PREDICTING FIRST TIME REACHING DEFICIENCY STATUS (FTRDS) FOR STEEL BRIDGES IN OKLAHOMA

By

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PREDICTING FIRST TIME REACHING DEFICIENCY
STATUS (FTRDS) FOR STEEL BRIDGES
IN OKLAHOMA

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Title of Study: PREDICTING FIRST TIME REACHING DEFICIENCY STATUS (FTRDS) FOR STEEL BRIDGES IN OKLAHOMA

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Abstract: The need of an accurate model to characterize deficiency time for bridges is an important issue for bridge owners to ensure an adequate maintenance schedule. The main objective of this research is to create a simple, rational statistical model that characterizes bridge conditions in Oklahoma. Thus, this research focuses on addressing the influence of age on bridge components including deck, superstructure, and substructure. This was done by tracking historical data for steel bridges built between 1992 and 2015. In this study, condition ratings of 2,145 steel bridges were analyzed to determine the First Time Reaching Deficiency Status (FTRDS). Four well-known statistical distributions (gamma, Weibull, lognormal, and log-logistic) were investigated to predict each bridge component's First Time Reaching Deficiency Status (FTRDS). The goal was to identify the best distribution that fits Oklahoma's steel bridges to obtain the probability for the FTRDS. Based on the Anderson-Darling test for the goodness of fit test process, the Weibull distribution was the most appropriate distribution that characterized the effect of age on bridge components. The Weibull parameters, scale and shape factors were estimated to calculate the FTRDS probabilities based on bridge ages from the year built to the point that bridge reached deficiency status for the first time. Results show that data for superstructure and substructure elements were useful to calculate FTRDS while the deck element was excluded due to insufficient data. Finally, these models will be helpful in assisting agencies such as Oklahoma Department of Transportation (ODOT) in monitoring the condition of their bridges and to develop more reliable maintenance and rehabilitation plans.

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CHAPTER I

INTRODUCTION

In recent years, bridge deficiency has been a major point of public safety concern in the United States. Nationally, as other long-term investment assets, bridges are important elements in the infrastructure inventory and represent key components in the transportation system. Over time and through continuous use, bridge conditions deteriorate faster by transferring from non-deficiency status to deficiency status. Without appropriate action, deteriorations in condition can lead to serious problems related to service, environment, and safety. With tight federal, state and local budgets, about $76 billion in maintenance spending is required to modernize the national inventory of bridges. Thus, a methodology is needed to assess when bridge conditions are approaching deficiency in order to prioritize future maintenance spending.

1.1. Background

In Oklahoma, there are about 23,680 bridges owned by the state or various counties with an average age of 44.6 years while the design life is about 75 years (ASCE, Report Card, 2013), (U.S. D. O. T., FHWY, 2010). However, Oklahoma was ranked highest in the number of deficient steel bridges, around 1,186 bridges in 2004, according to Oklahoma Department of Transportation, (2015). The reason for that was because the majority of these bridges were built during the 1940's. Figure 1 shows the forecasted number of steel bridges over 80 years old in Oklahoma over next seven years, (ODOT, 2015).

Several studies have been conducted to examine the behavior of bridges in order to reduce the potential of bridge collapse, such as the most recent collapse of the I-35 W Bridge in Minneapolis, Minnesota. These studies focused on modeling and correlating overall bridge behavior with variables such as age, average daily traffic (ADT), design loads, and span length. However, the aim of these studies was to enable government agencies on federal, state, and local levels to work to improve or maintain bridges in a better way with respect to cost and public safety.

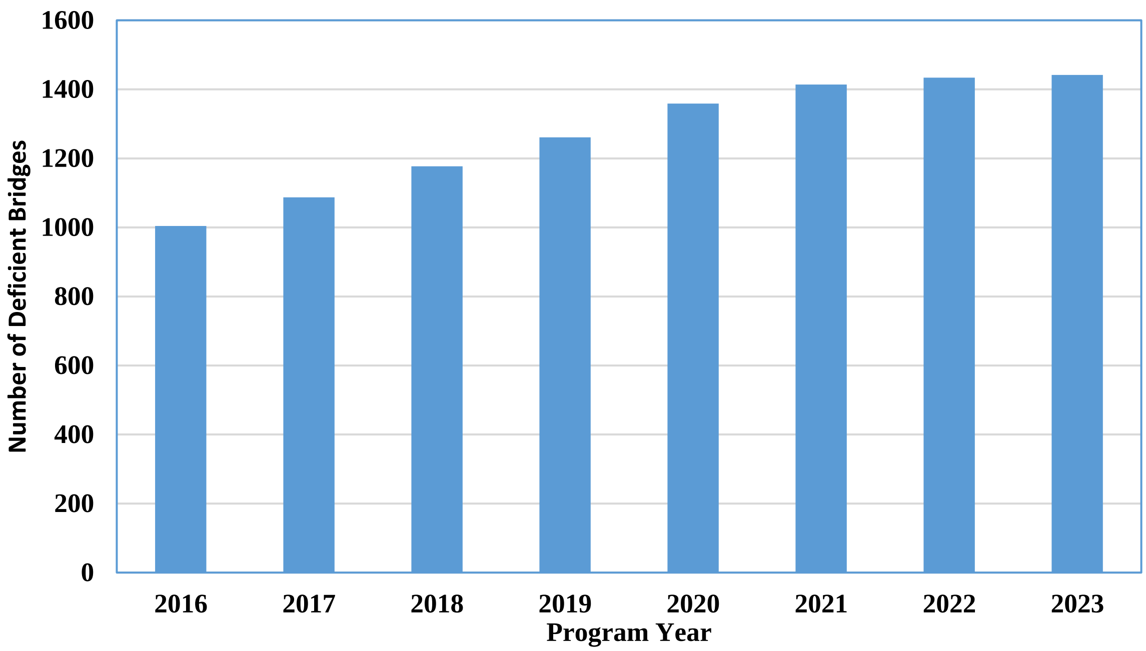

Figure 1. Number of Deficient Bridges Over 80 Years in Oklahoma State

1.2. Motivation

The influence of age on bridge components such as the deck, superstructure, and substructure in terms of deficiency was the primary motivation behind this research. Therefore, the process of determining First Time Reaching Deficiency Status (FTRDS) reported herein is a new paradigm that aims to ensure public safety in the transportation system as well as new approach for maintenance plans. Finally, the findings of this study may be helpful to allow agencies like Departments of Transportation (DOTs) to improve public safety within their required maintenance budget when planning to build new structures.

1.3. Thesis Objective

The primary goal of this study was to use fitted distributions to characterize FTRDS for steel bridge components including deck, superstructure and substructure. The distributions were developed using data from the National Bridge Inventory (NBI) for Oklahoma. This objective was achieved by analyzing historical records of steel bridges that found in the NBI. Also, this research was based on tracking bridges between specific periods of time and determining the FTRDS.

The outcome of this study is expected to be useful for agencies, such as DOTs. Adopting the FTRDS methodology will lead to: (i) applying the proper inspections, (ii) create a maintenance plans based on these inspections in order to improve public safety, and (iii) improve the design of future bridges based on the sudden change of condition rating from non-deficiency status to deficiency status.

1.3. Scope of Work

In order to achieve the objective behind this thesis, several tasks were included based on the bridge condition to determine FTRDS. The primary source of data for this research was the National Bridge Inventory (NBI) for Oklahoma. The focus was on steel bridges that were built between the years 1992 to 2013, which is the most recent available database for the research period. One reason behind this selection was availability of NBI data. According to Federal Highway Administrative (FHWA), no digital records were available prior to 1992. Thus, according to the approach used in the research methodology, all bridges that have been tracked were built after the year 1992.

Although the NBI contains more than 100 items that reflect a bridge's structural and physical condition, the research criteria only included items such as the structure number (ID), state, year built, material type (steel), and condition rating for the deck, superstructure, and substructure. In order to apply the methodology for FTRDS, results for deficient steel bridges were obtained while result for concrete were not. Therefore, concrete bridge were excluded from the study due to insufficent data for obtainng FTRDS. Also, the number of bridges collected for this analysis were due to the filtering of all bridges in the databases to candidates that matched the required rating standard. The process of this analysis is discussed in detail in section 3.2 in the methodology.

1.5 Thesis Layout

This thesis contains six chapters. The work in this thesis begins by providing a background (Chapter One) of the current status of bridges in Oklahoma. In Chapter Two, a complete literature review of previous studies is presented to discuss how the NBI was used for bridge deficiency prediction. Chapter Three describes the methodology and summarizes the processes that were used to achieve the research objective. Chapter Four shows the result for each section described in the methodology, for instance, the process of data filtering, the process for obtaining the probabilities, and the distribution that best fit the data. In Chapter Five, the conclusions drawn from this thesis are discussed and linked with previous studies. Finally, Chapter Six suggests recommendations for future research beyond this study. Appendix A contains the results of tables that were used to achieve this research.

CHAPTER II

LITERATURE REVIEW

In the past few decades, the topic of predicting bridge deficiency and condition ratings has become a prominent field of study for many researchers. The reason behind this was related to aging bridges and the expensive rehabilitation costs associated with them. Few of these studies focused on evaluating and monitoring the behavior and condition for bridges in the United States. Other efforts used mathematical techniques for characterizing bridge performance such as linear modeling, regression analysis, and survival analysis. Furthermore, the NBI was the primary source of data that most of those studies since it provided the required information for parameters such as bridge age ADT, and structure type. Most of these studies were based on selecting a single year of interest, or the year when the research was developed, but the methodology used in this thesis is based on taking advantage of time-series approaches by tracking bridges between within a specific time period and analyzing the outcomes. Finally, to address the gaps mentioned before, several previous studies are presented in order to link them with the current thesis.

A research study done by Dekelbab, Al-Wazeer, and Harris (2007) focused on predicting bridge conditions based on survival rates for decks and superstructures using NBI data from 1983 to 2006. Their interest was to address the effect on all condition ratings from 9 (Excellent Condition) to 0 (Failed Condition) using variables such as year built, average daily traffic

(ADT), and deck type. Also, their method of analysis was the Kaplan-Meier model in order to estimate the survival curves. Finally, they concluded that the factors of ADT and year built has the most influence on predicting the probabilities of bridge survival rate, where lower ADT increased the survival rates for both deck and superstructure. On the contrary, the type of bridge deck (precast concrete panels) had a higher effect in reducing the survival rate for the deck, while the year built needed more investigation due to a lack of data accuracy.

One year later, another study was done by Dekelbab, Al-Wazeer, and Harris (2008) using mostly the same NBI data from 1983 to 2006 with the same tool of analysis (Kaplan and Meier method). However, this study focused only on deterioration in bridge decks. Also, other important variable used in this study are the type of deck surface, ADT, and deck type. Other variables such as year built and maintenance were less important in the results outcome. Moreover, they noticed that after three or four years from year built, the deck showed a dramatic drop in the survival probability rate; however, this was based on limited data from the NBI. The reason for this was missing information from the NBI database.

Similar to Dekelbab *et al*. (2007), Dekelbab *et al*. (2008), a new study approach was done by Sobanjo, Mtenga, Rambo-roddenberry (2010) using the lifetime model for NBI in Florida from 1992 to 2005 for deck and superstructure only. Their main objective was to predict condition ratings for steel and concrete bridges between 9 (Excellent Condition) and 7 (Good Condition) basically, without rehabilitation. Also, the authors demonstrated that using Weibull distributions provided a good fit to the data. Finally, their results were divided into how many years that bridges stay in each condition rating. For instance, below two years for excellent condition, between five to 10 years for very good condition, and below six years for good condition.

Bolukbaso, Mohammadi and Arditi (2004), and Bolukbaso *et al*. (2006) conducted research that focused on deck, superstructure, and substructure. This study was based on selecting bridges from 1976 to 1998 for Illinois bridges in the NBI database. Regression analysis was used to develop two models. One was for adjusted (improved) values and the other for expected (no improvement) values. The variables used in the two models were “bridge improvement year” and “reconstruction data”. In conclusion, both methods showed almost the same results for predicting bridge element service life, but there was a significant difference between substructures (longest service life) followed by superstructure and deck.

Bridge decks received attention from researchers in predicting deterioration probabilities. A study by Huang (2010) used the NBI for Wisconsin bridges. He used Artificial Neural Networks (ANN) to analyze the influence of 11 variables. These significant factors were maintenance history, age, previous condition, and further eight factors including district, design load, deck length, deck area, ADT, environment, degree of skew, and number of spans. This approach consumed a lot of time because it depended on layering and connecting the data, but results were more accurate than those achieved by Markovian model. Also, this research concluded that all 11 factors had a significant effect on predicting deck deterioration.

Another study that uses the 2005 Wisconsin NBI data for decks was conducted by Tabatabai, Tabatabai, and Lee (2010). The purpose of this study was to predict the end service life of bridges using fitted distribution models. The bridges that were selected had a condition rating between 9 (Excellent condition) and condition rating of 5 (fair condition) before reaching the deficiency status 4 or below. Also, they used the same parameters such as age, type of structure, and ADT in order to obtain the best-fitted distribution. Finally, they concluded that using the Weibull distribution gave accurate results in predicting survival times. Also, bride age and ADT had the highest effect among other parameters.

The next group of researchers focused on monitoring the behavior of superstructure element only and for one year of interest from NBI. Work done by Veshosky, Beidleman, Buetow, and Demir (1994) used the 1990 NBI database to predict superstructure condition ratings. They selected a group of homogenous bridges and described the effect of parameters such as age, ADT, maintenance condition, and other factors on superstructure condition ratings. In their analysis, they created deterministic and stochastic models for steel and concrete bridges. The study concluded that age and ADT have the most effect on superstructure condition. However, due to the random error and the uncertainty for 1990 NBI database, another study was conducted by Contreras-Nieto (2014) using the same approach but multiple regression analysis and Pearson's correlation. Moreover, he used the 2010 NBI database for the same parameters such as age, average daily traffic. He concluded that age had the most effect on superstructure condition rating while ADT had little effect.

In conclusion, NBI contains a comprehensive source of information that can be used for research to understand bridge behavior. Some researchers such as Bolukbaso et al. (2006), Veshosky et al. (1994) and Contreras-Nieto (2014) developed linear regression models that depend on variables such as age and ADT. Researchers such as Huang (2010), Tabatabai *et al*. (2010) used more complicated methods in order to achieve more reliable results. Also, they included other factors such as bridge span length, maintenance improvement, and area of the deck in order to achieve more acceptable results.

CHAPTER III

METHODOLOGY

This chapter discuss how this research was conducted to meet the primary objective by providing details about how the data were collected, organized, and analyzed. Additionally, this chapter also includes the statistical processes for obtaining the distribution that best fits the data for bridge components such as the deck, superstructure, and substructure.

3.1 Data Collection

This section contains a full description for how the data was collected and converted to a small and reliable dataset. Also, the procedures of data filtering that were used to ensure high accuracy, for instance, the missing data records from year-to-year, out-of-range values and inappropriate input codes that do not conform to the NBI coding guide (Weseman, 1995).

3.1.1 Data Source

The primary source for the data in this research was the National Bridge Inventory (NBI) created by Federal Highway Administration office (FHWA). The focus was on steel bridges that were built in Oklahoma between 1992 and 2013. However, the decision behind selecting only 21 years and no earlier than 1992 is because: (i) no digital records for NBI data were availabule for bridges before 1992, (ii) some bridges were not inspected regularly before 1992, (iii) missing or/and miscoded information before 1992, and (iv) to maintain a good accuracy by having a sample of bridges that are no older than required. Furthermore, the 2013 inventory database was selected as the main database for tracking bridges because it was the most up to date database and it contained the highest number of bridges (2,145) that were built between 1992 and 2013 (see Figure 2 below).

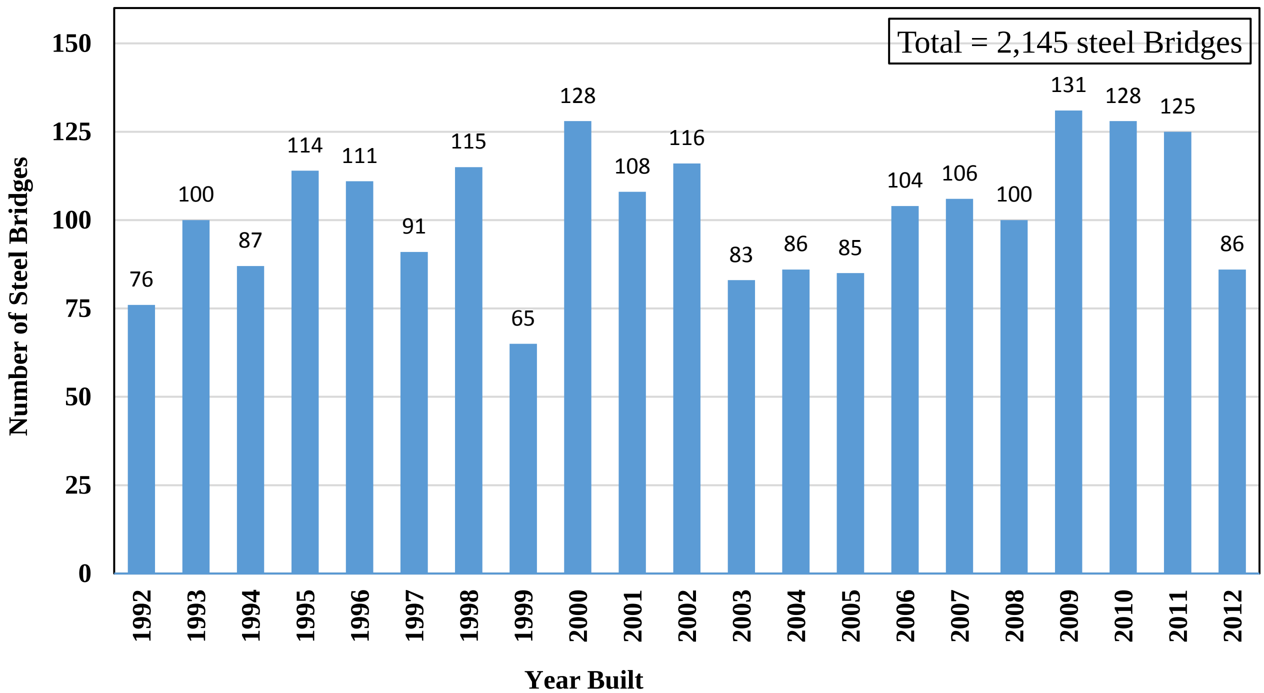

Figure 2. Number of Steel Bridges Built Per-Year (1992 – 2012)

After selecting the required databases, the databases were filtered and converted to a smaller dataset for this research. Therefore, the first task performed on the data was to determine what type of bridges were included in the database (e.g. Structure ID, year built, year collected, etc.). Table 1 shows all the items that were used in this research with their definition (Weseman, 1995). The researcher added parameters "age" and "year inspected" to the dataset to obtain the First Time Reaching Deficiency Status (FTRDS).

Table 1. Parameters of Research

Item Number	Description	Using of Parameter in Research
1	State Code	Oklahoma
8	Structure Number	Used to Track the Same Bridge for Each Year
27	Year Built	Determine FTRDS Age
41	Structure Status	Open No Restriction
43:A	Kind of Material/Design; Main	Determine Bridge Material (Steel and Steel continues)
58	Deck Rating	Determine Condition Rating for Deck
59	Superstructure Rating	Determine Condition Rating for Superstructure
60	Substructure Rating	Determine Condition Rating for Substructure

3.1.2 Data Sorting and Cleanup

After identifying the necessary parameters that were used in the research, a small dataset was created to track all the bridges for the same structure ID. This conversion was done by narrowing down the original database by several filtering processes to remove all erroneous data. The first step was the elimination of all non-necessary items and focusing only on the research interest parameters shown in Table 1. Secondly, by adopting the FTRDS methodology, bridges with "Closed", "Posted for Load" and "Temporary bridges" were removed from the dataset and that was about 283 bridges. The same approach was taken by (Bolukbasi *et al*. 2004). These bridges were not considered to be a part of the permanent bridge inventory in Oklahoma because a temporary bridge built in 1992 might be demolished after few years and won't have any record to track. Moreover, those bridges may result in a lower rating condition which may affect the distribution at early ages. Another cleanup was done for the databases by removing the blank, missing, and incomplete data for bridge condition rating and that was about 154 bridges, as seen in Table 2 and Table 3. Finally, these bridges were omitted because they may generate a range of error by increasing the FTRDS mean age for the three bridge elements.

Table 2. Missing Data for Substructure Element (Structure ID 253030000000000)

1998	**…..**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Fair	**…..**	Poor	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair

Table 3. Not Applicable Data for Superstructure Element (Structure ID 264230000000000)

2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
N	N	N	N	N	N	N	N	N	N	N	N	N

3.1.3 Identify Deficient Bridges

According to National Bridge Inspection Standards (NBIS) developed by the Federal Highway Administration (FHWA), condition ratings were established to evaluate or describe "an existing, in place bridge as compared to the as built condition" (Weseman, 1995). These condition ratings consist of a rating scale ranging from 9 being "excellent condition" to 0 for being "failed condition". These ratings are used to describe the three bridge elements including deck, superstructure, and substructure as shown in Table 4 (Weseman, 1995). As a result, deficiency status is defined as reaching any point in condition rating between 4 ("poor condition") and 0 ("failed condition)". Therefore, FTRDS method consisted of selecting all tracked bridges that transferred from non-deficiency status (any point in condition rating between 9 and 5) to deficiency status (any point in condition rating between 4 and 0) for the first time.

Table 4. Condition Rating Description

Rating	Description
9	Excellent Condition - No noticeable or noteworthy deficiencies.
8	Very Good Condition – Minor cracks with no problem noted.
7	Good Condition– Cracking at a spacing of 10 ft. or more, with light shallow scaling.
6	Satisfactory Condition – Minor deterioration including cracks at a spacing of 5 ft. or less, medium scaling, and 2% or less the deck area spilled or delaminated.
5	Fair Condition– Minor section loss, between 2% and 10% of the surface area is spalled or delaminated and excessive cracking in the surface.
4	Poor Condition– Advanced section loss, large parts of the surface is spelled or delaminated
3	Serious Condition – Deterioration has seriously affected primary structural components, and local failures are possible.
2	Critical Condition - Advanced deterioration of primary structural elements. Emergency surface repairs required by the crews.
1	"Imminent" Failure Condition – Major deterioration present in critical structural components. Bridge is closed to traffic, but corrective action may put the bridge back in service.”
0	Failed Condition - Bridge closed and is beyond corrective action

3.2. Data Analysis

This section contains a full description for the procedures of how the dataset was analyzed and used in obtaining the best distribution that fits Oklahoma NBI data.

3.2.1. Summary Statistics

Summary statistics, such as mean, median, mode, slandered deviation, maximum, and minimum were calculated for FTRDS based on the variable age. This was done similar to previous studies for the variable age. As described earlier, the variable age was added to the dataset because of its importance for obtaining the (FTRDS) for three bridge elements. The variable age was computed by subtracting the column of “year inspected” (the first time when the bridge becomes deficient condition four or below) from the year built (item 27) as shown in equation 1.

$$\textbf{Age = Year Inspected – Year Built (Item 27)} \qquad (1)$$

3.2.2. Best Distribution

After finishing all the required analyses and creating the summary table for the variable age, the final step was to fit the parameter age to a specific distribution based on the data properties. A similar approach was undertaken by (Sobanjo *et al*. 2010). Table 5 shows four well-known distributions which are commonly in used in engineering research (Lee, 2013). The reason for selecting those four distribution was related to their function usage in lifetime modeling, such as continuous or discrete (Lee, 2013). Also, all four distributions have one thing in common called “two-parametric distribution” which are γ and λ, the shape and scale factors, respectively. A goodness of fit test was used to ensure that the distributions used to obtain the probabilities was suitable. After determining the distribution, the maximum likelihood estimation method was used to estimate the two distribution parameters for the statistical models. Finally, the fitted distribution represents the research objective, which was characterizing the (FTRDS)

Table 5. Most Common Distribution

Distribution	Parameter	Probability Density Function	Cumulative Density Function
Weibull	λ>0 γ >0	λγ(λt)^(γ−1) exp(−λt)^γ	1 – exp(−λt)^γ
Lognormal	μ,σ > 0 a = exp(−μ)	1/(tσ √ 2π) exp[−1/2σ^2 (ln at)^2]	$1/\sqrt{2\pi}\int_0^t \exp(-u 2 /2)du$
Log logistic	λ>0 γ >0	λγ(λt)^(γ−1) [1 + (λt)^γ]^−2	(λx)^ γ (1+ (λx))^- γ
Gamma	λ>0 γ >0	[λ/Γ(γ)](λγ)^(γ−1) exp(−λt)	$\int_0^t$ λ(Γγ^-1)(λt)^ (γ-1) exp- λt dt

CHAPTER IV

RESULTS

This chapter includes the results for the analysis including summary statistics for each of the three bridge elements deck, superstructure, and substructure. The result of finding the best distribution that fits the data is also presented.

4.1. Data Collection

The primary result of the data collection process was a summry table for all steel bridges that reached deficiency status for the first time (condition rating equal to 4 or below). Figure 3 and Figure 4 are a graphicl depiction of the FTRDS. Although the analysis in this research started with 2,145 permanent open-no restriction steel bridges, the final dataset was 538 deficient bridges (approximately 25% of the total bridges). The criteria of selecting the bridges were based on moving from any non-defiency status condition ratings to any deficiency status condition ratings for the first time.

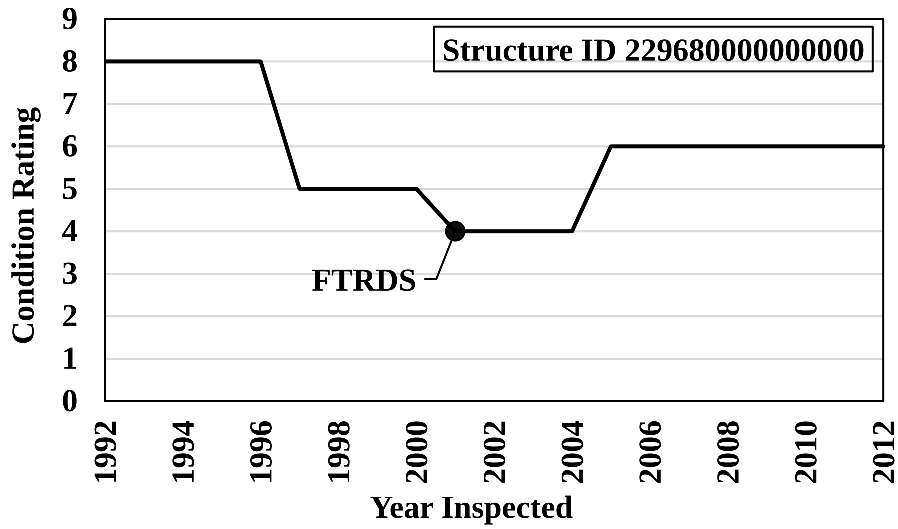

Figure 3. First Time Reaching Deficiency Status (FTRDS) for Superstructure

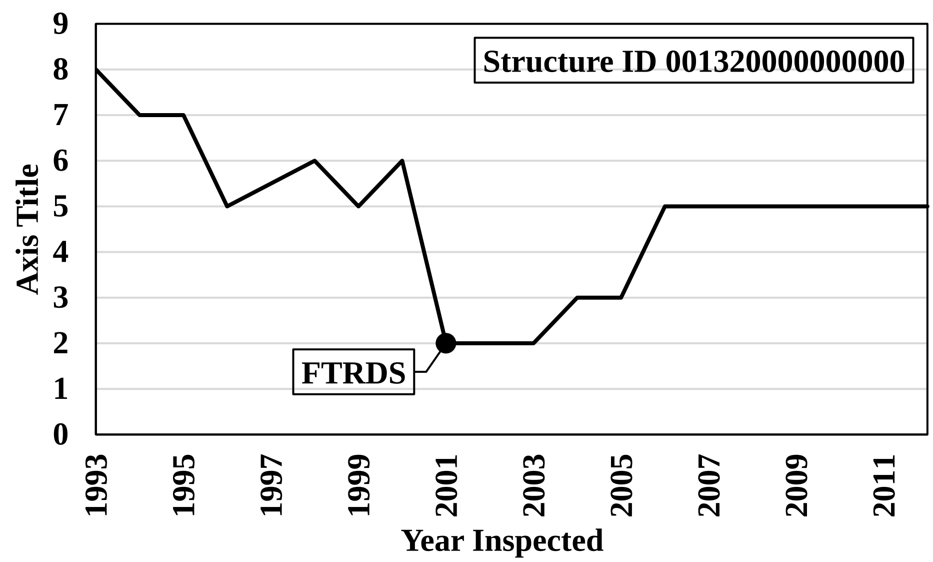

Figure 4. First Time Reaching Deficiency Status (FTRDS) for Substructure

After tracking all records for the same bridge ID, a table was produced including the age and the frequencies for that age in order to find the probability of occurrence. However, one issue recounted was the sharp increase in condition rating for each bridge elements. According to the NBIS, it is required that each bridge be routinely inspected yearly or biennially, therefore, the issue of having a condition rating fluctuation (cycles of decrease followed by one or more years of increase in condition rating) was detected (Sobanjo *et al*. 2010) and (Agrawal *et al.* 2009) as shown in Figure 5 and Figure 6. This issue appears in some cases as a result of maintenance activities during the two years of inspection that leads to improved condition ratings. There is insufficient information in the NBI database to resolve this issue. Thus, a final filtration process was done by eliminating bridges with age zero and one for the three bridge elements.

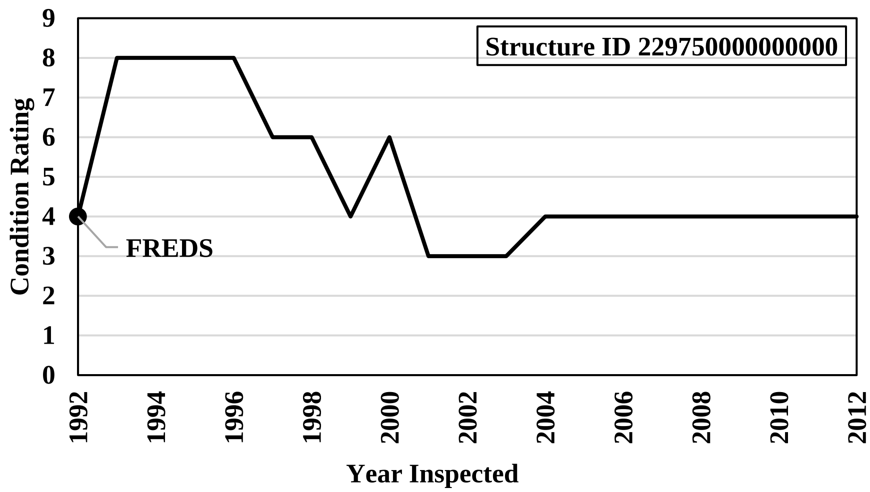

Figure 5. Inconsistent Condition Rating for (FTRDS) for Superstructure

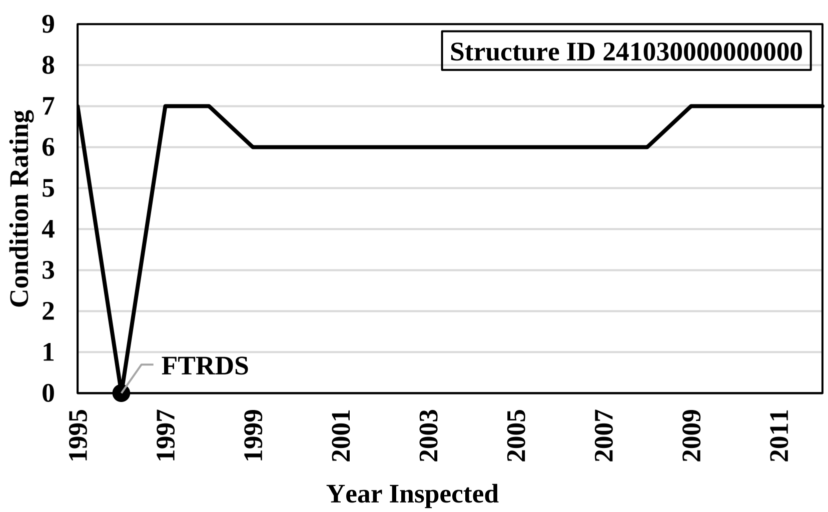

Figure 6. Inconsistent Condition Rating for (FTRDS) for Substructure

4.2 Data Analysis

This section includes the result of each process described in the Methodology, such as the summary statistics tables for the three bridge elements as well as the distribution that best fits that data for the three elements.

4.2.1. Summary Statistics

Table 6 shows a basic summary for steel bridges from Oklahoma NBI data. These statistics were based on tracked bridges that rated as first time reached deficiency status for the three bridge elements including deck, superstructure, and substructure. Although the number of observations obtained was 538 deficient steel bridges, some bridges had only one condition rating while other had two or more in common as shown in Table 7 below full observation records can be seen in Appendix 1. Therefore, these 538 bridges were divided separately as 10 observations for deck, 178 for superstructure and 474 for substructure as seen in Figure 7 below. Since the observations for deck were only 10 bridges, it was eliminated from the result due to insufficiency of observations. Superstructure and substructures had a sufficient number of observations to be used to obtain the probabilities for deficient ages.

Table 6. Statistical Information for Oklahoma NBI Bridges

	Bridge Element		
	Deck	**Superstructure**	**Substructure**
Mean	6.8	4.2	5.15
Median	5	4	5
Mode	5	3	5
Standard Deviation	3.85	1.86	2.11
No. of Bridges	10	178	474

Table 7. Sample for Dataset

Structure ID Number	Year Built	Deck		Superstructure		Substructure	
		Age	Deck Rating	Age	Superstructure Rating	Age	Substructure Rating
231690000000000	1992	11	4	6	4	-	-
232150000000000	1992	13	4	6	4	7	4
262970000000000	1992	9	2	-	-	9	2

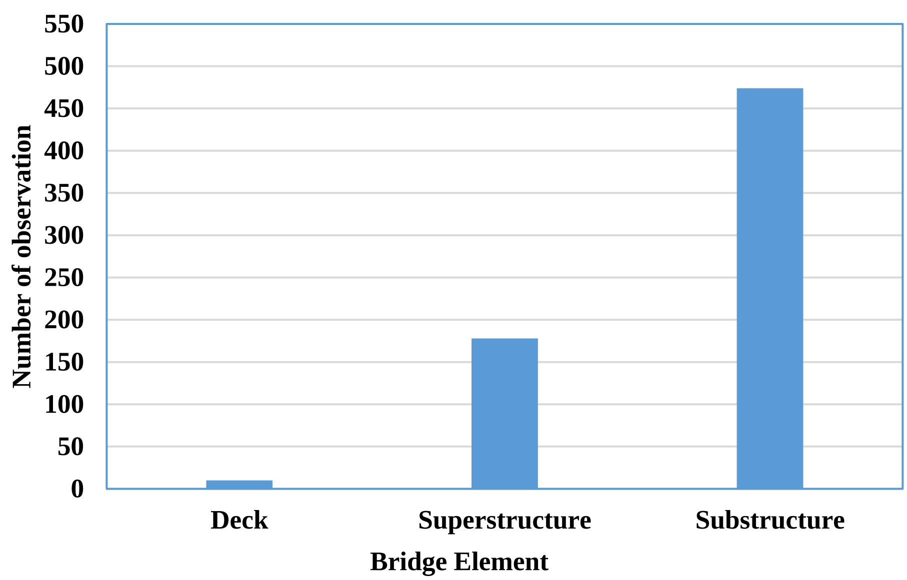

Figure 7. Number of FTRDS Bridges for Each Element

Figure 8 and Figure 9 illustrate the frequency distribution for both superstructure and substructure, respectively. Superstructure shows a median age of 6 years and an average deficient age of 4.3 years, which represents approximately 65% from the total sample of superstructure observations. Approximately 60% of the total observations for substructure were deficient at an average age of 5.2 years while the median age was 7.5 years.

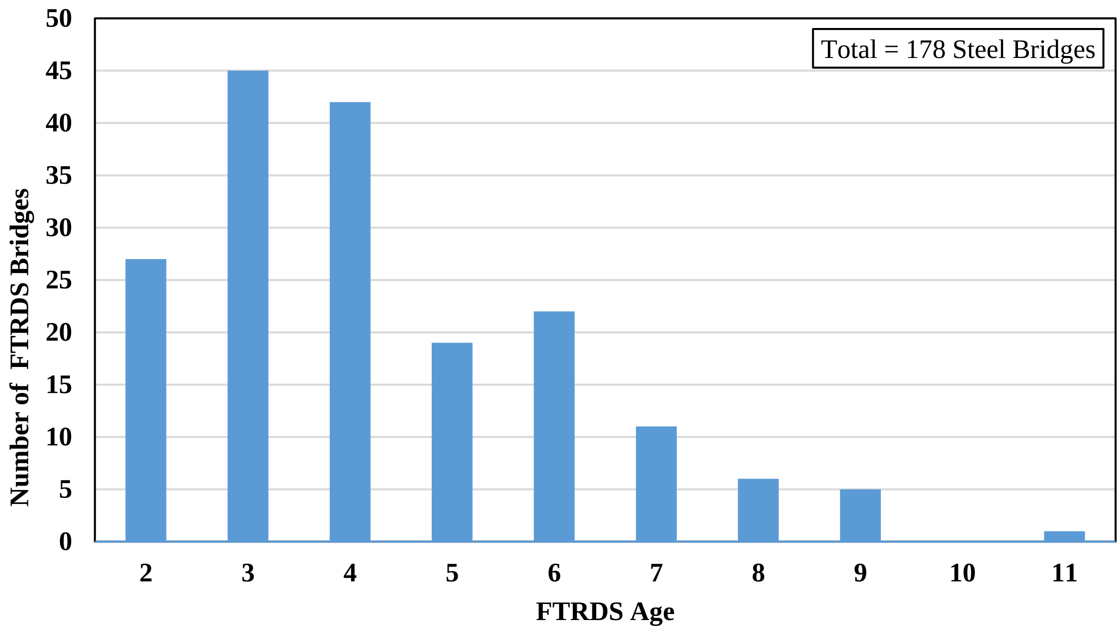

Figure 8. FTRDS Age Distribution for Deficient Superstructure Steel Element

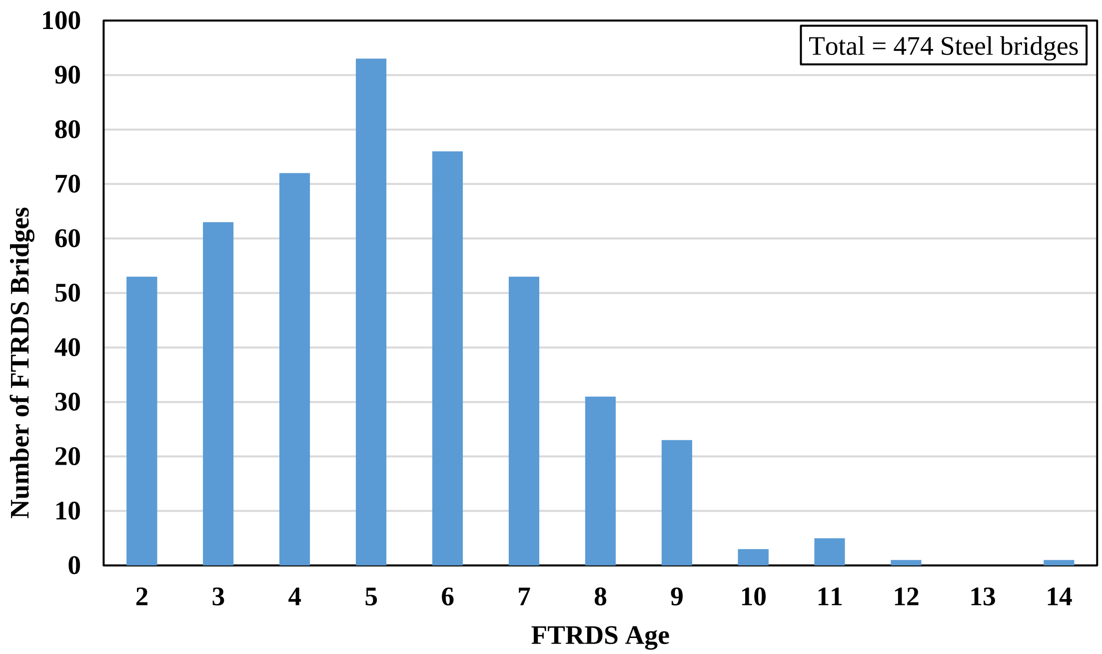

Figure9. FTRDS Age Distribution for Deficient Substructure Element

4.2.2 Best Distributions

In this section, four distributions were analyzed to identify the best fit for steel bridges in Oklahoma.

4.2.2.1 Goodness of Fit Test

A goodness of fit test was performed to ensure that the data fit the particular distribution. Among all the available goodness of fit tests, the Anderson-Darling test (AD) was used to characterize the most suitable distribution for the NBI data. According to the AD test, the smallest test statistic indicates a better fit for the distribution. When comparing between more than one distributions, the distribution with the lowest AD test statistic generally indicates a better fits for the data. However, for close statistic values, additional criteria must be used such as simplicity or probability plots. The AD test statistics were calculated according to the following equation.

$$AD= -n - \frac{1}{n}\sum_{i=0}^{n}(2j-1)[\ln F(Xi) + \ln(1-F(X_{n-j+1}))] \qquad (2)$$

Where n = number of observation for each element, F(X) = cumulative distribution function for the specified distribution.

The first step to carry out the test was selecting the alpha-value (α) usually 0.05 or 0.10, but for this research, the alpha-value (α) was assumed as 0.05. Therefore, the FTRDS null and alternative hypothesis were:

H_o: The data follows the specific distribution and,

H_A: The data do not follow that distribution (the expected value differs from the observed).

Higher p-value (greater than alpha) for AD test for the given distributions, means that the null hypothesis was not rejected and the distribution fits the data. Even though by saying that the specific distribution is significant at alpha level (α= 0.05), this does not mean it is the best to use among other distributions. In fact, there is no sufficient evidence to conclude that this data do not follow the specific distribution and thus, it can be used to generate the probabilities for FTRDS.

Table 8 shows the Anderson-Darling Statistic results for superstructures and substructure. Substructure results show that the Weibull distribution had the lowest AD test statistic followed by Gamma, log-logistic, and lognormal. Superstructure had close values between the four distributions (the difference was approximately 0.5 between the Lognormal and Weibull). By considering the minimum differences (less than 1) between the Weibull and other candidate distributions, Weibull could replace the lognormal distribution (lowest AD test statistic) because of its shape and scale parameters (Lee, 2013). The Weibull distribution has been used to characterize the time to failure in many research fields (Dodson 2006; McCool 2012). The Weibull distribution was selected as the most suitable distribution for characterizing FTRDS for superstructure steel bridges because there was no statistically significant difference among the test statistics for the four distributions.

Table 8. Anderson-Darling Test Statistics

Distribution	**Bridge Element**	
	Superstructure	**Substructure**
Weibull	4.2	5.2
Lognormal	3.7	9.4
Log-logistic	3.8	8.6
Gamma	3.8	6.6

4.2.2.2 Parameters of Weibull Distribution

The two-parameter Weibull distribution were used to estimate FTRDS probabilities for Oklahoma steel bridges. Since the Weibull distribution is characterized by the scale (λ) and the shape (γ) factors, the method of maximum-likelihood was used to calculate the parameters. Table 9 shows the calculated parameters for superstructure and substructure.

Table 9. Parameters of Weibull Distribution

Parameter	Superstructure	Substructure
Shape	2.467	2.621
Scale	4.863	5.806

Although the Table 10 shows the estimated Weibull parameters, Table 9 shows the 95% confidence interval (upper and lower bounds) for the shape and scale parameter for better probabilities estimating.

Table 10. 95% Confidence Interval for Weibull Parameters

Element	95 % Bound	Superstructure	Substructure
Shape	Lower	2.2128	2.4472
	Upper	2.7513	2.8064
Scale	Lower	4.5629	5.5991
	Upper	5.177	6.0206

After identifying the distribution and its parameters, the density and cumulative plot was drawn for each bridge element. The Probability Density Function (PDF) and Cumulative Density Function (CDF) for the FTRDS were calculated for each year using equation 3 and 4, respectively (Lee, 2013).

$$PDF = \lambda\gamma(\lambda t)\hat{}(\gamma - 1)\ \mathrm{exp}(-\lambda t)\hat{}\gamma \quad (3)$$

$$CDF = \int_0^t [(\gamma t\hat{}\gamma\text{-}1)\ \lambda\hat{}\gamma\ exp(t/\lambda)\hat{}\ \gamma]\ dt = 1 - exp(-\lambda t)\hat{}\gamma \quad (4)$$

Where λ is the scale factor and γ is the shape factor.

Figure 10 and Figure 11 represent the probability density for both superstructure and substructure respectively, as a function of age. Generally, these figures represent the overlapping of the Weibull distribution with the observations shown in Figure 8 and 9, respectively. Based on Figure 10, there is approximately 55% probability that a superstructure will achieve FTRDS in four years and approximately 40% probability a substructure will achieve FTRDS in four years as well Figure 11. Note that four years represent a typical two bridge inspection cycles in Oklahoma.

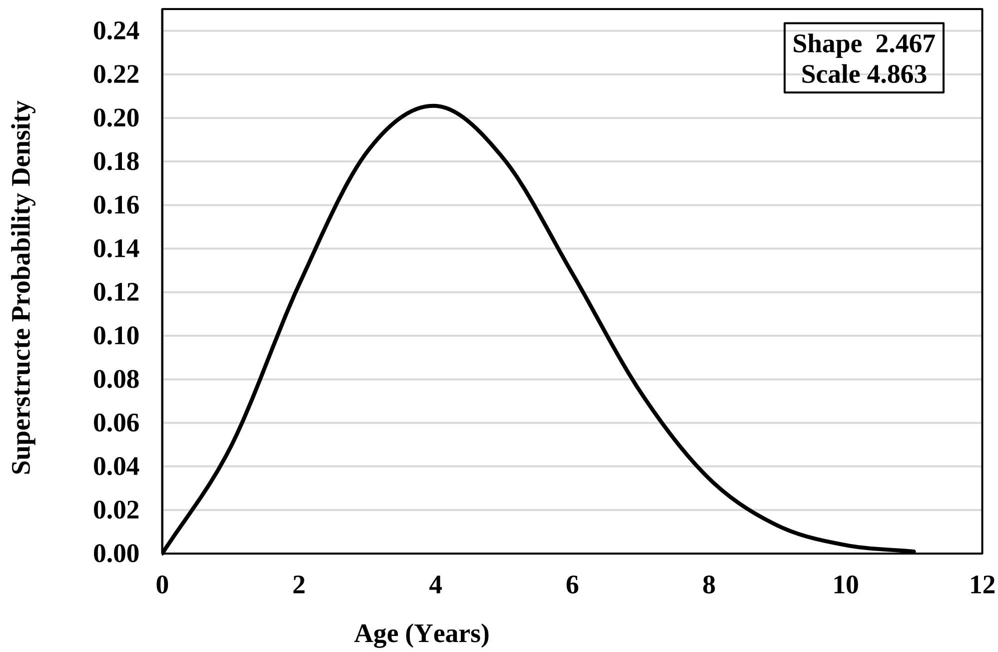

Figure 10. FTRDS Probability Density Function for Superstructure Element

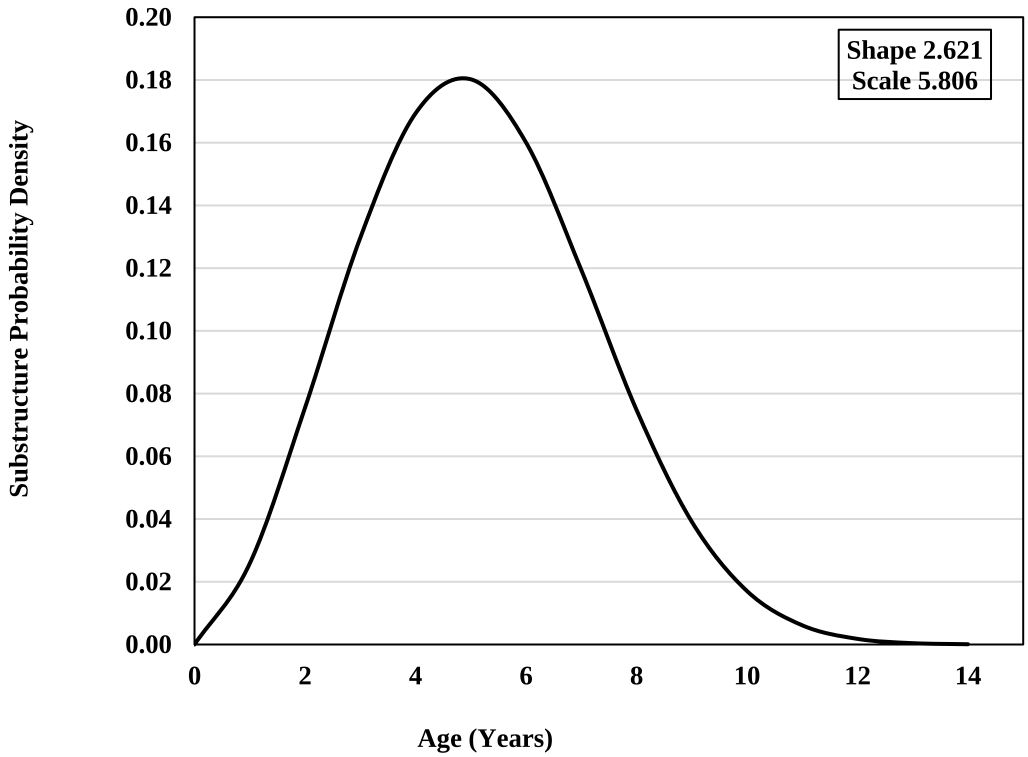

Figure 11. FTRDS probability Density Function for Substructure Element

Figure 12 and Figure 13 represent the cumulative FTRDS rate and associated with their 95% confidence intervals (upper and lower bound) for both bridge elements which was calculated based on equation 4. It shows the cumulative frequency for achieving FTRDS rate for steel superstructure and substructure elements. Furthermore, reaching deficiency status indicate that maintenance plan is required either immediately or in the future.

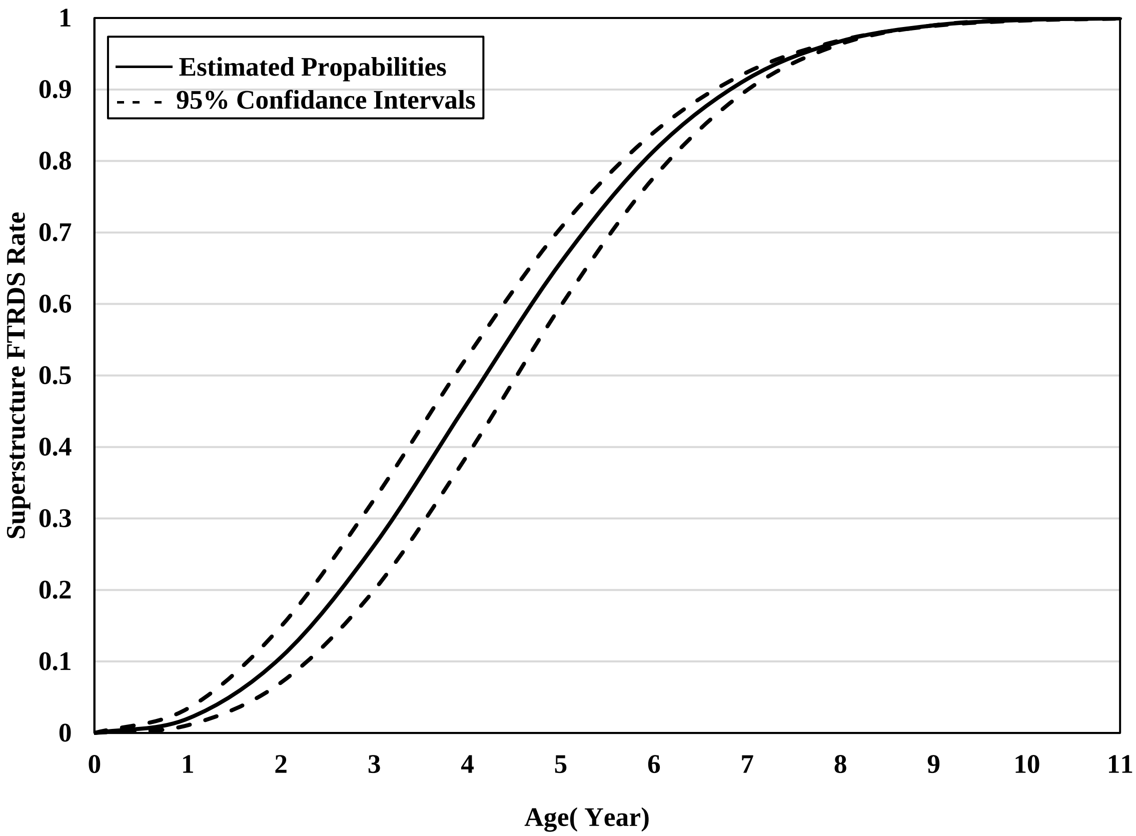

Figure 12. Weibull FTRDS Rate for Superstructure Element

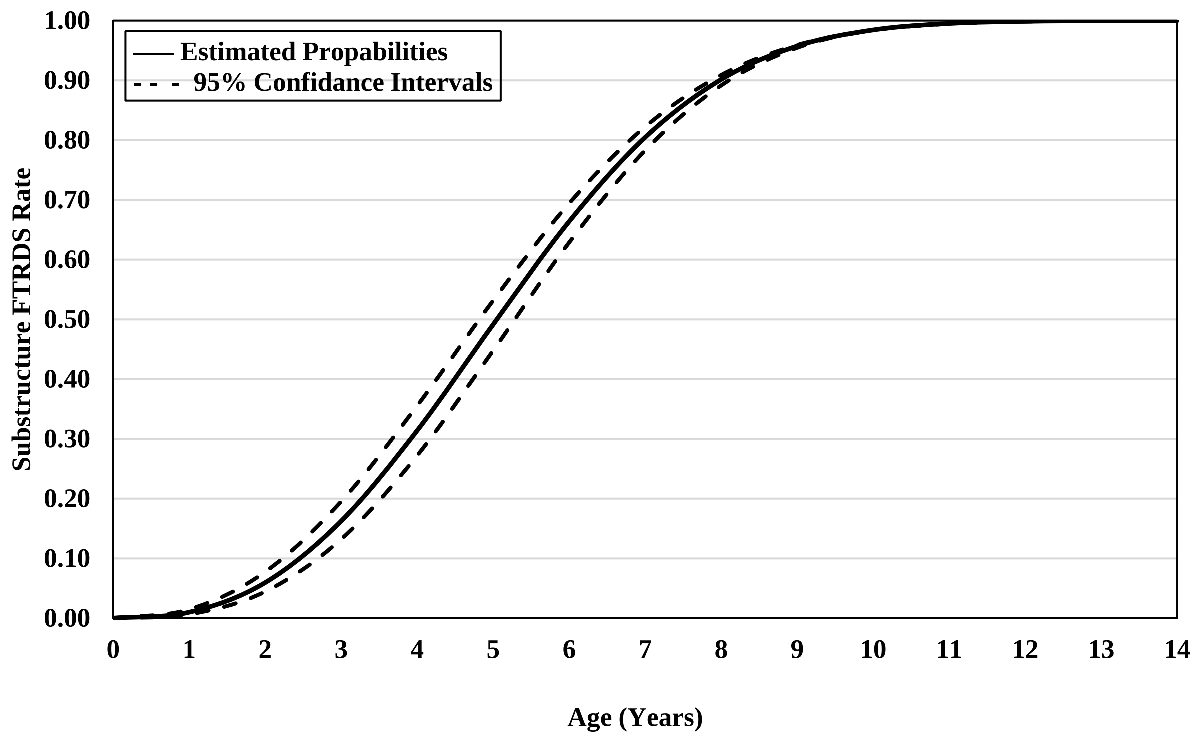

Figure 13. Weibull FTRDS Rate for Substructure Element

Results show that superstructure has higher probabilities for reaching deficiency status compared with substructure for given age. For instance, at the age of 5 years (around the mean) from the year that bridge was built, there is approximately 65% probability that the superstructure will reach deficiency. While the probability that the substructure will reach deficiency for the first time is approximately 50%. Also, results show that at 11 and 14 years, both superstructure and substructure will reach 100% probability for becoming deficient for the first time. Although it can be said that both superstructure and substructure need (at most) 11 and 14 years respectively to reach deficiency, but the fact that between 8 to 11 and 10 to 14 years both bridge components will achieve 90% probability before transferring to deficiency status.

Although the estimated probabilities show an indication for the FTRDS, the 95% confidence probabilities for both bridge elements were obtained for better understanding. These two curves for each element represent the lower and upper probability interval for each given year. For example, at age 5 years, bridge superstructure has about a 60 to 70 percent of FTRDS while substructure has a 45 to 53 percent chance of FTRDS. Also, notes that at early ages, the gap between the upper and lower CI tends to increase up to a specific age then it nearly matches the estimate probability for that age.

CHAPTER V

CONCLUSION

Bridge deficiency is an important topic that has generated much attention recently. For this reason, an extensive literature review for previous studies was conducted to gain a better understanding of the research approach in order to model Oklahoma's bridge conditions. Since Oklahoma ranked as the worst state in the nation the in number of deficient bridges, (ODOT, 2015), (ASCE, 2013), implementing research was necessary to address the issue. The NBI data within a 21 year period was the primary source for this study. As a result, this thesis focused on studying the influence of age on bridge components such as the deck, superstructure, and substructure.

Developing the methodology of First Time Reaching Deficiency Status (FTRDS) was the primary objective of this thesis. This objective was to assess when bridge elements such as the deck, superstructure, and substructure will reach deficiency based on statistical distributions. Therefore, several conventional distributions including gamma, Weibull, log-logistic, and lognormal were analyzed to select the most suitable distribution that characterizes Oklahoma bridge data. Results show that the Weibull distribution was the most suitable to characterize the FTRDS for bridge components. Also, an accurate estimation for probability graphs (condition rating change) were provided to help agencies for decision-making for the future.

One of the research findings was the average FTRDS frequency age distribution for superstrate and substructure. There are a total of 178 and 474 FTRDS steel bridges for superstructure and substructure, respectively, which make up approximately 30% from the total of Oklahoma's bridges. According to the FTRDS frequency distribution graphs, approximately 65% of the superstructures reached deficiency and between two and six years while 60% of substructures reached deficiency between two and nine years. Also, the average FTRDS age was 4.3 years for the superstructure and 5.2 years for the substructure. From these results, it can be concluded that Oklahoma deficient bridges tend to achieve FTRDS in less than 10 years from initial construction.

Since this research was to address the influence of age on condition ratings, another finding was the expected probabilities of FTRDS of both superstructure and substructure. The density curves for both bridge elements showed that more than 60% of Oklahoma deficient bridges will achieve FTRDS within four years (around the mean for both bridge elements), which represents two inspection cycle. The cumulative curves show the performance of each element over time. On average, at five years, both superstructure and substructure will achieve approximately 50% of their FTRDS. Therefore, it cannot concluded which steel bridge element shows better performance upon the other especially without any results for deck FTRDS.

This study showed that the FTRDS will take place in 11 years for superstructure and 14 years for substructure for Oklahoma deficient bridges. Based on these results, it can be concluded that condition ratings play a significant role in determining FTRDS. This is characterized as the age when bridges transfer from non-deficiency status to deficiency status. Even though this study relied only on age to create the FTRDS model, this model can be aligned with what previous studies concluded about the age as the most significant deficiency predictor.

Overall, the FTRDS characterization developed in this study may impact for future decision-making. FTRDS can be applied on any large sample size with more than one variable which has not been conducted in previous studies. Thus, the PDF and CDF curves, in the future, will aid those bridge stakeholders in understanding performance behavior while designing new bridges, or by applying required maintenance before reaching deficiency status. Moreover, this consideration can be applied to the National Bridge Inspection Standards for improving safety and reliability.

CHAPTER VI

RECOMMENDATIONS

The NBI database is a comprehensive source of information for historical records and assessments. The methodology in this research has developed a new groundwork for addressing NBI data by characterizing a statistical model of First Time Reaching Deficiency Status (FTRDS). The approach is based on tracking samples of bridges for the three elements including deck, superstructure, and substructure from 1992 to 2013. This approach characterized the data by a simple and acceptable model that reflects the existing condition of bridges in Oklahoma State. Therefore, repeating the methodology that implement in this research for other states would allow for more opportunity to continue developing future studies. One example which is comparing Oklahoma results with other states to identify whether the issue for Oklahoma bridges only or across the nation.

To continue developing this research methodology, more hazard and environmental data should be collected and combine them with the from NBI data. Climate parameters are necessary to explore how bridge components reach deficiency. By doing so, bridges can be divided into groups or sub-groups and classified based on their location factors. This will help qualify the results for calculating FTRDS. Therefore, utilizing information from federal and local agencies such as ODOT, reliabil database can be created for future analysis.

The results in this research are the first step in a series of future studies based on the same methodology. Possible studies can be explored based on this research methodology. A related study may be done by using deferent statistical models and comparing them with the existing FTRDS analysis. By doing so, research can be done based on summarizing the results for each deterioration model and determine the based approach that can characterize the NBI data.

The current FTRDS assessment addresses the effect of one variable, which is age. Therefore, other variables, such as ADT, maximum span length bridge location might have an effect on bridge condition ratings. With that said, Artificial Neural Network (ANN) can address these issues and develop a deterioration model for the deck, superstructure, and substructure. However, using this technique may require additional analysis in the NBI to identify missing information and unbalanced condition ratings.

Another study, which is Time Based on Each Condition Rating (TBECR) for non-deficient bridges. In this study TBECR models can be created for condition ratings between nine (Excellent Condition) and five (Fair Condition). The outcomes of this study can be compared with the FTRDS framework. In addition, this technique would allow agencies to understand the performance of bridges for each status, non-deficiency (TBECR) and deficiency status (FTRDS).

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APPENDICES

Appendix 1. Deck, Superstructure, and Substructure Observations

Structure ID Number	Year Built	Deck		Superstructure		Substructure	
		Age	Deck Rating	Age	Superstructure Rating	Age	Substructure Rating
231690000000000	1992	11	4	6	4	-	-
232150000000000	1992	13	4	6	4	7	4
262970000000000	1992	9	2	-	-	9	2
239470000000000	1994	2	4	7	4	-	-
239820000000000	1995	5	4	-	-	7	4
241150000000000	1995	5	0	-	-	-	-
243860000000000	1995	4	4	-	-	6	3
242300000000000	1996	11	4	-	-	-	-
245050000000000	1996	3	4	-	-	-	-
256640000000000	1996	5	2	5	2	-	-
015650000000000	-	-	-	4	4	-	-
042610000000000	-	-	-	6	4	7	4
085010000000000	-	-	-	6	4	7	4
089300000000000	-	-	-	5	4	9	4
091680000000000	-	-	-	4	4	7	4

Structure ID Number	Year Built	Deck		Superstructure		Substructure	
		Age	Deck Rating	Age	Superstructure Rating	Age	Substructure Rating
119980000000000	-	-	-	3	4	3	4
121560000000000	-	-	-	3	4	7	4
229680000000000	-	-	-	9	4	-	-
229700000000000	-	-	-	5	4	9	3
229710000000000	-	-	-	4	4	9	3
229750000000000	-	-	-	5	4	7	4
229780000000000	-	-	-	4	4	7	4
229790000000000	-	-	-	4	4	7	3
229810000000000	-	-	-	3	4	3	4
231160000000000	-	-	-	6	4	7	4
231620000000000	-	-	-	5	4	-	-
231860000000000	-	-	-	6	2	-	-
233860000000000	-	-	-	8	4	9	4
233870000000000	-	-	-	4	3	4	4
001320000000000	-	-	-	3	4	8	2
126810000000000	-	-	-	7	4	3	4
233370000000000	-	-	-	5	4	8	2
233380000000000	-	-	-	3	4	10	4
233920000000000	-	-	-	7	4	8	4
233930000000000	-	-	-	8	4	8	4
233990000000000	-	-	-	11	4	6	4

Structure ID Number	Year Built	Deck		Superstructure		Substructure	
		Age	Deck Rating	Age	Superstructure Rating	Age	Substructure Rating
234060000000000	-	-	-	9	3	8	3
234090000000000	-	-	-	5	4	-	-
234220000000000	-	-	-	3	4	-	-
234390000000000	-	-	-	2	4	-	-
234720000000000	-	-	-	3	4	8	4
235090000000000	-	-	-	3	4	-	-
235120000000000	-	-	-	3	4	8	3
235150000000000	-	-	-	3	4	-	-
235160000000000	-	-	-	3	4	4	4
235220000000000	-	-	-	2	4	-	-
235440000000000	-	-	-	7	4	8	4
235810000000000	-	-	-	8	4	8	4
235830000000000	-	-	-	4	4	6	4
235970000000000	-	-	-	7	4	-	-
235980000000000	-	-	-	3	4	8	3
236120000000000	-	-	-	4	2	-	-
237060000000000	-	-	-	4	4	-	-
237070000000000	-	-	-	8	4	8	4
239200000000000	-	-	-	3	4	-	-
245920000000000	-	-	-	8	4	8	2
245980000000000	-	-	-	8	4	8	4

Structure ID Number	Year Built	Deck		Superstructure		Substructure	
		Age	Deck Rating	Age	Superstructure Rating	Age	Substructure Rating
249880000000000	-	-	-	7	2	8	3
235730000000000	-	-	-	3	4	7	3
235990000000000	-	-	-	6	4	-	-
237270000000000	-	-	-	3	4	-	-
237580000000000	-	-	-	3	4	5	4
237590000000000	-	-	-	3	1	5	3
237850000000000	-	-	-	6	4	7	3
237860000000000	-	-	-	3	4	7	4
237900000000000	-	-	-	3	4	5	4
238630000000000	-	-	-	6	4	-	-
238790000000000	-	-	-	4	4	-	-
238810000000000	-	-	-	2	4	-	-
238830000000000	-	-	-	7	4	5	3
239610000000000	-	-	-	3	2	-	-
240970000000000	-	-	-	9	4	-	-
241110000000000	-	-	-	2	4	-	-
241360000000000	-	-	-	7	4	7	2
243420000000000	-	-	-	3	4	7	2
245260000000000	-	-	-	3	2	7	3
239660000000000	-	-	-	3	4	4	4
239670000000000	-	-	-	9	4	6	3

Structure ID Number	Year Built	Deck		Superstructure		Substructure	
		Age	Deck Rating	Age	Superstructure Rating	Age	Substructure Rating
239930000000000	-	-	-	3	4	-	-
239960000000000	-	-	-	5	4	6	4
240760000000000	-	-	-	3	4	6	3
240820000000000	-	-	-	5	4	6	4
241120000000000	-	-	-	5	4	6	3
241440000000000	-	-	-	2	2	6	2
241450000000000	-	-	-	4	4	6	3
241650000000000	-	-	-	2	4	6	4
241770000000000	-	-	-	4	3	6	4
242080000000000	-	-	-	2	2	-	-
243260000000000	-	-	-	4	4	6	3
247650000000000	-	-	-	4	2	6	3
250030000000000	-	-	-	5	4	6	4
241390000000000	-	-	-	3	4	-	-
242210000000000	-	-	-	3	2	5	3
242450000000000	-	-	-	5	4	5	3
242670000000000	-	-	-	4	4	4	2
243840000000000	-	-	-	5	4	5	4
244000000000000	-	-	-	4	4	5	3
244020000000000	-	-	-	4	4	5	4
244030000000000	-	-	-	6	4	5	4

Structure ID Number	Year Built	Deck		Superstructure		Substructure	
		Age	Deck Rating	Age	Superstructure Rating	Age	Substructure Rating
245100000000000	-	-	-	3	3	-	-
246360000000000	-	-	-	6	4	-	-
246380000000000	-	-	-	2	4	5	4
246790000000000	-	-	-	4	4	-	-
247110000000000	-	-	-	3	4	4	4
247940000000000	-	-	-	3	1	5	4
247980000000000	-	-	-	3	2	5	3
247990000000000	-	-	-	9	4	5	4
249410000000000	-	-	-	2	4	-	-
251290000000000	-	-	-	4	4	5	4
251750000000000	-	-	-	4	4	5	4
249730000000000	-	-	-	7	4	5	4
249960000000000	-	-	-	5	4	5	4
250240000000000	-	-	-	6	4	6	4
250420000000000	-	-	-	3	4	5	4
256770000000000	-	-	-	7	4	-	-
251080000000000	-	-	-	2	3	-	-
252320000000000	-	-	-	6	3	6	3
252580000000000	-	-	-	6	4	6	3
252660000000000	-	-	-	6	4	6	3
252790000000000	-	-	-	6	3	6	3

Structure ID Number	Year Built	Deck		Superstructure		Substructure	
		Age	Deck Rating	Age	Superstructure Rating	Age	Substructure Rating
253110000000000	-	-	-	6	4	5	4
253250000000000	-	-	-	6	4	-	-
256780000000000	-	-	-	2	4	4	2
253030000000000	-	-	-	7	4	-	-
254680000000000	-	-	-	4	4	-	-
254690000000000	-	-	-	4	4	-	-
255080000000000	-	-	-	4	4	4	3
255100000000000	-	-	-	4	4	4	4
255270000000000	-	-	-	4	3	4	3
255310000000000	-	-	-	4	3	-	-
255600000000000	-	-	-	4	4	4	3
255850000000000	-	-	-	5	2	5	3
255860000000000	-	-	-	4	4	4	3
255880000000000	-	-	-	5	4	5	3
256340000000000	-	-	-	4	4	4	3
256480000000000	-	-	-	6	4	4	4
257510000000000	-	-	-	4	4	4	4
257520000000000	-	-	-	4	4	4	4
261240000000000	-	-	-	6	4	-	-
264070000000000	-	-	-	5	4	5	3
273760000000000	-	-	-	6	4	-	-

Structure ID Number	Year Built	Deck		Superstructure		Substructure	
		Age	Deck Rating	Age	Superstructure Rating	Age	Substructure Rating
256790000000000	-	-	-	3	4	3	4
256460000000000	-	-	-	2	3	3	4
256690000000000	-	-	-	5	4	3	4
259110000000000	-	-	-	4	4	4	4
261460000000000	-	-	-	4	4	3	4
261980000000000	-	-	-	4	4	4	2
262520000000000	-	-	-	4	4	3	4
263250000000000	-	-	-	3	4	3	3
265370000000000	-	-	-	3	3	3	4
265580000000000	-	-	-	3	4	3	4
266110000000000	-	-	-	3	3	3	4
275880000000000	-	-	-	6	4	-	-
163420000000000	-	-	-	2	4	-	-
262290000000000	-	-	-	3	4	3	4
262430000000000	-	-	-	3	4	3	4
262740000000000	-	-	-	2	3	2	3
262760000000000	-	-	-	4	4	-	-
263860000000000	-	-	-	3	4	-	-
263960000000000	-	-	-	2	4	2	3
263980000000000	-	-	-	3	4	3	4
264140000000000	-	-	-	3	4	3	4

Structure ID Number	Year Built	Deck		Superstructure		Substructure	
		Age	Deck Rating	Age	Superstructure Rating	Age	Substructure Rating
265320000000000	-	-	-	2	4	2	4
265490000000000	-	-	-	2	3	2	3
265570000000000	-	-	-	4	4	-	-
266940000000000	-	-	-	2	4	4	4
269510000000000	-	-	-	3	4	3	4
270650000000000	-	-	-	5	4	-	-
015920000000000	-	-	-	4	4	4	4
268080000000000	-	-	-	2	4	-	-
269290000000000	-	-	-	2	4	-	-
269300000000000	-	-	-	2	4	-	-
269310000000000	-	-	-	2	4	-	-
269740000000000	-	-	-	4	4	-	-
270140000000000	-	-	-	4	4	-	-
270330000000000	-	-	-	4	4	-	-
270380000000000	-	-	-	2	4	2	4
270740000000000	-	-	-	2	2	-	-
276160000000000	-	-	-	4	4	-	-
270230000000000	-	-	-	3	2	-	-
270340000000000	-	-	-	3	4	-	-
272840000000000	-	-	-	2	4	-	-
276170000000000	-	-	-	2	3	-	-

Structure ID Number	Year Built	Deck		Superstructure		Substructure	
		Age	Deck Rating	Age	Superstructure Rating	Age	Substructure Rating
276750000000000	-	-	-	2	4	-	-
009140000000000	-	-	-	-	-	10	4
027790000000000	-	-	-	-	-	7	4
028160000000000	-	-	-	-	-	7	4
062190000000000	-	-	-	-	-	9	4
074720000000000	-	-	-	-	-	7	4
082800000000000	-	-	-	-	-	7	4
092940000000000	-	-	-	-	-	7	4
093010000000000	-	-	-	-	-	7	4
094670000000000	-	-	-	-	-	9	4
118950000000000	-	-	-	-	-	7	4
229580000000000	-	-	-	-	-	9	4
229620000000000	-	-	-	-	-	9	4
229640000000000	-	-	-	-	-	4	4
229760000000000	-	-	-	-	-	12	4
229770000000000	-	-	-	-	-	9	4
229980000000000	-	-	-	-	-	7	4
231530000000000	-	-	-	-	-	7	4
231540000000000	-	-	-	-	-	7	4
232060000000000	-	-	-	-	-	9	4
234150000000000	-	-	-	-	-	9	4

Structure ID Number	Year Built	Deck		Superstructure		Substructure	
		Age	Deck Rating	Age	Superstructure Rating	Age	Substructure Rating
236050000000000	-	-	-	-	-	7	4
237150000000000	-	-	-	-	-	9	4
237160000000000	-	-	-	-	-	9	4
243790000000000	-	-	-	-	-	9	3
262980000000000	-	-	-	-	-	11	3
232180000000000	-	-	-	-	-	8	3
233950000000000	-	-	-	-	-	8	4
234380000000000	-	-	-	-	-	2	4
234610000000000	-	-	-	-	-	8	4
235780000000000	-	-	-	-	-	9	4
235790000000000	-	-	-	-	-	6	4
235820000000000	-	-	-	-	-	8	4
236020000000000	-	-	-	-	-	6	4
236060000000000	-	-	-	-	-	6	4
236070000000000	-	-	-	-	-	6	4
237140000000000	-	-	-	-	-	8	4
237170000000000	-	-	-	-	-	8	4
237180000000000	-	-	-	-	-	6	4
237680000000000	-	-	-	-	-	6	4
237920000000000	-	-	-	-	-	6	4
237940000000000	-	-	-	-	-	6	4

Structure ID Number	Year Built	Deck		Superstructure		Substructure	
		Age	Deck Rating	Age	Superstructure Rating	Age	Substructure Rating
237980000000000	-	-	-	-	-	6	4
238030000000000	-	-	-	-	-	6	4
238040000000000	-	-	-	-	-	6	4
238060000000000	-	-	-	-	-	6	4
238440000000000	-	-	-	-	-	11	4
238460000000000	-	-	-	-	-	11	3
245270000000000	-	-	-	-	-	8	3
245280000000000	-	-	-	-	-	8	4
246210000000000	-	-	-	-	-	8	3
254540000000000	-	-	-	-	-	8	2
236920000000000	-	-	-	-	-	5	4
236950000000000	-	-	-	-	-	7	4
237190000000000	-	-	-	-	-	7	4
237280000000000	-	-	-	-	-	7	4
237330000000000	-	-	-	-	-	7	4
237340000000000	-	-	-	-	-	7	4
237660000000000	-	-	-	-	-	5	3
237670000000000	-	-	-	-	-	5	4
237690000000000	-	-	-	-	-	5	4
237790000000000	-	-	-	-	-	7	4
237800000000000	-	-	-	-	-	7	4

Structure ID Number	Year Built	Deck		Superstructure		Substructure	
		Age	Deck Rating	Age	Superstructure Rating	Age	Substructure Rating
237970000000000	-	-	-	-	-	5	3
238070000000000	-	-	-	-	-	5	4
238140000000000	-	-	-	-	-	5	4
238150000000000	-	-	-	-	-	5	4
238170000000000	-	-	-	-	-	9	4
238190000000000	-	-	-	-	-	5	4
238200000000000	-	-	-	-	-	5	4
238420000000000	-	-	-	-	-	5	4
238510000000000	-	-	-	-	-	8	3
238590000000000	-	-	-	-	-	9	4
238740000000000	-	-	-	-	-	5	4
238820000000000	-	-	-	-	-	5	4
238840000000000	-	-	-	-	-	5	4
240360000000000	-	-	-	-	-	7	4
240370000000000	-	-	-	-	-	7	4
240960000000000	-	-	-	-	-	7	2
241200000000000	-	-	-	-	-	7	3
245480000000000	-	-	-	-	-	7	4
245490000000000	-	-	-	-	-	7	4
245810000000000	-	-	-	-	-	7	2
088050000000000	-	-	-	-	-	6	4

Structure ID Number	Year Built	Deck		Superstructure		Substructure	
		Age	Deck Rating	Age	Superstructure Rating	Age	Substructure Rating
239680000000000	-	-	-	-	-	4	4
239690000000000	-	-	-	-	-	6	4
239950000000000	-	-	-	-	-	6	4
239980000000000	-	-	-	-	-	7	3
240160000000000	-	-	-	-	-	4	4
240220000000000	-	-	-	-	-	4	4
240230000000000	-	-	-	-	-	4	4
240300000000000	-	-	-	-	-	6	4
240350000000000	-	-	-	-	-	6	4
241030000000000	-	-	-	-	-	5	0
241100000000000	-	-	-	-	-	4	3
241290000000000	-	-	-	-	-	6	4
241560000000000	-	-	-	-	-	6	4
241660000000000	-	-	-	-	-	6	4
241760000000000	-	-	-	-	-	6	4
242070000000000	-	-	-	-	-	6	2
242530000000000	-	-	-	-	-	6	4
242610000000000	-	-	-	-	-	8	4
242790000000000	-	-	-	-	-	6	4
242800000000000	-	-	-	-	-	6	4
242880000000000	-	-	-	-	-	6	4

Structure ID Number	Year Built	Deck		Superstructure		Substructure	
		Age	Deck Rating	Age	Superstructure Rating	Age	Substructure Rating
242950000000000	-	-	-	-	-	6	2
243390000000000	-	-	-	-	-	6	3
243590000000000	-	-	-	-	-	6	4
243740000000000	-	-	-	-	-	6	2
243780000000000	-	-	-	-	-	6	2
243810000000000	-	-	-	-	-	6	2
246070000000000	-	-	-	-	-	6	3
246100000000000	-	-	-	-	-	6	2
246190000000000	-	-	-	-	-	6	4
246730000000000	-	-	-	-	-	6	4
247260000000000	-	-	-	-	-	6	2
247320000000000	-	-	-	-	-	6	3
247410000000000	-	-	-	-	-	6	2
247420000000000	-	-	-	-	-	6	2
247430000000000	-	-	-	-	-	6	2
247460000000000	-	-	-	-	-	6	2
247480000000000	-	-	-	-	-	7	4
247540000000000	-	-	-	-	-	6	4
247620000000000	-	-	-	-	-	6	4
248500000000000	-	-	-	-	-	6	4
248510000000000	-	-	-	-	-	6	2

Structure ID Number	Year Built	Deck		Superstructure		Substructure	
		Age	Deck Rating	Age	Superstructure Rating	Age	Substructure Rating
250160000000000	-	-	-	-	-	8	2
250170000000000	-	-	-	-	-	8	4
250280000000000	-	-	-	-	-	7	4
241630000000000	-	-	-	-	-	5	4
242200000000000	-	-	-	-	-	5	4
242270000000000	-	-	-	-	-	5	3
242290000000000	-	-	-	-	-	5	4
242460000000000	-	-	-	-	-	9	4
242540000000000	-	-	-	-	-	5	3
242620000000000	-	-	-	-	-	5	2
242840000000000	-	-	-	-	-	5	4
242940000000000	-	-	-	-	-	5	2
242960000000000	-	-	-	-	-	5	2
243250000000000	-	-	-	-	-	5	3
243350000000000	-	-	-	-	-	5	3
243580000000000	-	-	-	-	-	5	4
243880000000000	-	-	-	-	-	5	2
243930000000000	-	-	-	-	-	5	4
244220000000000	-	-	-	-	-	5	4
245830000000000	-	-	-	-	-	8	4
246110000000000	-	-	-	-	-	5	2

Structure ID Number	Year Built	Deck		Superstructure		Substructure	
		Age	Deck Rating	Age	Superstructure Rating	Age	Substructure Rating
246120000000000	-	-	-	-	-	5	2
246370000000000	-	-	-	-	-	6	4
246430000000000	-	-	-	-	-	5	3
247180000000000	-	-	-	-	-	4	4
247310000000000	-	-	-	-	-	5	2
247500000000000	-	-	-	-	-	5	2
247740000000000	-	-	-	-	-	5	3
249240000000000	-	-	-	-	-	6	4
249630000000000	-	-	-	-	-	5	3
249760000000000	-	-	-	-	-	5	2
249890000000000	-	-	-	-	-	4	3
250050000000000	-	-	-	-	-	5	4
250970000000000	-	-	-	-	-	14	4
251500000000000	-	-	-	-	-	5	4
252270000000000	-	-	-	-	-	4	4
252290000000000	-	-	-	-	-	4	4
252590000000000	-	-	-	-	-	7	3
252800000000000	-	-	-	-	-	5	4
267440000000000	-	-	-	-	-	7	4
244700000000000	-	-	-	-	-	5	4
246550000000000	-	-	-	-	-	5	4

Structure ID Number	Year Built	Deck		Superstructure		Substructure	
		Age	Deck Rating	Age	Superstructure Rating	Age	Substructure Rating
246610000000000	-	-	-	-	-	5	3
246960000000000	-	-	-	-	-	5	4
247510000000000	-	-	-	-	-	5	4
247960000000000	-	-	-	-	-	5	4
248290000000000	-	-	-	-	-	5	3
248690000000000	-	-	-	-	-	5	4
249250000000000	-	-	-	-	-	5	2
249460000000000	-	-	-	-	-	5	4
249640000000000	-	-	-	-	-	7	3
249970000000000	-	-	-	-	-	5	4
250180000000000	-	-	-	-	-	5	4
250190000000000	-	-	-	-	-	5	4
250410000000000	-	-	-	-	-	5	4
250450000000000	-	-	-	-	-	5	3
250650000000000	-	-	-	-	-	7	4
250790000000000	-	-	-	-	-	5	4
250800000000000	-	-	-	-	-	6	4
250830000000000	-	-	-	-	-	5	2
250840000000000	-	-	-	-	-	5	2
250850000000000	-	-	-	-	-	5	2
250950000000000	-	-	-	-	-	7	4

Structure ID Number	Year Built	Deck		Superstructure		Substructure	
		Age	Deck Rating	Age	Superstructure Rating	Age	Substructure Rating
251110000000000	-	-	-	-	-	5	4
251410000000000	-	-	-	-	-	3	2
251420000000000	-	-	-	-	-	3	4
251620000000000	-	-	-	-	-	5	2
251930000000000	-	-	-	-	-	5	4
252260000000000	-	-	-	-	-	3	2
252280000000000	-	-	-	-	-	3	2
252570000000000	-	-	-	-	-	7	4
252650000000000	-	-	-	-	-	6	3
252680000000000	-	-	-	-	-	6	3
253300000000000	-	-	-	-	-	6	4
255460000000000	-	-	-	-	-	7	4
259380000000000	-	-	-	-	-	5	4
260480000000000	-	-	-	-	-	5	2
260910000000000	-	-	-	-	-	5	4
268420000000000	-	-	-	-	-	5	2
252560000000000	-	-	-	-	-	4	4
253760000000000	-	-	-	-	-	4	4
253970000000000	-	-	-	-	-	4	4
253980000000000	-	-	-	-	-	5	3
254320000000000	-	-	-	-	-	4	2

Structure ID Number	Year Built	Deck		Superstructure		Substructure	
		Age	Deck Rating	Age	Superstructure Rating	Age	Substructure Rating
254340000000000	-	-	-	-	-	4	2
254370000000000	-	-	-	-	-	4	3
254450000000000	-	-	-	-	-	4	2
254550000000000	-	-	-	-	-	4	4
254560000000000	-	-	-	-	-	4	2
254590000000000	-	-	-	-	-	2	4
254750000000000	-	-	-	-	-	4	4
254800000000000	-	-	-	-	-	4	2
254810000000000	-	-	-	-	-	4	2
254820000000000	-	-	-	-	-	5	4
254910000000000	-	-	-	-	-	4	4
255020000000000	-	-	-	-	-	6	4
255090000000000	-	-	-	-	-	4	4
255130000000000	-	-	-	-	-	4	2
255260000000000	-	-	-	-	-	4	3
255720000000000	-	-	-	-	-	4	4
256610000000000	-	-	-	-	-	4	3
257020000000000	-	-	-	-	-	4	2
257590000000000	-	-	-	-	-	4	4
257840000000000	-	-	-	-	-	4	4
259400000000000	-	-	-	-	-	4	3

Structure ID Number	Year Built	Deck		Superstructure		Substructure	
		Age	Deck Rating	Age	Superstructure Rating	Age	Substructure Rating
260490000000000	-	-	-	-	-	4	4
267040000000000	-	-	-	-	-	4	4
267530000000000	-	-	-	-	-	4	4
276180000000000	-	-	-	-	-	7	4
276190000000000	-	-	-	-	-	7	4
148000000000000	-	-	-	-	-	4	2
177240000000000	-	-	-	-	-	3	3
256630000000000	-	-	-	-	-	3	3
256700000000000	-	-	-	-	-	3	4
257100000000000	-	-	-	-	-	3	4
257110000000000	-	-	-	-	-	3	4
258320000000000	-	-	-	-	-	4	4
258390000000000	-	-	-	-	-	3	4
259260000000000	-	-	-	-	-	3	4
259270000000000	-	-	-	-	-	3	3
260430000000000	-	-	-	-	-	4	4
260680000000000	-	-	-	-	-	4	4
261090000000000	-	-	-	-	-	3	4
261100000000000	-	-	-	-	-	3	4
261130000000000	-	-	-	-	-	3	4
261560000000000	-	-	-	-	-	4	4

Structure ID Number	Year Built	Deck		Superstructure		Substructure	
		Age	Deck Rating	Age	Superstructure Rating	Age	Substructure Rating
261890000000000	-	-	-	-	-	3	3
263230000000000	-	-	-	-	-	4	4
263260000000000	-	-	-	-	-	4	4
263270000000000	-	-	-	-	-	4	3
263280000000000	-	-	-	-	-	4	4
264060000000000	-	-	-	-	-	4	3
264520000000000	-	-	-	-	-	3	4
265630000000000	-	-	-	-	-	3	2
266970000000000	-	-	-	-	-	3	4
241880000000000	-	-	-	-	-	2	4
261330000000000	-	-	-	-	-	3	4
261420000000000	-	-	-	-	-	4	4
261840000000000	-	-	-	-	-	2	2
262730000000000	-	-	-	-	-	3	4
262770000000000	-	-	-	-	-	2	4
262820000000000	-	-	-	-	-	3	3
263090000000000	-	-	-	-	-	3	4
263110000000000	-	-	-	-	-	3	3
263160000000000	-	-	-	-	-	2	3
263180000000000	-	-	-	-	-	3	4
263490000000000	-	-	-	-	-	4	4

Structure ID Number	Year Built	Deck		Superstructure		Substructure	
		Age	Deck Rating	Age	Superstructure Rating	Age	Substructure Rating
263500000000000	-	-	-	-	-	2	3
263510000000000	-	-	-	-	-	2	4
263520000000000	-	-	-	-	-	2	3
263870000000000	-	-	-	-	-	2	4
263950000000000	-	-	-	-	-	2	4
263970000000000	-	-	-	-	-	2	4
263990000000000	-	-	-	-	-	3	3
264000000000000	-	-	-	-	-	2	4
264090000000000	-	-	-	-	-	3	4
264290000000000	-	-	-	-	-	3	2
264350000000000	-	-	-	-	-	2	4
264380000000000	-	-	-	-	-	2	4
264490000000000	-	-	-	-	-	3	2
264530000000000	-	-	-	-	-	3	3
264670000000000	-	-	-	-	-	2	3
264680000000000	-	-	-	-	-	3	4
265550000000000	-	-	-	-	-	2	4
265590000000000	-	-	-	-	-	4	4
265640000000000	-	-	-	-	-	2	2
265650000000000	-	-	-	-	-	2	2
265880000000000	-	-	-	-	-	2	4

Structure ID Number	Year Built	Deck		Superstructure		Substructure	
		Age	Deck Rating	Age	Superstructure Rating	Age	Substructure Rating
266950000000000	-	-	-	-	-	2	4
266980000000000	-	-	-	-	-	2	4
267140000000000	-	-	-	-	-	3	4
267370000000000	-	-	-	-	-	2	4
271040000000000	-	-	-	-	-	3	4
271090000000000	-	-	-	-	-	3	4
271150000000000	-	-	-	-	-	3	4
271710000000000	-	-	-	-	-	3	4
274580000000000	-	-	-	-	-	4	3
274590000000000	-	-	-	-	-	4	3
274650000000000	-	-	-	-	-	4	3
176480000000000	-	-	-	-	-	2	4
222400000000000	-	-	-	-	-	3	3
258440000000000	-	-	-	-	-	4	4
265190000000000	-	-	-	-	-	2	2
265200000000000	-	-	-	-	-	2	2
265210000000000	-	-	-	-	-	2	2
265220000000000	-	-	-	-	-	2	2
265480000000000	-	-	-	-	-	10	2
265500000000000	-	-	-	-	-	3	4
266700000000000	-	-	-	-	-	3	3

Structure ID Number	Year Built	Deck		Superstructure		Substructure	
		Age	Deck Rating	Age	Superstructure Rating	Age	Substructure Rating
266840000000000	-	-	-	-	-	9	4
266890000000000	-	-	-	-	-	11	4
267560000000000	-	-	-	-	-	11	4
268330000000000	-	-	-	-	-	2	4
269360000000000	-	-	-	-	-	2	2
270060000000000	-	-	-	-	-	2	2
270070000000000	-	-	-	-	-	2	2
270680000000000	-	-	-	-	-	2	4
270720000000000	-	-	-	-	-	2	4
271770000000000	-	-	-	-	-	2	2
274620000000000	-	-	-	-	-	3	4
269110000000000	-	-	-	-	-	3	4
269700000000000	-	-	-	-	-	9	4
270710000000000	-	-	-	-	-	2	3
270860000000000	-	-	-	-	-	3	4
270870000000000	-	-	-	-	-	3	4
270950000000000	-	-	-	-	-	3	4
270990000000000	-	-	-	-	-	9	4
271850000000000	-	-	-	-	-	8	2
272300000000000	-	-	-	-	-	3	2
272870000000000	-	-	-	-	-	2	3

Structure ID Number	Year Built	Deck		Superstructure		Substructure	
		Age	Deck Rating	Age	Superstructure Rating	Age	Substructure Rating
272880000000000	-	-	-	-	-	2	3
274570000000000	-	-	-	-	-	2	3
274600000000000	-	-	-	-	-	2	4
274610000000000	-	-	-	-	-	2	3
274630000000000	-	-	-	-	-	2	4
275640000000000	-	-	-	-	-	2	4
244960000000000	-	-	-	-	-	8	4
259370000000000	-	-	-	-	-	2	4
272890000000000	-	-	-	-	-	2	4
275020000000000	-	-	-	-	-	2	2
275080000000000	-	-	-	-	-	9	4
276130000000000	-	-	-	-	-	2	3
247710000000000	-	-	-	-	-	6	4
284830000000000	-	-	-	-	-	5	4
284860000000000	-	-	-	-	-	4	4
286230000000000	-	-	-	-	-	6	4
286360000000000	-	-	-	-	-	6	4
291950000000000	-	-	-	-	-	3	4
296110000000000	-	-	-	-	-	2	4

VITA

Mohammed Alabdullah

Candidate for the Degree of

Master of Science

Thesis: PREDICTING FIRST TIME REACHING DEFICIENCY STATUS (FTRDS) FOR STEEL BRIDGES IN OKLAHOMA

Major Field: Civil Engineering

Biographical:

Education:

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INDUSTRY EXPERIENCE

2013 - 2015

Site Engineer, N.S.C.C International limited - Construction of an Inverted Siphon on Arab Gulf. Basra, Iraq.

http://www.nsccme.com/highlights-images-webapp/shatt-al-arab-siphon

2011 - 2013

Site Engineer, Coat Estimator Basra Sports City (65,000 seats), Basra, Iraq.