Determine Operating Rating	264	1/ Nominal
64	Operating rating	265-267	3/ Real
65	Method Used To Determine Inventory Rating	268	1/ Nominal
66	Inventory Rating	269-271	3/ Real
67	Structural Evaluation	272	1/ Ordinal
68	Deck geometry	273	1/ Ordinal
69	Underclearnce, Vertical& Horizontal	274	1/ Ordinal
70	Bridge Posting	275	1/ Ordinal
71	Waterway Adequacy	276	1/ Ordinal
72	Approach Roadway Alignment	277	1/ Ordinal
75A	Type of Work Proposed	278-279	2/ Nominal
75B	Work Done By	280	1/ Nominal
76	Length of Structural Improvement	281-286	6/ Real
90	Inspection Date	287-290	4/ Integer
91	Designated Inspection Frequency	291-292	2/ Integer
92A	Fracture Critical Details Date	293-295	3/ Nominal
92B	Underwater Inspection	296-298	3/ Nominal
92C	Other Special Inspection	299-301	3/ Nominal
93A	Fracture Critical Details Date	302-305	4/ Integer
93B	Underwater Inspection Date	306-309	4/ Integer
93C	Other Special Inspection Date	310-313	4/ Integer

94	Bridge Improvement Cost	314-319	6/ Integer
95	Road Improvement Cost	320-325	6/ Integer
96	Total Project Cost	326-331	6/ Integer
97	Year of Improvement Cost Estimate	332-335	4/ Integer
98A	Neighboring State Code	336-338	3/ String
98B	Percent Responsibility	339-340	2/ Integer
99	Border Bridge Structure Number	341-355	15/ String
100	STRAHNET Highway Designation	356	1/ Nominal
101	Parallel Structure Designation	357	1/ Nominal
102	Direction of Traffic	358	1/ Nominal
103	Temporary Structure Designation	359	1/ Nominal
104	Highway System of Inventory Route	360	1/ Nominal
105	Federal lands Highways	361	1/ Nominal
106	Year Reconstructed	362-365	4/ Integer
107	Deck Structure Type	366	1/ Integer
108A	Type of Wearing Surface	367	1/ Nominal
108B	Type of Membrane	368	1/ Nominal
108C	Deck Protection	369	1/ Nominal
109	Average Daily Truck Traffic	370-371	2/ Integer
110	Designated National Network	372	1/ Nominal
111	Pier/Abutment Protection	373	1/ Nominal
112	NBIS Bridge length	374	1/ Nominal
113	Scour Critical Bridges	375	1/ Ordinal
114	Future Average Daily Traffic	376-381	6/ Integer
115	Year of Future Average Daily traffic	382-385	4/ Integer
116	Minimum Navigation Vertical Clearance Lift Bridge	386-389	4/ Real
Washington headquarters Use		390-426	
Status	Status	427	1/Ordinal
N/A	Asterisk field in SR	428	1/ String
SR	Sufficiency Rating (Select from last 4 positions only)	429-432	4/ Real

Appendix C: An example of queries: number of bridges by material by county

```
% NBICNTYANAL an m-file script to perform a query on the NBI tabulated by
% County
RecordCount = 0;
NumCntys = 3237;
%Load the State/County FIPS codes from a text file into a vector
load STCNTYFIPS.txt;
%preallocate the storage for the results
CNTYCnt = zeros(1,NumCntys);
CNTYArea = zeros(1,NumCntys);
CNTYADT = zeros(1,NumCntys);
%assigns the file name of the data file
NBIFileName = 'C:\Documents and Settings\sbc2h\My Documents\NBIDATA\2009\NBI09.txt';
%open the file
fid = fopen(NBIFileName);
%loops through the file and read each record in sequence
while ~feof(fid)
  NBIRecord = fgetl(fid);
  if feof(fid) break
  end
  % selects only valid highway bridges
  if (NBIRecord(19)== '1')&(NBIRecord(374) == 'Y')&((NBIRecord(200) ==
'1')|(NBIRecord(200) == '5')|(NBIRecord(200) == '6')...
      |(NBIRecord(200) == '7')|(NBIRecord(200) == '8'))
  %determine the STCNTY code
    STCNTY = str2num (strcat(NBIRecord(1:2),NBIRecord(30:32)));
    Try
      % use the MATLAB finds function to look up the correct index
      Ind = find (STCNTYFIPS==STCNTY);
    catch
      Ind = 3237; % deal with possible errors in the data
    end
    if is empty(Ind)
        Ind = 3237; % deal with possible errors in the data
    end
    if Ind ~= 3237 % deal with possible errors in the data
      Mt1= str2num (strcat(NBIRecord(202)));
        CNTYCnt(Ind) = CNTYCnt(Ind,Mt1)+1

    end
  end
end
% Close the file
fclose(fid);
%arrange data for export to excel by concatenating the transpose of the
%data into a single array
D = cat (CNTYCnt(Ind));
%Export the data to excel in the file name CountyData.xls
xlswrite('CountyData.xls',D);
```