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16. Abstract

Bridge Management System (BMS) needs an analytical tool that can predict bridge element deterioration and answer questions related to bridge preservation. PONTIS, a comprehensive BMS software, was developed to serve this purpose. However, the intensive data requirement in PONTIS has prevented the Louisiana Department of Transportation and Development (LA DOTD), like 40 other state DOTs in the country, from fully utilizing PONTIS modeling capabilities, despite an annual maintenance fee of $25,000 paid to the program developer. To solve this problem, an innovative approach was developed in this project. The long-term performance of the bridge system under various alternatives of BMS was evaluated using readily available National Bridge Inventory (NBI) data in PONTIS. The deterioration process of three elements was thoroughly studied, and the element deterioration models were developed based on these observations. The bridge preservation plans and associated cost schemes were also developed according to LA DOTD's current practice and available information.

The results from this project have demonstrated that it is feasible and practical to use rich historical NBI data for BMS analysis. The current LA DOTD $70 million annual budget for bridge systems seems sufficient to meet the preservation need, but it is not adequate for meeting the needs of bridge functional improvement. The bridge preservation plan, if implemented successfully, can maintain the bridge system in good operating conditions for a long time under a limited annual budget.

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Analysis of Past NBI Ratings to Determine Future Bridge Preservation Needs

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ABSTRACT

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To solve this problem, an innovative approach was developed in this project. The long-term performance of the bridge system under various alternatives of BMS was evaluated using readily available National Bridge Inventory (NBI) data in PONTIS. The deterioration process of three NBI elements was thoroughly studied, and the element deterioration models were developed based on these observations. The bridge preservation plans and associated cost schemes were also developed according to LA DOTD's current practice and available information.

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ACKNOWLEDGEMENTS

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IMPLEMENTATION STATEMENT

The implementation of this project should lead to better-informed decisions on planning and budgeting for the Louisiana highway bridge system. The Planning Division of LA DOTD can use the procedures developed in this project for funding decisions on the bridge management system. Specifically, the LA DOTD Budgeting and Planning Office can fully apply the comprehensive PONTIS program to evaluate many planning scenarios and answer various what-if questions concerning the trade-offs between serviceability and budgetary constraints.

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INTRODUCTION

There are more than 8,000 bridges in the Louisiana state highway system. To maintain these bridges in acceptable operating conditions, limited funds are allocated to the system annually. To effectively utilize the resources, the Louisiana Department of Transportation and Development (LA DOTD) needs a procedure that can optimize the long-term system performance under the budgetary constraints. The ability to predict future bridge preservation needs is critical to the 2001 LA DOTD Strategic Plan and to the update of the Statewide Transportation Plan. Currently, LA DOTD is contributing $25,000 annually to maintain a comprehensive bridge management software named PONTIS. PONTIS requires extensive bridge inventory data and condition ratings data at the very detailed bridge element level. Mainly due to the large amount of work required, LA DOTD had never collected this type of data until very recently. The newly initiated data collection project will take several years to complete (with both inventory details and ratings)[1].

While there are no data available for executing the PONTIS program, LA DOTD has collected the extensive National Bridge Index (NBI) data for the past two decades. The NBI data are not at the detailed PONTIS element level; therefore, it cannot be directly used as it is input to the program. PONTIS software, a result of many years of development by a group of experts, is a complex program for bridge system optimization and simulation. Despite PONTIS' powerful modeling capability, only a few state DOTs have fully utilized PONTIS for their bridge management systems.

OBJECTIVE

The goal of this project is to develop a practical procedure for the LA DOTD bridge management system. Specifically, the research team will use the current and past NBI data to:

- Develop a three-element database for the PONTIS program that consists of the elements of deck, superstructure, and substructure.

- Develop and calibrate the generalized Louisiana bridge element-deterioration models to be used in the PONTIS program.

- Obtain expertise in running the PONTIS program.

- Collect the cost information, develop, and calibrate a generalized cost database to be used in the PONTIS program.

- Establish a usable and reliable procedure to trace bridge preservation and replacement activities.

SCOPE

The scope of this project is limited to analyzing the preservation and improvement needs for planning the Louisiana bridge system with the PONTIS program and current available NBI data. The comprehensive PONTIS program requires a set of input that includes bridge-element deterioration models, preservation action plans, and the associated costs, which are developed by this project. The results of the project can be used as a decision-making tool for planning and budgeting the bridge management system. Once the on-going PONTIS inspection project is completed, the procedures developed in this project can be readily applied to a more detailed analysis with PONTIS.

METHODOLOGY

Louisiana Bridge System

LA DOTD is responsible for maintaining approximately 17,000 miles of roads and 8,000 on-system bridges. Among these bridges, about 7,000 are in operation with a total deck surface area of 130 million square feet. More than 55 percent of state bridges were built before 1970, as shown in figure 1. Maintaining all bridges, old and new, in good, operating condition under the limited annual budget is a challenge for LA DOTD.

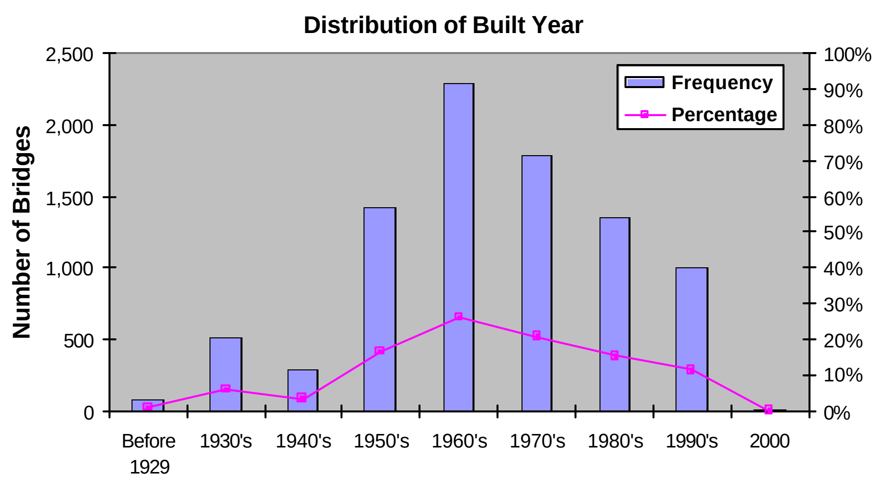


Figure 1
The distribution of bridges built year

The number of bridges sorted by construction materials and type of structures is listed in table 1 according to the NBI system. The culverts are not included in this study because of their small sizes and functions. The number and deck area of on-system bridges change slightly from year to year because of the addition of new bridges, removal of old bridges, and widening of bridges.

Table 1
An overview of Louisiana highway bridges

No.	Type of Materials	No.	Type of Structures	Deck Area (kft2)					Number of Structures				
				1980	1985	1990	1995	2000	1980	1985	1990	1995	2000
1	Blank	1	Blank	-	-	-	54	1,887	-	-	-	13	85
2	0-OTHER	2	00-OTHER	259	4,809	5,830	12	6	131	174	141	4	2
3	1-CONCRETE	3	01-SLAB	12,734	11,159	12,303	13,017	13,987	2,392	2,586	2,753	2,886	3,049
		4	02-STRINGER	22,416	19,330	13,445	-	-	564	426	423	-	-
		5	04-TEE BEAM	6,068	4,200	4,126	3,695	3,627	474	356	343	326	308
		6	05-BOX BEAM	158	466	783	-	-	7	21	36	-	-
		7	11-ARCH	10	6	6	31	31	5	2	2	4	4
		8	18-TUNNEL	45	45	45	45	45	3	3	3	3	3
		9	22-CHNL BEM	-	-	-	2	4	-	-	-	1	2
4	2-CONCRETE	10	01-SLAB	133	129	146	239	328	18	17	19	29	33
		11	04-TEE BEAM	161	285	673	646	833	9	28	54	67	73
		12	05-BOX BEAM	-	-	-	938	991	-	-	-	44	47
5	3-STEEL	13	00-OTHER	58	161	155	6	6	19	21	18	5	5
		14	02-STRINGER	44,031	39,492	28,434	22,723	25,985	538	543	547	825	789
		15	03-GIRDER	-	-	-	4,233	4,162	-	-	-	97	85
		16	09-TRUSS	500	-	-	94	598	2	-	-	1	3
		17	10-TRUSS	1,226	12,256	12,389	1,857	1,526	16	47	45	37	29
		18	15-MOV-LIFT	744	1,327	1,440	1,195	1,176	22	56	56	38	36
		19	16-MOV-BASC	1,214	1,296	1,294	945	934	9	11	10	8	7
		20	17-MOV-SWNG	211	1,047	1,070	1,088	1,134	13	63	63	70	71
6	4-STEEL	21	02-STRINGER	546	5,358	11,826	3,362	4,316	41	97	131	97	115
		22	03-GIRDER	-	3,300	3,265	12,295	6,441	-	47	46	159	143
		23	05-BOX BEAM	-	-	-	3,950	4,402	-	-	-	29	52
		24	10-TRUSS	-	-	-	3,657	3,581	-	-	-	24	24
		25	14-STAYED	-	-	-	254	254	-	-	-	1	1
7	5-PRESTRES	26	02-STRINGER	48,842	40,239	45,022	35,717	43,525	705	782	953	1,055	1,102
8	6-PRESTRES	27	02-STRINGER	-	-	-	7,434	9,463	-	-	-	157	257
9	7-TIMBER	28	02-STRINGER	3,957	2,671	2,435	2,236	1,771	1,838	1,350	1,213	1,077	835
Sub-total				143,314	147,577	144,686	119,726	131,013	6,806	6,630	6,856	7,057	7,160

There are 134,677,000 square feet of deck area and 8,751 bridges in the 2000 NBI database. Most of the bridges were constructed with concrete and steel. Figures 2 and 3 show that the bridges constructed with concrete have the most number of structures of 4,700, while the bridges with stressed concrete have the largest deck area of 43,525,000 square feet.

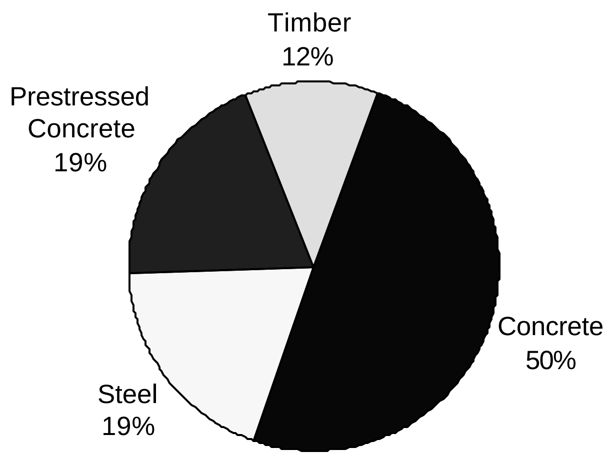


Figure 2
Number of bridge distribution by constructed materials (2000)

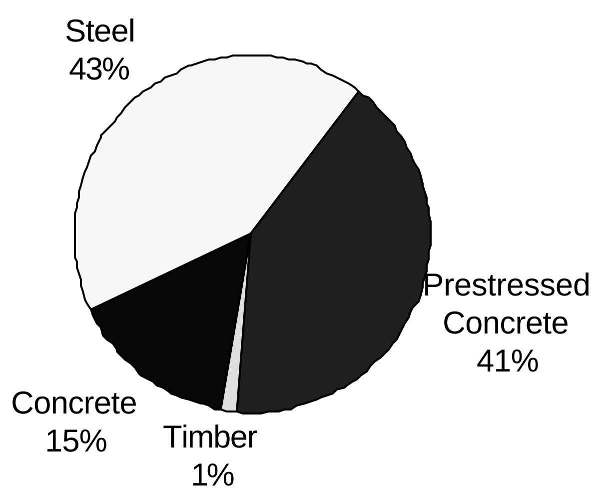
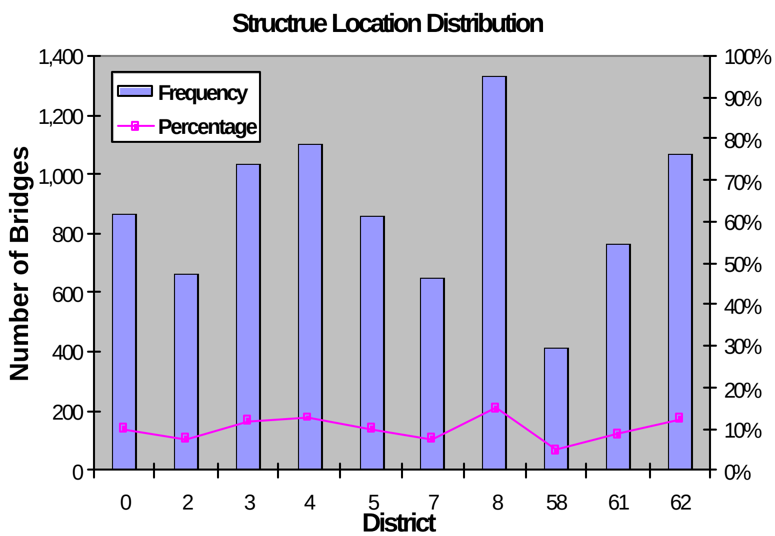


Figure 3
Bridges deck area distribution by construction materials (2000)

The number of bridges is not distributed evenly among the nine LA DOTD district offices, as show in figure 4. For example, District 8 housed in Alexandria has 1,323 structures, or 15 percent of the total bridges in the state, constituting the largest quantity among all districts.



Code	District
0	Missing
2	Bridge City
3	Lafayette
4	Bossier City
5	Monroe
7	Lake Charles
8	Alexandria
58	Chase
61	Baton Rouge
62	Hammond

Figure 4
Bridges distribution by LA DOTD districts

To evaluate bridge conditions, several measurements, or condition indicators, have been widely used: NBI Rating, Health Index (HI), and Sufficiency Rating (SR). The NBI rating deals with three bridge elements: deck, superstructure, and substructure. The Health Index and Sufficiency Rating are for a whole bridge. PONTIS, the most widely accepted bridge management software, has its own rating systems for commonly recognized bridge elements (CoRe.) that will be discussed later in this report [1,2].

Following the FHWA requirements, LA DOTD has been collecting NBI data for more than 20 years. The historical NBI data have revealed a great deal of information on element conditions and the subjected maintenance actions over the years. The NBI system classifies element conditions into nine categories as explained in table 2 [3].

Table 2 NBI condition rating

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.

The overall conditions of the highway bridge system in 2002 are plotted in terms of NBI ratings for deck, superstructure, and substructure as displayed in figures 5, 6, and 7. The total number of bridges is 7,146 (excluding culverts) and the total deck area is 113.5 million square feet.

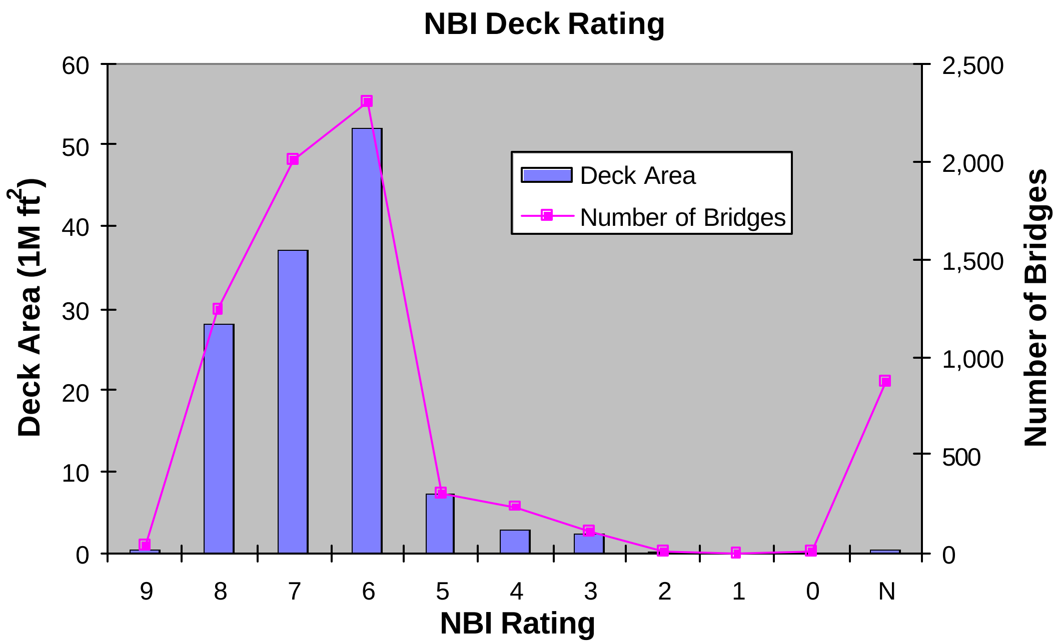


Figure 5
NBI deck ratings in 2002

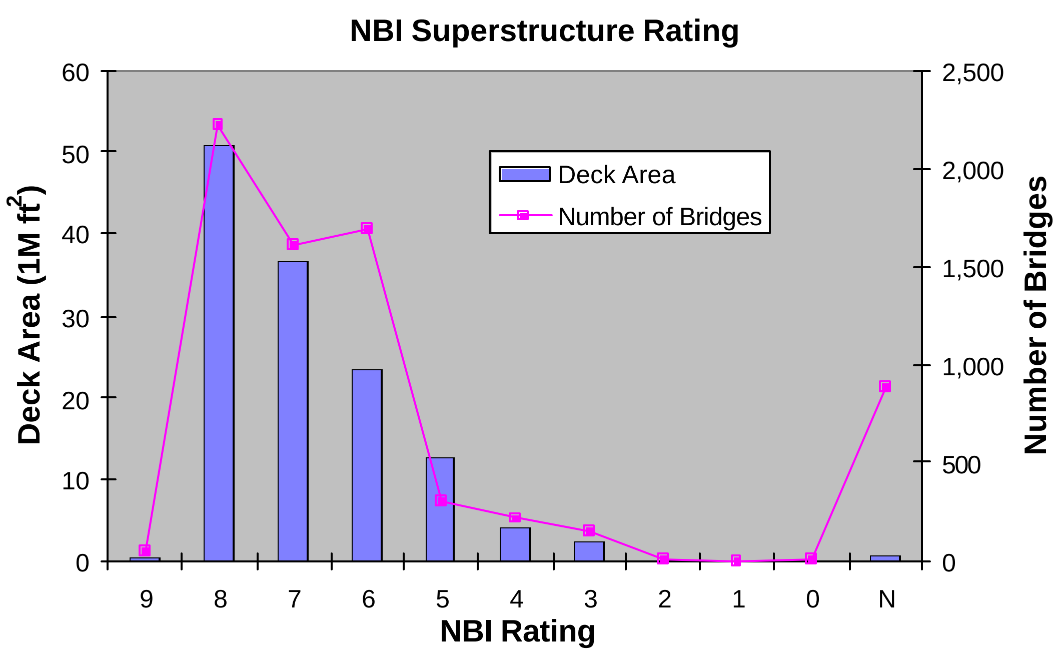


Figure 6
NBI superstructure ratings in 2002

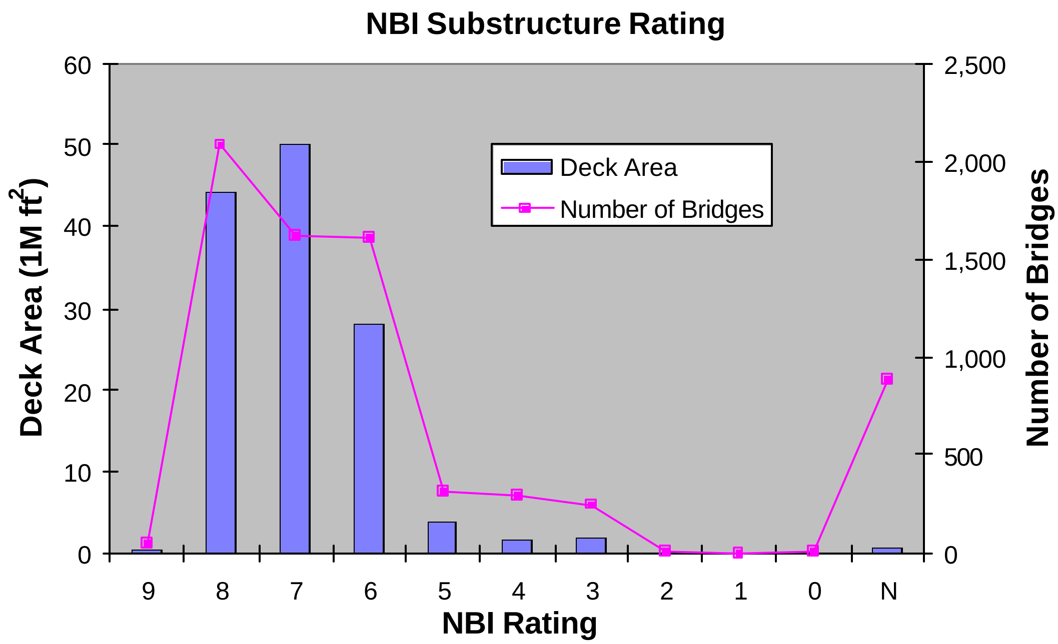


Figure 7
NBI substructure ratings in 2002

The 2002 NBI ratings show that the majority of the bridges under the LA DOTD system are in good conditions, and about 20 percent of the bridges need improvement.

Sufficiency Rating (SR) is another measurement for a bridge. It is a function of NBI ratings of the three elements, traffic volume, and structure deficiency. Figures 8 and 9 show, respectively, the components and distribution of SR in year 2002. The number and deck area of bridges with an SR greater than 50 are 5,406 and 123 million square feet, respectively [2].

Both NBI and SR show that the on-system bridges in Louisiana are generally in good conditions. However, as the brides are getting older, the needs for maintenance and replacement will increase. How fast the bridges will deteriorate and how sufficient the current budget is for the bridge system are the questions that need to be answered for the LA DOTD's bridge management system.

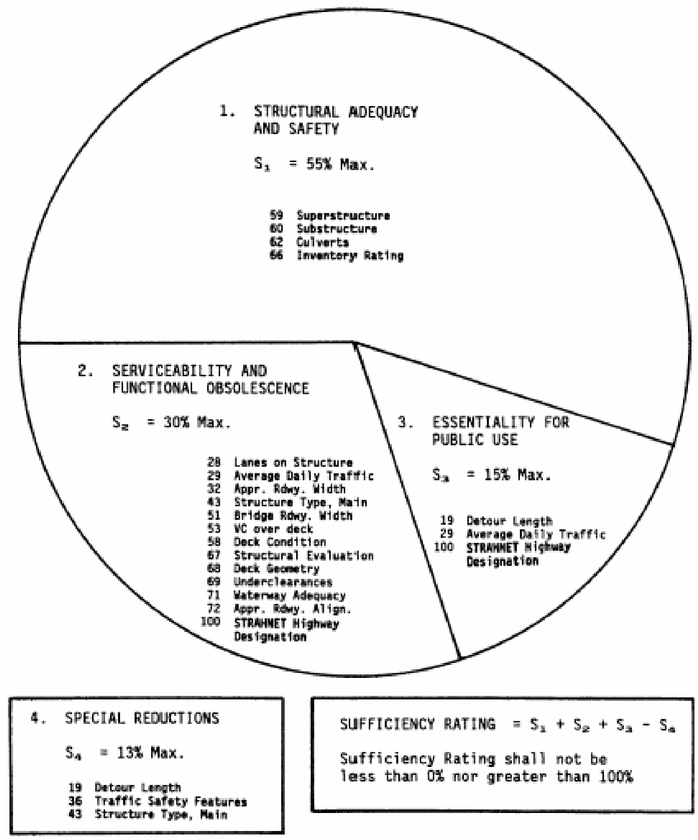


Figure 8
The sufficiency rating calculation chart

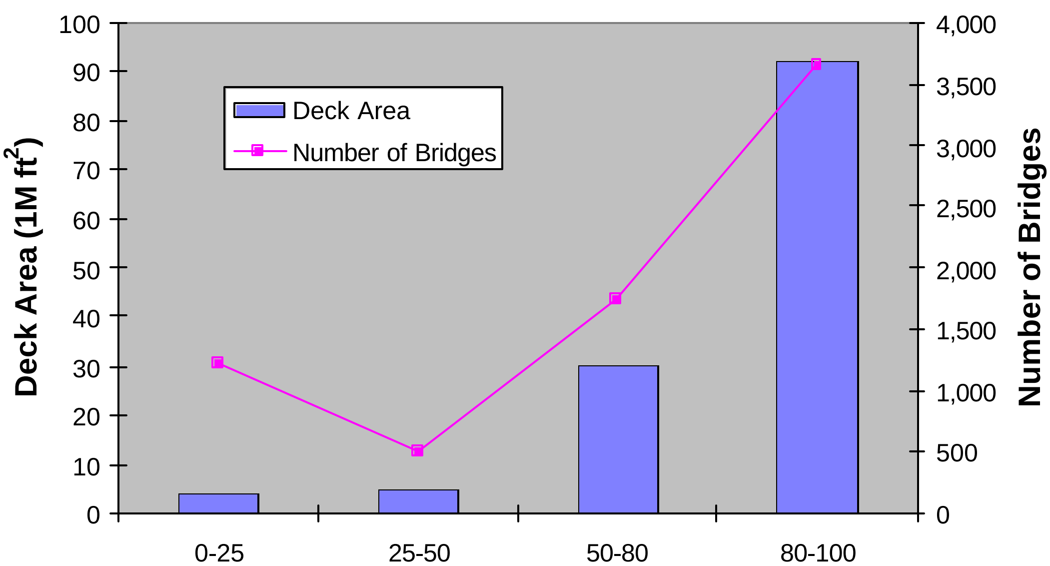


Figure 9
Distribution of sufficiency rating in 2002

Development of Louisiana Bridge Deterioration Model

One important task of this project is to develop a Louisiana bridge- element deterioration model that can be used to predict future-bridge system performance. Although PONTIS, the adopted BMS software, has the default-element deterioration models, they cannot be applied to the NBI elements. Three major steps involved in developing the deterioration models are described below.

Step 1. Developing the Historical NBI Rating Matrices for the Four Aggregated Bridge Groups

As presented in table 1, there are 28 NBI bridge categories (excluding curvets). Considering their similarities in deterioration patterns and construction materials, four major bridge groups are defined. They are concrete, steel, prestressed concrete, and timber bridges, as shown in table 3. Each group of bridges has three NBI elements leading to 12 elements.

Table 3
The four major bridge groups

	Deck (Ft2)	Super (Ft)	Sub (Item)
Concrete	22,074,867	2,857,781	59,841
Steel	54,326,379	6,492,388	180,990
Prestress	53,863,558	6,264,197	162,487
Timber	1,650,716	252,527	5,059
Total	131,915,520	15,866,893	408,377

The changes in NBI ratings for the three elements of concrete bridges after five years are displayed in figures 10 to 18. Similar figures for the three elements of steel, prestressed concrete, and timber bridges are given in Appendix A.

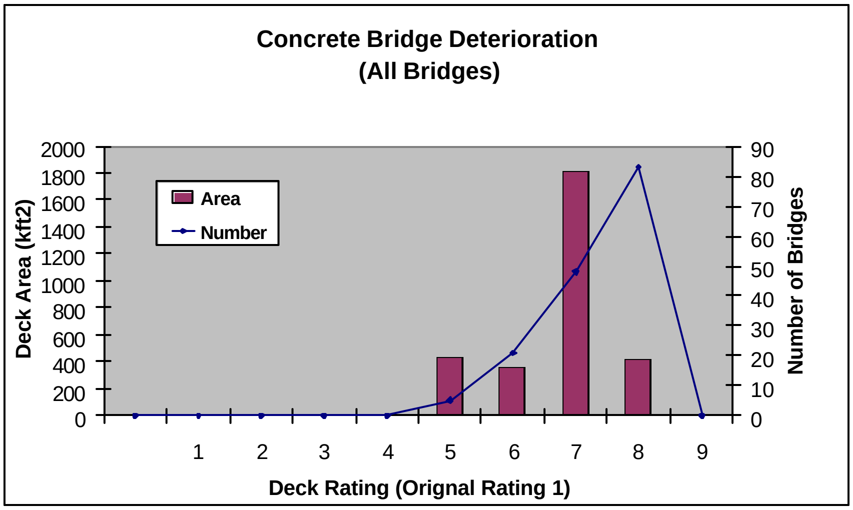


Figure 10
NBI rating distribution after five years (original NBI rating =1)

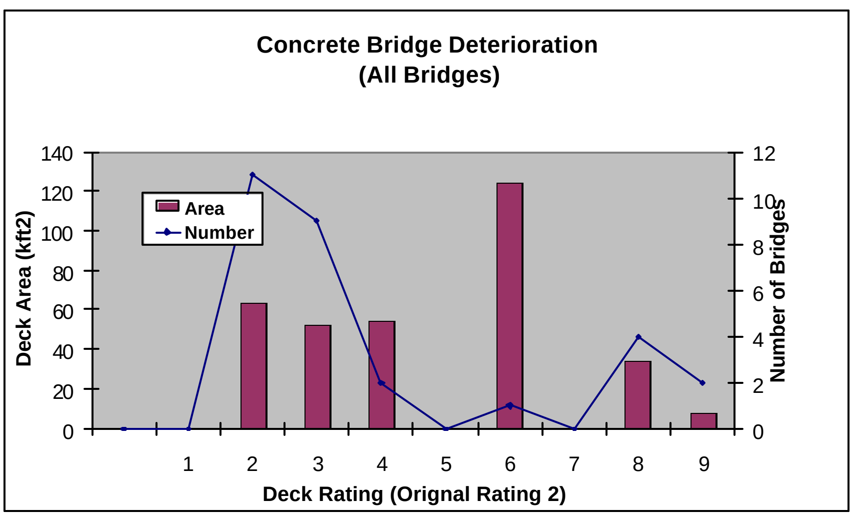


Figure 11
NBI rating distribution after five years (original NBI rating =2)

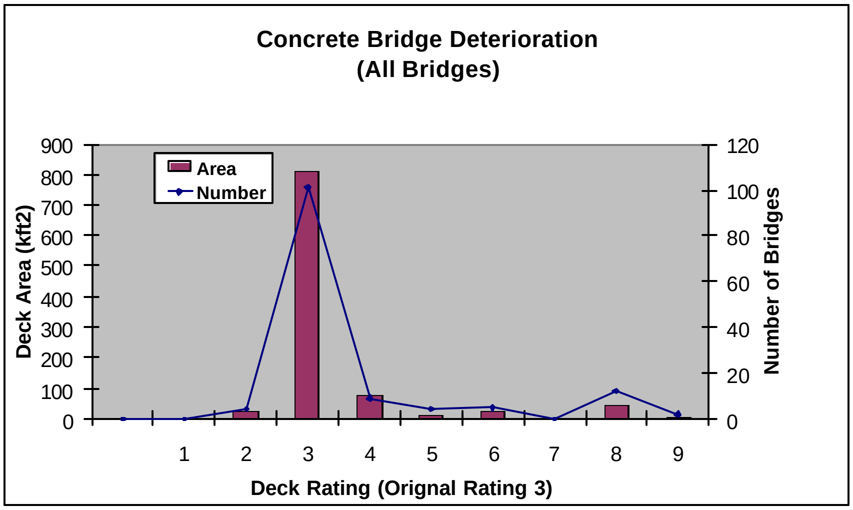


Figure 12
NBI rating distribution after five years (original NBI rating =3)

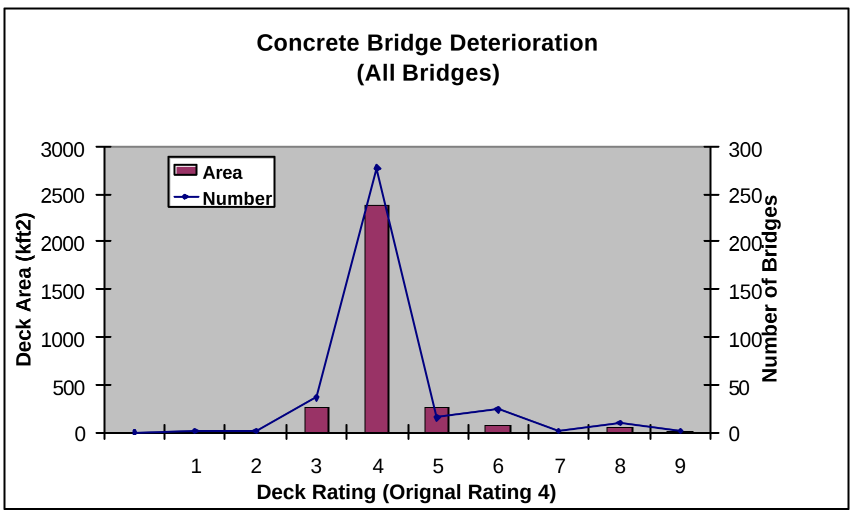


Figure 13
NBI rating distribution after five years (original NBI rating =4)

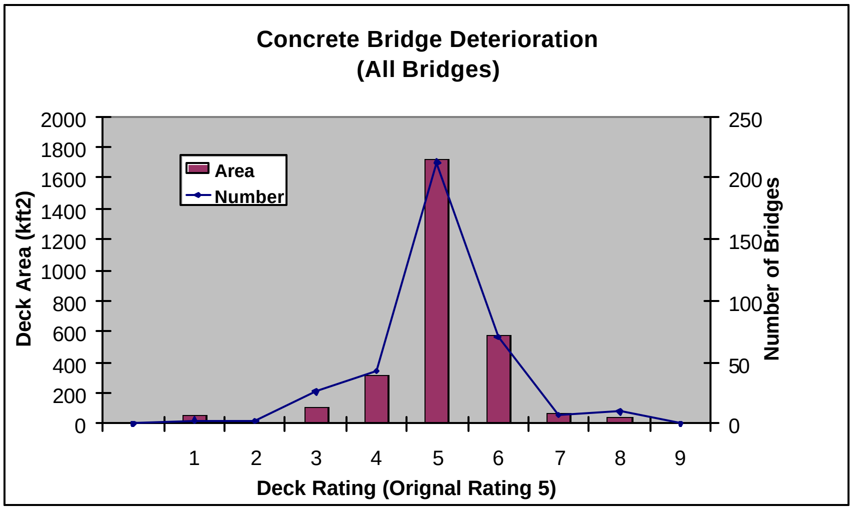


Figure 14
NBI rating distribution after five years (original NBI rating =5)

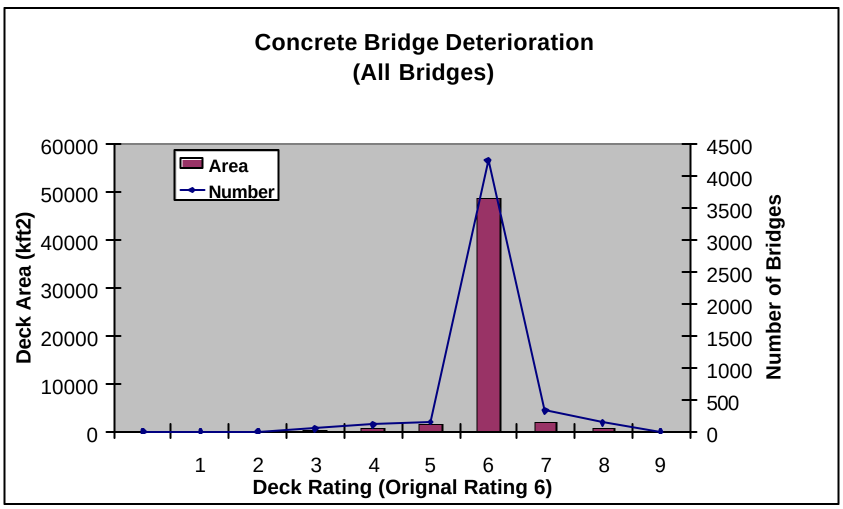


Figure 15
NBI rating distribution after five years (original NBI rating =6)

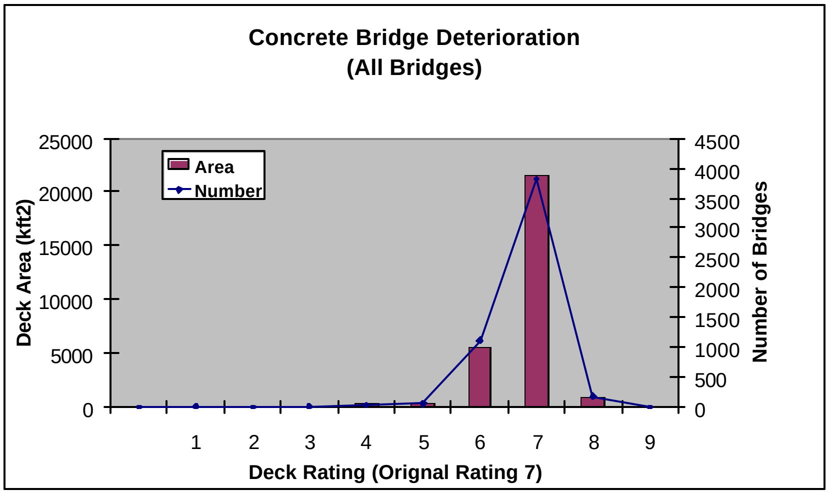


Figure 16
NBI rating distribution after five years (original NBI rating =7)

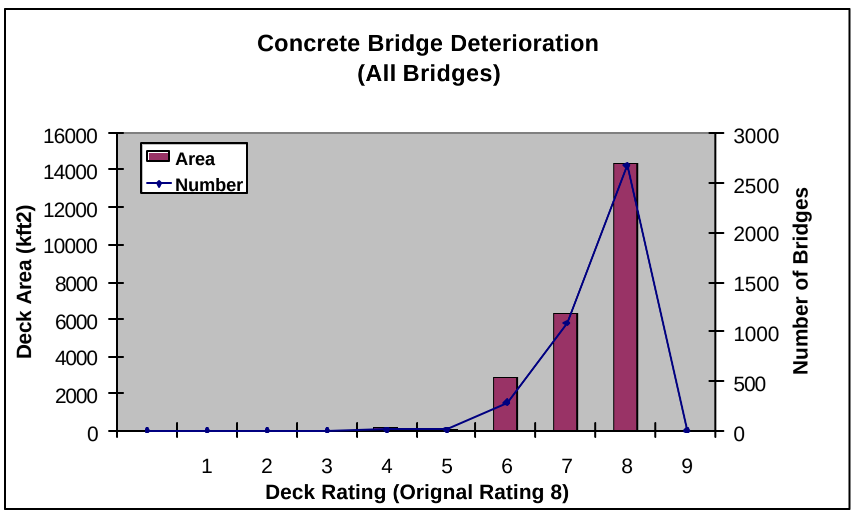


Figure 17
NBI rating distribution after five years (original NBI rating =8)

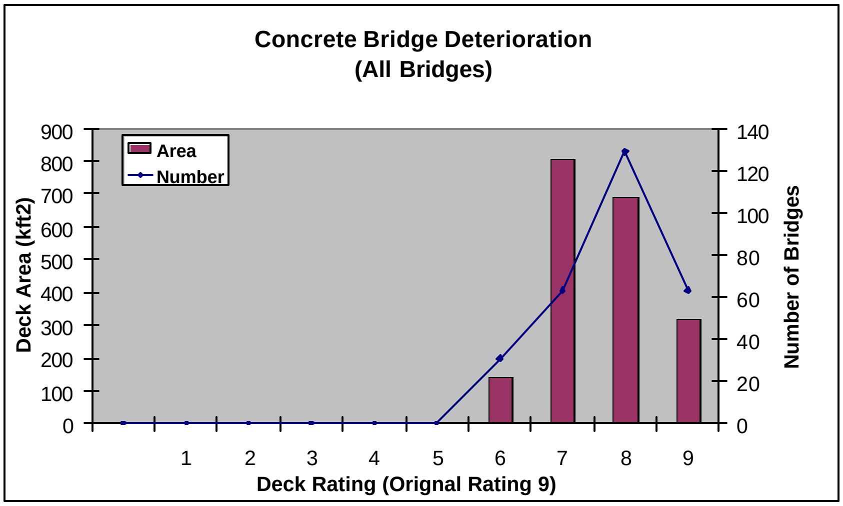


Figure 18
NBI rating distribution after five years (original NBI rating =9)

The above figures indicate that when the original NBI ratings are less than 5, the majority of ratings after five years are higher than the original one, indicating that some types of maintenance actions were conducted during those five years. The NBI ratings of 6, 7, and 8 are considered stable states in which a high proportion of elements stay in the original ratings after five years. For the original rating of 9, figure 18 shows pure deterioration of the element. The NBI rating changes are summarized in figure 19 where the concept of probability indicates the percentage of bridges in each rating group after five years. This probability is naturally called the transition probability that reflects both deterioration and maintenance effects.

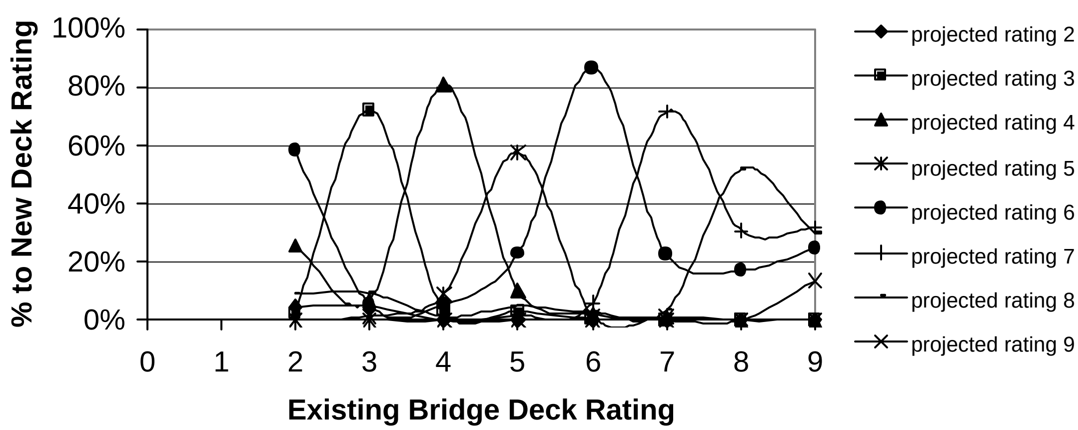


Figure 19
The probability distribution of deck NBI ratings after five years

Step 2. Transferring NBI Rating to PONTIS Rating System

In order to use the PONTIS program, the NBI ratings must be converted to PONTIS ratings. Although the two systems have the same objectives, the NBI ratings differ from PONTIS ratings in three aspects:

1. There are nine rating classes in the NBI ratings, but only four or five rating scales in PONTIS.

2. The NBI rating is set for a whole element (deck, superstructure, or substructure) while the PONTIS rating is for a part of an element.

3. The NBI element is larger and encompasses many PONTIS elements.

Considering the difference in the definitions of the two rating systems, the rating conversion was conducted as shown in table 4. The rating-transfer program developed by the University of Colorado is slightly more complex than ours since its purpose was to convert the PONTIS rating to that of NBI [4].

Table 4
Rating conversions from NBI to PONTIS

<table>
<tr><th rowspan="2">NBI Rating</th><th colspan="3">PONTIS Condition State</th></tr>
<tr><th>Deck</th><th>Superstructure</th><th>Substructure</th></tr>
<tr><td>7-9</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td>6</td><td>2</td><td>2</td><td>2</td></tr>
<tr><td>5</td><td>3</td><td>3</td><td>3</td></tr>
<tr><td>3-4</td><td>4</td><td rowspan="2">4</td><td rowspan="2">4</td></tr>
<tr><td>1-2</td><td>5</td></tr>
</table>

The five-year transition matrices in PONTIS rating for all 12 elements are listed in tables 5 to 16.

Table 5
Five-year transition matrix for concrete bridge deck

Original State	New State				
	1	2	3	4	5
1	82.43	15.59	0.84	1.09	0.06
2	4.35	90.52	2.51	2.53	0.09
3	3.90	19.84	59.19	14.58	2.49
4	2.55	2.49	6.80	87.05	1.10
5	67.65	14.36	12.87	3.20	1.91

Table 6
Five-year transition matrix for concrete bridge superstructure

Original State	New State			
	1	2	3	4
1	80.52	18.03	0.82	0.64
2	3.22	93.11	1.69	1.97
3	8.79	5.81	55.03	30.37
4	32.84	6.45	1.21	59.50

Table 7
Five-year transition matrix for concrete bridge substructure

Original State	New State			
	1	2	3	4
1	90.28	7.03	0.92	1.77
2	4.71	88.00	4.18	3.11
3	8.33	6.31	56.51	28.85
4	45.64	3.85	7.79	42.73

Table 8
Five-year transition matrix for prestressed concrete bridge deck

Original State	New State				
	1	2	3	4	5
1	83.02	10.64	4.38	1.90	0.07
2	7.17	90.23	2.09	0.33	0.17
3	2.66	3.27	74.84	19.01	0.22
4	7.52	15.68	3.05	72.91	0.84
5	14.80	65.01	0.00	12.14	8.05

Table 9
Five-year transition matrix for prestressed concrete bridge superstructure

Original State	New State			
	1	2	3	4
1	91.90	5.83	0.96	1.31
2	2.82	79.31	14.68	3.19
3	0.03	30.11	65.78	4.07
4	44.35	3.46	1.92	50.27

Table 10
Five-year transition matrix for prestressed concrete substructure

Original State	New State			
	1	2	3	4
1	94.98	4.43	0.25	0.34
2	18.50	78.25	1.69	1.56
3	1.99	12.24	63.08	22.69
4	42.66	2.69	1.21	53.44

Table 11
Five-year transition matrix for steel bridge deck

Original State	New State				
	1	2	3	4	5
1	68.89	28.77	0.64	0.00	1.70
2	1.91	97.96	0.10	0.03	0.00
3	28.94	48.41	22.57	0.08	0.00
4	13.20	10.62	0.00	76.17	0.00
5	69.82	25.05	3.57	0.00	1.56

Table 12
Five-year transition matrix for steel bridge superstructure

Original State	New State			
	1	2	3	4
1	98.23	1.47	0.22	0.08
2	19.11	78.22	0.50	2.17
3	24.19	5.09	57.14	13.59
4	85.99	10.45	0.51	3.05

Table 13
Five-year transition matrix for steel bridge substructure

Original State	New State			
	1	2	3	4
1	88.26	11.63	0.10	0.01
2	6.94	92.27	0.74	0.05
3	49.60	21.55	27.78	1.07
4	97.72	0.00	0.19	2.09

Table 14
Five-year transition matrix for timber bridge superstructure

Original State	New State				
	1	2	3	4	5
1	45.04	37.14	7.72	9.70	0.40
2	4.18	67.66	8.96	18.92	0.28
3	0.82	13.48	45.74	37.45	2.51
4	1.71	5.85	7.97	83.28	1.19
5	0.00	0.00	54.83	24.71	20.45

Table 15
Five-year transition matrix for timber bridge superstructure

Original State	New State			
	1	2	3	4
1	51.00	28.48	5.93	14.59
2	3.32	67.98	8.50	20.20
3	1.28	8.28	53.62	36.82
4	0.29	9.33	7.15	83.23

Table 16
Five-year transition matrix for timber bridge substructure

Original State	New State			
	1	2	3	4
1	43.98	32.29	5.42	18.30
2	2.60	57.55	8.03	31.82
3	0.00	11.38	38.39	50.23
4	0.17	3.10	4.76	91.98

The upper triangles of the matrices indicate element deterioration (the condition state getting worse), while the lower parts reflect the maintenance actions (the condition state getting better). The diagonal numbers represent the probability of an element staying at the same condition rating after five years.

Step 3. Development of Deterioration Matrices

The development of a pure deterioration model is based on the assumption that there were no maintenance actions during the past five years. In this case, the numbers on the lower triangle of table 5 are zeros. The final deterioration matrix, D, is computed by the transition matrix P as shown below:

$$P = \begin{bmatrix} p_{11} & p_{12} & p_{13} & p_{14} & p_{15} \\ p_{21} & p_{22} & p_{23} & p_{24} & p_{25} \\ p_{31} & p_{32} & p_{33} & p_{34} & p_{35} \\ p_{41} & p_{42} & p_{43} & p_{44} & p_{45} \\ p_{51} & p_{52} & p_{53} & p_{54} & p_{55} \end{bmatrix}_t \quad \text{...(1)}$$

Where P_{ij} represents the transition probability with which the rating of a bridge component changes from i to j on a t-year interval. The diagonal probabilities P_{ij} (i=j) are the probability of bridge components staying with the same ratings after the t-year interval. The lower triangle (i>j) of the matrix indicates an increase in rating due to bridge maintenance or replacement (increasing the condition rating to one).

An element deterioration matrix is of the form

$$D = \begin{bmatrix} d_{11} & d_{12} & d_{13} & d_{14} & d_{15} \\ 0 & d_{22} & d_{23} & d_{24} & d_{25} \\ 0 & 0 & d_{33} & d_{34} & d_{35} \\ 0 & 0 & 0 & d_{44} & d_{45} \\ 0 & 0 & 0 & 0 & d_{55} \end{bmatrix}_t \quad \text{...(2)}$$

where d_{ij} represents the probability with which a bridge component (element) deteriorates from a rating i to a rating j on a t-year interval. The deterioration matrix D_t was developed in this study from the transition-probability matrix P_t as follows:

$$D=\begin{bmatrix} p_{11} & p_{12} & p_{13} & p_{14} & p_{15} \\ 0 & p_{22}+\frac{1}{2}p_{21} & p_{23}+\frac{1}{6}p_{21} & p_{24}+\frac{1}{6}p_{21} & p_{25}+\frac{1}{6}p_{21} \\ 0 & 0 & p_{33}+\frac{3}{5}\sum_{1}^{2}p_{3j} & p_{34}+\frac{1}{5}\sum_{1}^{2}p_{3j} & p_{35}+\frac{1}{5}\sum_{1}^{2}p_{3j} \\ 0 & 0 & 0 & p_{44}+\frac{7}{10}\sum_{1}^{3}p_{4j} & p_{45}+\frac{3}{10}\sum_{1}^{3}p_{4j} \\ 0 & 0 & 0 & 0 & p_{55}+\frac{8}{10}\sum_{1}^{4}p_{5j} \end{bmatrix}_t \quad ....(3)$$

This is an empirical formula justified by the following consideration. Historically, Louisiana did not have a bridge preservation program in place; therefore, most actions taken on bridges were conducted either under the federal bridge replacement program or by local maintenance crews in different engineering districts of the state. When a bridge was replaced, its components' new PBMS rating should have been one. In most cases, replacement occurred when these bridges were in very poor condition. On the other hand, interviews with local bridge inspectors indicated that routine maintenance could only raise the NBI rating by one in most cases; therefore, it could reduce the PBMS rating by one. The suggested formula has simulated these two factors. Another reason for adopting this formula is that it was developed through a trial and error process. Mathematically, it produced a reasonable convergence between one-year and five-year deterioration matrices that were developed independently from the original NBI rating data.

Step 4. Model Calibration

The deterioration matrices developed at this point are based on a five-year interval. During this period of five years, it is possible that an element could have been subjected to some kind of maintenance actions first and then experienced deterioration, which may have affected the accuracy of the deterioration model. To validate the models, the one-year deterioration matrix developed with the same historical NBI data is applied according to the following procedure:

$$\begin{aligned} D_2 &= D_1^1 \times D_1^1 \\ D_3 &= D_2 \times D_1^1 \\ D_4 &= D_3 \times D_1^1 \\ D_5 &= D_4 \times D_1^1 = (D_1)^5 \\ D_5^1 &= \sqrt[5]{D_5} \end{aligned} \quad ....(4)$$

where D_n is deterioration matrix developed in a n year interval, and $D^n{}_m$ is the m^{th} year deterioration matrix developed in a n year interval. The comparison of the two one-year matrices developed at one- and five-year intervals leads to the final one-year deterioration matrices for all 12 elements shown in tables 17 to 28.

Table 17
Final one-year deterioration matrix for concrete deck

Original State	New State				
	1	2	3	4	5
1	96.21	3.47	0.15	0.17	0.00
2	0.00	98.49	0.75	0.62	0.14
3	0.00	0.00	94.01	4.44	1.55
4	0.00	0.00	0.00	99.05	0.95
5	0.00	0.00	0.00	0.00	95.73

Table 18
Final one-year deterioration matrix for concrete superstructure

Original State	New State			
	1	2	3	4
1	95.76	4.01	0.16	0.07
2	0.00	98.99	0.56	0.45
3	0.00	0.00	91.81	8.19
4	0.00	0.00	0.00	90.14

Table 19
Final one-year deterioration matrix for concrete substructure

Original	New State			
	1	2	3	4
1	97.98	1.52	0.18	0.32
2	0.00	98.09	1.25	0.66
3	0.00	0.00	92.24	7.76
4	0.00	0.00	0.00	84.36

Table 20
final one-year deterioration matrix for steel deck

Original State	New State				
	1	2	3	4	5
1	96.35	2.35	1.00	0.30	0.00
2	0.00	98.73	0.74	0.26	0.27
3	0.00	0.00	95.25	4.61	0.14
4	0.00	0.00	0.00	98.19	1.81
5	0.00	0.00	0.00	0.00	96.02

Table 21
Final one-year deterioration matrix for steel super-structure

Original State	New State			
	1	2	3	4
1	98.32	1.31	0.12	0.25
2	0.00	95.87	3.51	0.62
3	0.00	0.00	97.23	2.77
4	0.00	0.00	0.00	87.15

Table 22
Final one-year deterioration matrix for steel sub-structure

Original	New			
	1	2	3	4
1	98.98	0.95	0.03	0.04
2	0.00	97.77	1.28	0.95
3	0.00	0.00	93.91	6.09
4	0.00	0.00	0.00	88.22

Table 23
Final one-year deterioration matrix for pre-stressed concrete deck

Original State	New State				
	1	2	3	4	5
1	92.82	6.67	0.16	0.00	0.35
2	0.00	99.78	0.10	0.06	0.06
3	0.00	0.00	92.84	3.70	3.46
4	0.00	0.00	0.00	98.53	1.47
5	0.00	0.00	0.00	0.00	95.71

Table 24
Final one-year deterioration matrix for pre-stressed concrete superstructure

Original State	New State			
	1	2	3	4
1	99.64	0.31	0.04	0.01
2	0.00	97.85	1.00	1.15
3	0.00	0.00	95.06	4.94
4	0.00	0.00	0.00	49.76

Table 25
Final one-year deterioration matrix for pre-stressed concrete substructure

Original	New			
	1	2	3	4
1	97.53	2.47	0.00	0.00
2	0.00	99.28	0.48	0.24
3	0.00	0.00	95.05	4.95
4	0.00	0.00	0.00	46.16

Table 26
Final one-year deterioration matrix for timber deck

Original State	New State				
	1	2	3	4	5
1	85.26	11.71	1.88	1.15	0.00
2	0.00	93.05	2.84	4.05	0.06
3	0.00	0.00	88.51	10.42	1.07
4	0.00	0.00	0.00	98.80	1.20
5	0.00	0.00	0.00	0.00	96.59

Table 27
Final one-year deterioration matrix for timber superstructure

Original State	New State			
	1	2	3	4
1	87.40	8.57	1.38	2.65
2	0.00	93.11	2.59	4.30
3	0.00	0.00	90.38	9.62
4	0.00	0.00	0.00	96.40

Table 28
Final one-year deterioration matrix for timber sub-structure

Original	New			
	1	2	3	4
1	84.85	11.03	1.26	2.86
2	0.00	90.02	2.86	7.12
3	0.00	0.00	85.75	14.25
4	0.00	0.00	0.00	98.34

Bridge System Analysis with PONTIS

PONTIS is a comprehensive bridge management software with many modules requiring a large amount of input as summarized in Figure 20 [4,5].

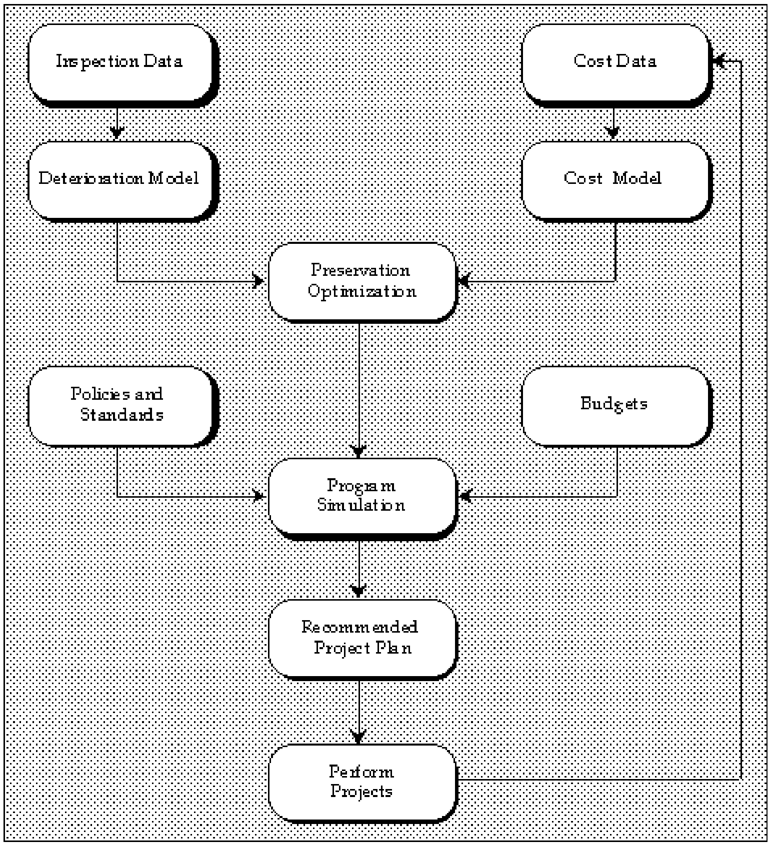


Figure 20
The framework of PONTIS

There are two major modeling functions in PONTIS: bridge preservation and bridge improvement. Preservation projects consist of bridge maintenance, repair, and rehabilitation (MRR) actions performed on individual bridge elements. The PONTIS simulation model predicts how MRR actions improve element conditions, and how bridge elements deteriorate over time in the absence of MRR actions. The overall objective of preservation projects is to minimize long-term costs while maintaining the system in steady operating conditions.

The improvement projects alter functional aspects of bridges. These projects are intended to address bridges' functional shortcomings. To develop improvement projects, PONTIS identifies those instances where adequate design standards are not met, develops strategies to meet them, and prioritizes candidate improvements. Example improvement projects include widening a deck, raising a bridge to gain added vertical clearance, or strengthening a bridge to support heavier loads.

The applications of PONTIS are summarized in the following steps:

Step 1. Define the preservation actions, corresponding costs, and condition states

It is infeasible to collect and apply the detailed unit cost data for this project because of the inconsistent practices of various LA DOTD project contractors in their bidding calculations. The unit costs for element replacement are estimated based on: (a) LA Standard Specifications, which give the general information on pay items and items identifications; (b) the average unit cost of $90 per square foot of deck area from LA DOTD; and (c) an approximate 50-50 cost distribution between upper (deck and superstructure) and lower parts (substructure) of a bridge.

Considering the aggregated nature of the NBI elements, the preservation action plans defined in this project are not as detailed as PONTIS default action plans. Tables 29 to 31 list preservation action, cost, and condition state for all the 12 elements.

Table 29
The preservation action plan for deck

Current Rating	Actions	Rating Change Due to the action	Cost ($ per ft^2)
1	Do Nothing	None	$0
2	Do Nothing	None	$0
3	Do Nothing Minor Maintenance	None Up to 2	$0 10% of replacement
4	Do Nothing Major Maintenance	None Up to 3	$0 60% of replacement
5	Do Nothing Major Maintenance Replace Element	None Up to 4 Up to 1	$0 60% of replacement $28

Table 30
The preservation action plan for superstructure

Current Rating	Actions	Rating Change Due to the action	Cost ($ per ft)
1	Do Nothing	None	$0
2	Do Nothing	None	$0
3	Do Nothing Minor Maintenance	None Up to 2	$0 10% of replacement
4	Do Nothing Major Maintenance Replace Element	None Up to 3 Up to 1	$0 60% of replacement $210

Table 31
The preservation action plan for substructure

Current Rating	Actions	Rating Change Due to the action	Cost ($ per item)
1	Do Nothing	None	$0
2	Do Nothing	None	$0
3	Do Nothing Minor Maintenance	None Up to 2	$0 10% of replacement
4	Do Nothing Major Maintenance Replace Element	None Up to 3 Up to 1	$0 60% of replacement $12,000

Step 2. Define input parameters and scenarios

PONTIS includes 1,109 configuration parameters, 170 configuration options, 324 scenario parameters, and 88 input and output tables plus some very important maintenance and rehabilitation rules. Preparing the input data is truly a time-consuming process that can take many hours. The definitions and values of the parameter and scenario settings are presented in Appendix B of this report [4].

Step 3. Apply PONTIS Program

There are two models in PONTIS, optimization and simulation. The results of optimization model are automatically generated once all required input data are in place. Appendix C gives the preservation details for all the 12 elements.

Due to the large number of bridges, the execution of the PONTIS program takes about two hours with the most recent state-of-the-art computers. Similar to input data preparation, it also takes many hours to retrieve and export the output of PONTIS to a database for analysis. The detailed work of this part is presented in Appendix B as well.

Results

The analysis results over a period of 30 simulated years (2002-2032) are both summarized and presented at a detailed level. To investigate the impact of three key settings-annual budget, preservation action cost, and modeling functions-on the long-term performance of the LA DOTD bridge system, 9 scenarios were defined as shown in table 32. The zero budget scenarios were designed to evaluate the pure deterioration process as well as to debug the program. The separation and combination of MRR and Functional Improvement (Func.) scenarios show the work needs for two different purposes.

Table 32
List of scenario names

Modeling Plan / Annual Budget	MRR (60%, 30%)	MRR (10%, 5%)	MRR (30%, 15%)	MRR + Func (60%, 30%)
$0	S-0-1	S-0-2 (Same as S-0-1)	---	S-0-4
$70M	S-70-1	S-70-2	S-70-3	S-70-4
$140M	S-140-1	S-140-2	---	---

** Major and minor maintenance costs as the percentage of the element replacement cost*

The results at the detailed level include:

a. Needs vs. selected work

b. PONTIS condition rating

c. Health index (accumulated curves)

d. Sufficiency rating (accumulated curve)

Summary

Table 33
Summary of results in last programming year needs and health index

Budget	MRR (30%, 60%)*	MRR (10%, 60%)	MRR (5%, 15%)	MRR+Func. (10%, 60%)
$0	$1,457M 59.4	$1,185M 59.4	-	$4,404M 59.4
$70M	$66M 73.5	$109M 72.8	$107M 74.3	$2,165M 75.4
$140M	$64M 73.5	$45M 73.3	-	-

** Major and minor maintenance costs as the percentage of the element replacement cost*

Table 34
Summary of results in total funds spent on each preservation and improvement action

Budget	MRR (30%, 60%)	MRR (10%, 60%)	MRR (5%, 15%)	MRR+Func. (10%, 60%)
$0	0	0	-	0
$70M	Rep.=$85M Elem.=$659M Major =$793M Minor =$343M	Rep.=$16M Major=$974M Minor=$340M	Rep.=$17M Major=$934M Minor=$372M	Rep.=$797M Major=$927M Minor=$326M Wid.=$47M Str.=$2.4M
$140M	Rep.=$85M Elem.=$663M Major =$799M Minor =$349M	Rep.=$81M Major=$981M Minor=$341M	-	-

** Minor and major maintenance costs as the percentage of the element replacement cost*
**Rep. = bridge replacement, Elem..= element replacement, Major = major maintenance, Minor = minor maintenance,*
** Wid. = widening bridge, Str. = bridge strengthen*

Table 33 shows that the last year's need at the zero-budget scenario is about one billion dollars more than the need with a $70 million annual budget. Health Index (HI) increases about 14 percentage points as the annual budget increases from $0 to $70 million, which demonstrates the effect of the preservation actions. The results from the annual budget of $140 million scenario, however, do not show significant difference from the scenario with the annual budget of $70 million. It is reasonable, therefore, to conclude that the annual budget of $70M is sufficient for the bridge preservation needs. As shown in table 34, with an annual budget of $70 million the total replacement cost over 30 years increases from $16 million to $797 million when the scenario changes from MRR only to the combination of MRR and functional improvement. This increase indicates a large number of bridge replacements due to functional obsolescence or structural deficiency.

Predicted Needs vs. Work

The results in terms of needs and selected work for the three budgetary scenarios under S-0-1, S-70-1, and S-140-1 are presented in figures 21, 22, and 23.

Under the zero-budget scenario, the need increases greatly and reaches $1,400 million at the end of the 30th year. Although the $70M annual budget could not meet all the needs initially, it reduces the needs rapidly, and by the end of the10th year, the $70M annual budget is more than the predicted bridge preservation needs. The only difference between the $70M and $140M annual budget scenarios is the number of years required to meet the needs as shown in figures 21 and 22. The figures for annual needs vs. work for other scenarios are presented in Appendices D, E, and F.

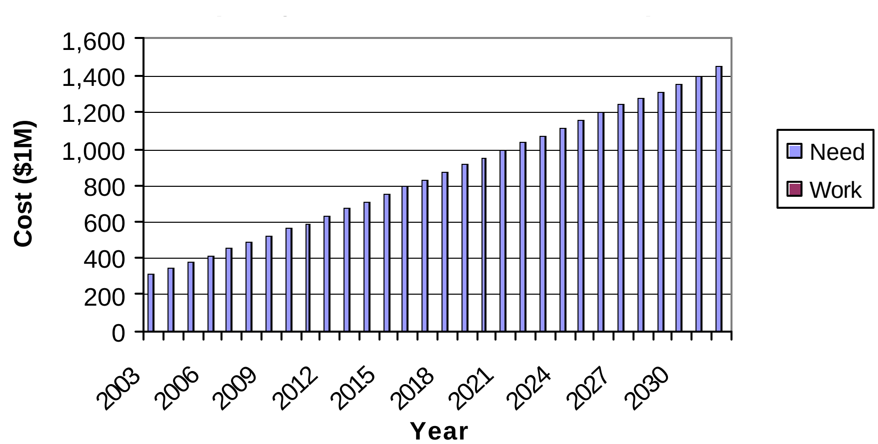


Figure 21
Annual needs vs. work with S-0-1

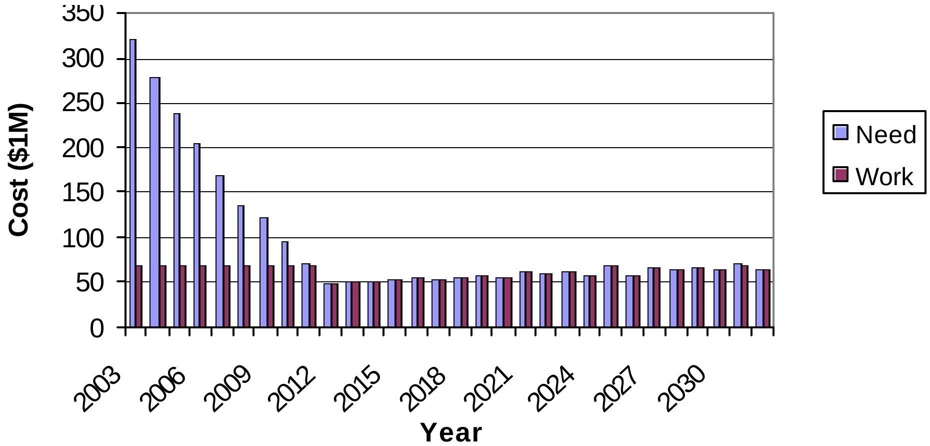


Figure 22
Annual needs vs. work with S-70-1

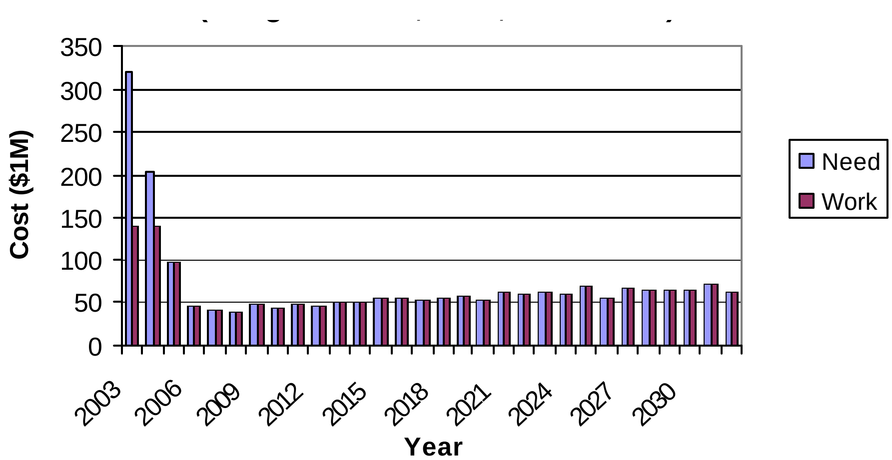


Figure 23
Annual needs vs. work with S-140-1

PONTIS Condition Ratings
The condition state ratings for the deck under the same scenarios are shown in figures 24 and 25.

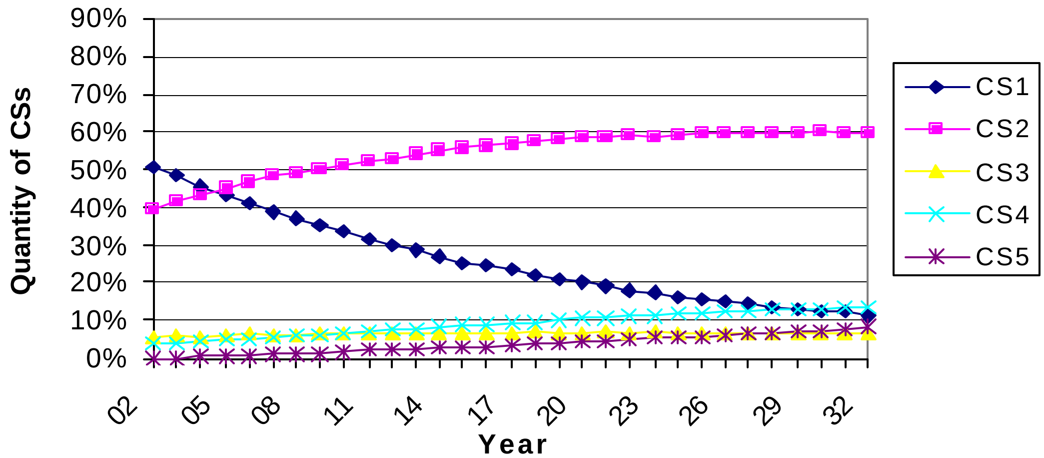


Figure 24
PONTIS condition state rating for deck with S-0-1

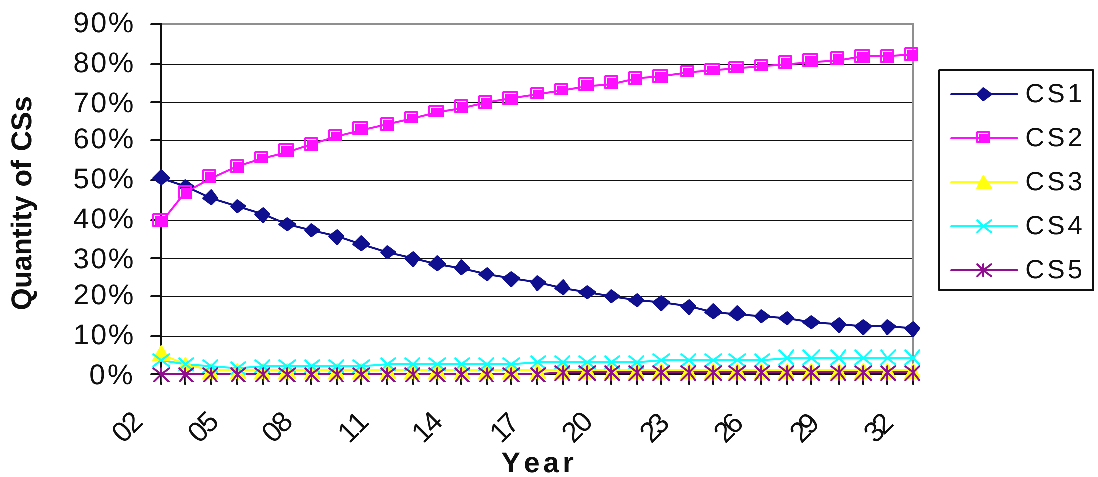


Figure 25
PONTIS condition state rating for deck with S-70-1

Under both budgetary situations, the deck areas with condition state ratings of 1 decrease with time, and the amount of deck areas with condition rating of 1 at the end of the 30th year is slightly different between the two scenarios. Most importantly, under an annual budget of $70M, there are a much higher percentage of deck areas with condition rating 2 and a lower percentage of deck areas with condition ratings 4 and 5. The annual budget of $70M has greatly constrained deck elements falling into the condition states 4 and 5 as illustrated in figures 16 and 17. The distributions of condition state ratings for superstructures and substructures show very similar trends in figures 26 to 29.

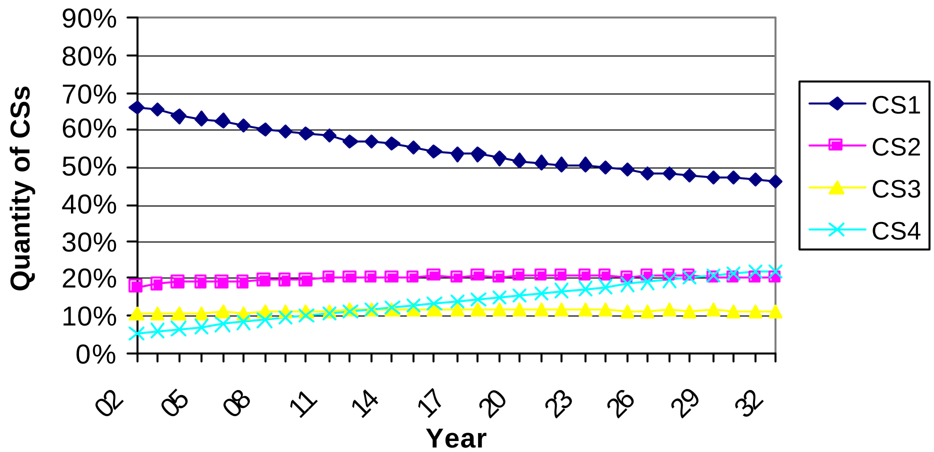


Figure 26
PONTIS condition state rating for superstructure with S-0-1

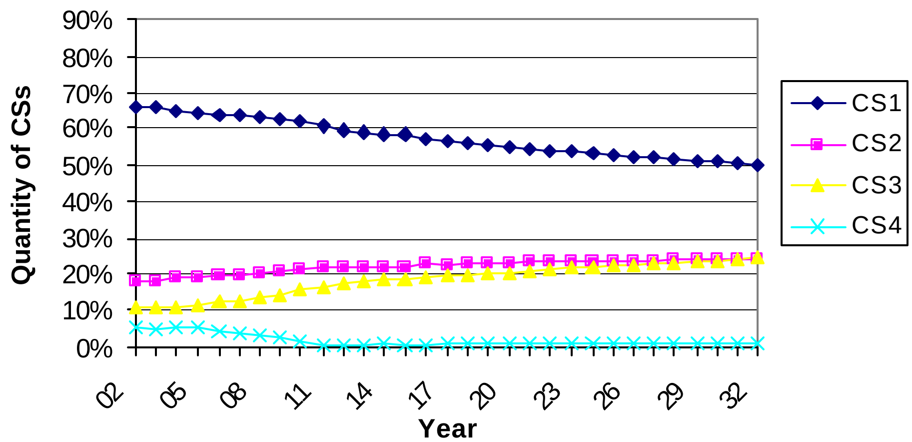


Figure 27
PONTIS condition state rating for superstructure with S-70-1

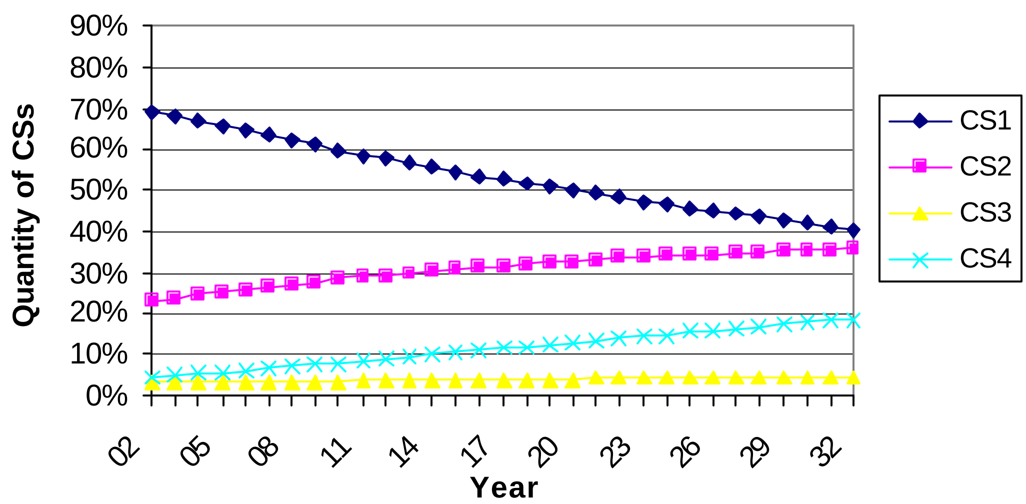


Figure 28
PONTIS condition state rating for substructure with S-0-1

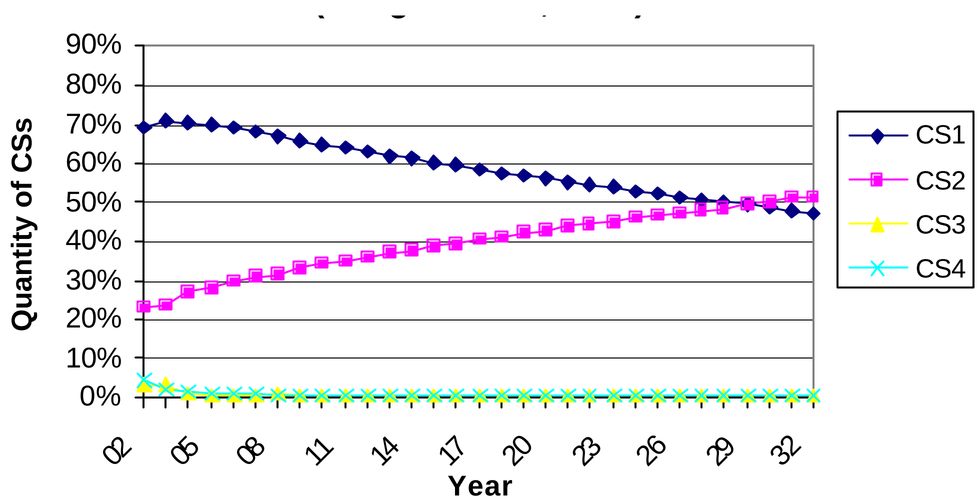


Figure 29
PONTIS condition state rating for substructure with S-70-1

It is clear that with an annual budget of $70M, most of the elements with lower condition ratings (4 or 5) are subjected to either major and minor maintenance actions or element replacement. With sufficient budget, the number of elements with low condition ratings can be limited to fewer than five percent.

Health Index

The health index is a combined indicator for a bridge as a whole. It is mainly a function of PONTIS element condition ratings. Figures 30 to 33 display the distribution of the health index for the same two budgetary scenarios [4].

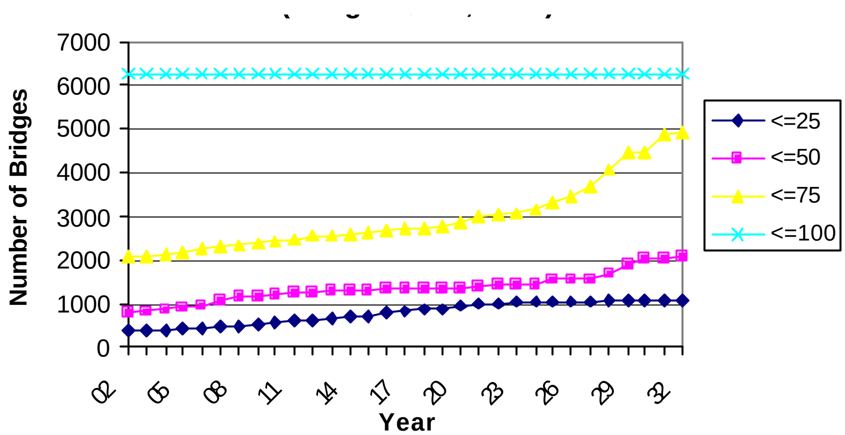


Figure 30
Accumulated HI distribution by number of bridges with S-0-1

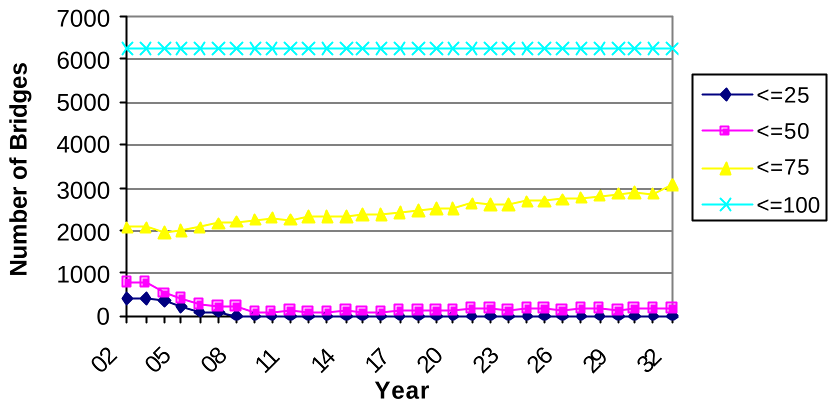


Figure 31
Accumulated HI distribution by number of bridges with S-70-1

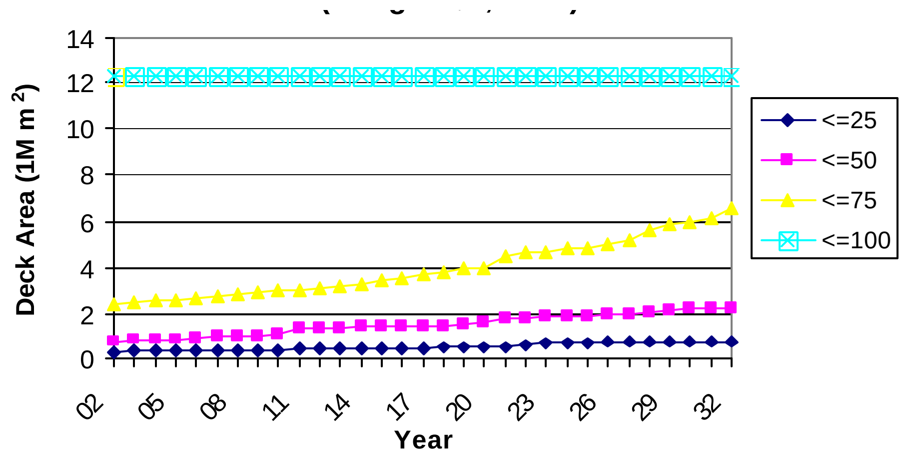


Figure 32
Accumulated HI distribution by deck area with S-0-1

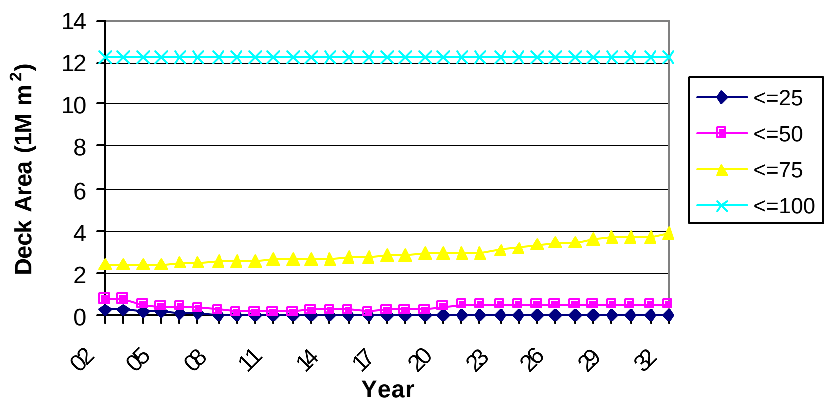


Figure 33
Accumulated HI distribution by deck area with S-70-0

Again, it is demonstrated that with an annual budget of $70M, the majority of bridges or a high percentage of deck areas have an HI higher than 75; with zero budget, the process of deterioration would have resulted in many bridges falling into poor and unacceptable condition states. The number of bridges with the unacceptable HI (less than 25) is almost eliminated with a $70M annual budget.

Sufficiency Rating

Sufficiency rating is another combined bridge condition indicator, which is a function of NBI ratings for the three elements and other bridge features such as structural adequacy, serviceability and functional obsolescence, and essentiality for public use, as shown in figure 8. The distribution of SR under the two budgetary situations is illustrated in figures 34 and 35 [2].

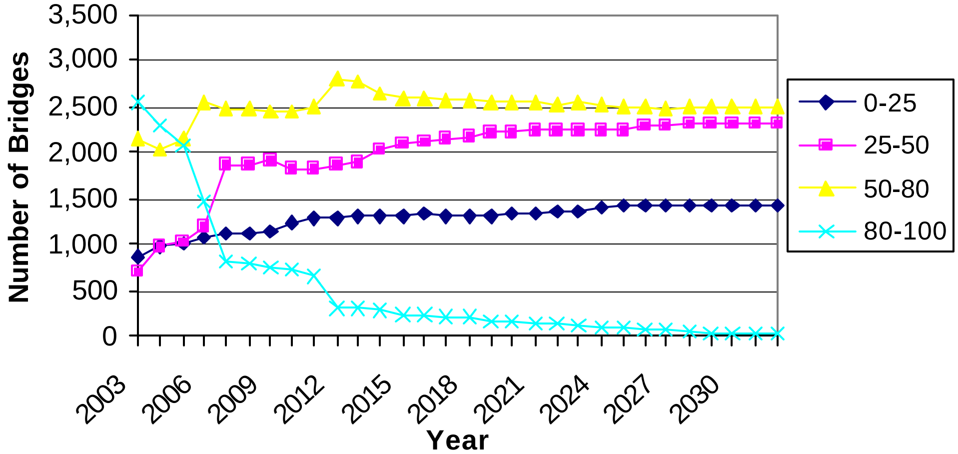


Figure 34
Distribution of sufficiency rating with S-0-1

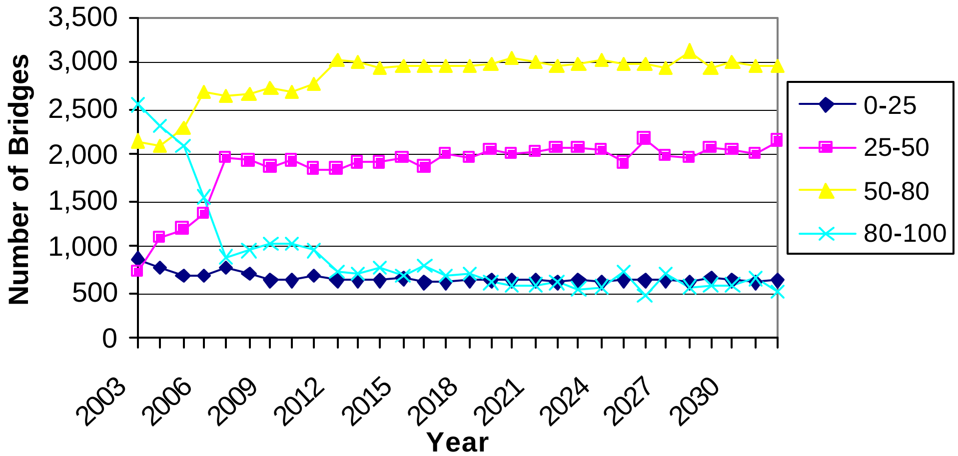


Figure 35
Distribution of sufficiency rating with S-70-1

According to the FHWA guidelines, bridges with SR greater than 80 are considered in excellent condition, bridges with SR between 50 and 80 are considered in fair conditions and in need of certain types of maintenance; and bridges with SR under 50 need to be replaced. Again, figures 34 and 35 demonstrate that the differences in bridge conditions between the two budgetary scenarios are significant. With an annual budget of $70M, there are more bridges with SR greater than 80. The number of bridges with SR less than 50 is also greatly reduced with an annual budget of $70M. The results of all designed scenarios are presented in Appendices D and F [2].

CONCLUSIONS

The following conclusions are drawn from this project:

1. By accomplishing the objectives specified in the proposal, the project has demonstrated that it is not only feasible but also very practical to use NBI data for the bridge management system, particularly in helping make effective funding decisions at the network system level.

2. The current $70 million annual bridge program budget is not sufficient to satisfy both the preservation and improvement needs of the Louisiana highway bridge system. It is only enough for the state-bridge preservation work.

3. Based on the preliminary results, it is clear that bridge preservation actions do have an impact on the long-term system performance. Therefore, identifying effective and efficient bridge management strategies is crucial to LA DOTD's bridge management system.

4. To identify the best cost-effective BMS strategy, a detailed sensitivity analysis on the preservation actions, associated costs, and improved ratings needs to be conducted.

ABBREVIATIONS AND SYMBOLS

AASHTO	American Association of State Highway and Transportation Officials
ADT	Average Daily Traffic
BMS	Bridge Management System
CASTS	Center for the Analysis of Spatial and Temporal Systems
CoRe	Commonly Recognized
DOT	Department of Transportation
FHWA	Federal Highway Administration
LA DOTD	Louisiana Department of Transportation and Development
LTRC	Louisiana Transportation Research Center
NBI	National Bridge Inventory
PBMS	PONTIS Bridge Management System

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3. FHWA, (2001). Report – NBI 2000. FHWA. http://www.nationalbridgeinventory.com/new_page_1.htm

4. Cambridge Systematics, Inc., (2001). PONTIS Release 4 Technical Manual. AASHTO.

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APPENDICES
(All Appendices Are Included On Accompanying CD)

A. The NBI Deterioration Charts

B. The PONTIS Settings

C. The Preservation Model Details

D. The Results without budget

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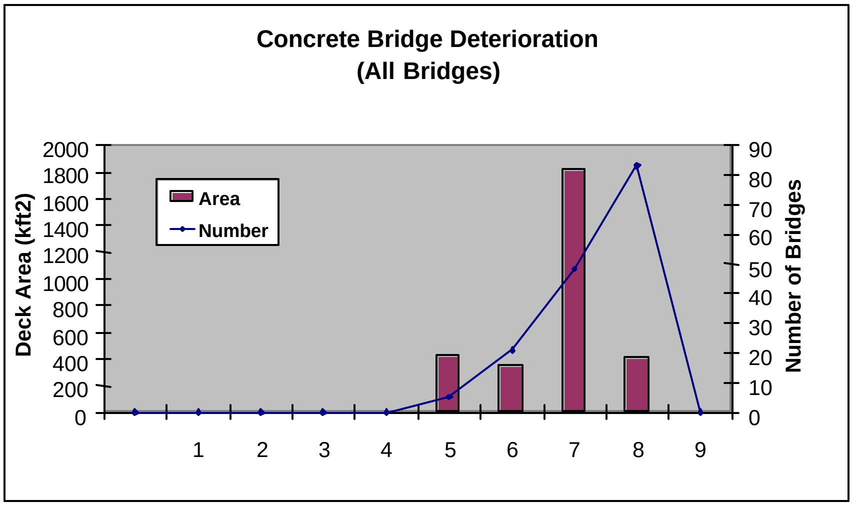


Figure A. 1
The concrete deck deterioration with original rating of 1

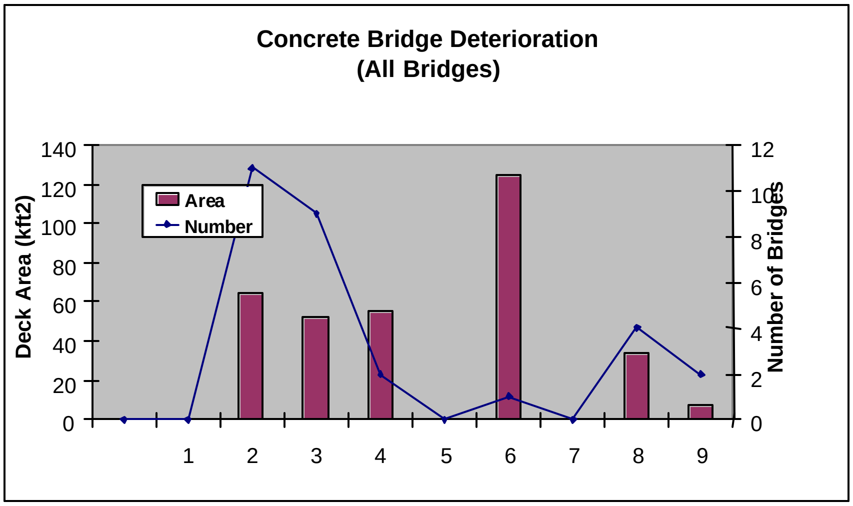


Figure A. 2
The concrete deck deterioration with original rating of 2

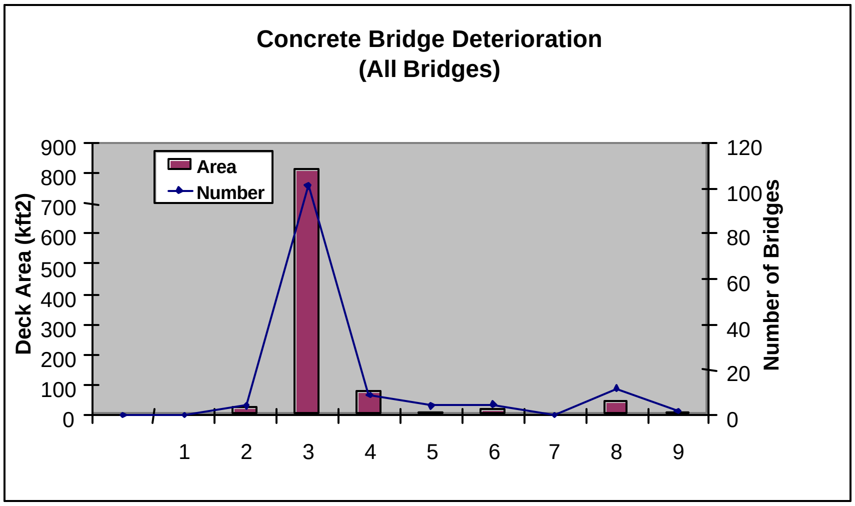


Figure A. 3
The concrete deck deterioration with original rating of 3

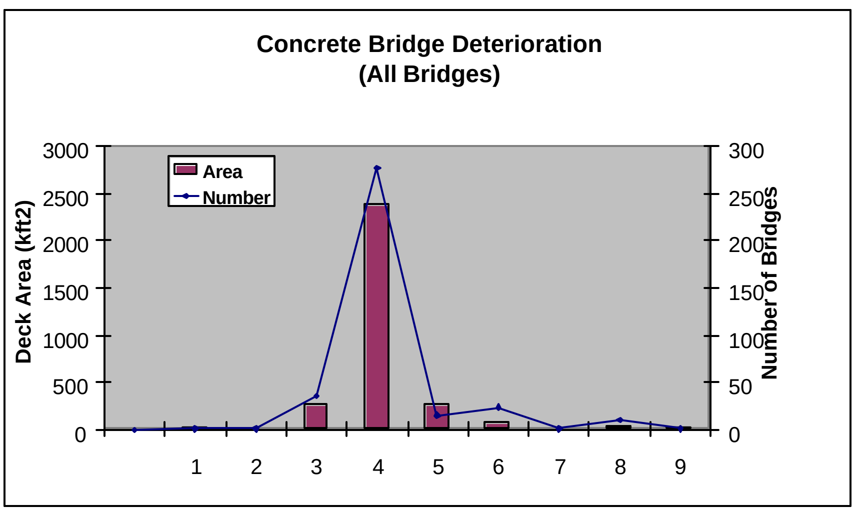


Figure A. 4
The concrete deck deterioration with original rating of 4

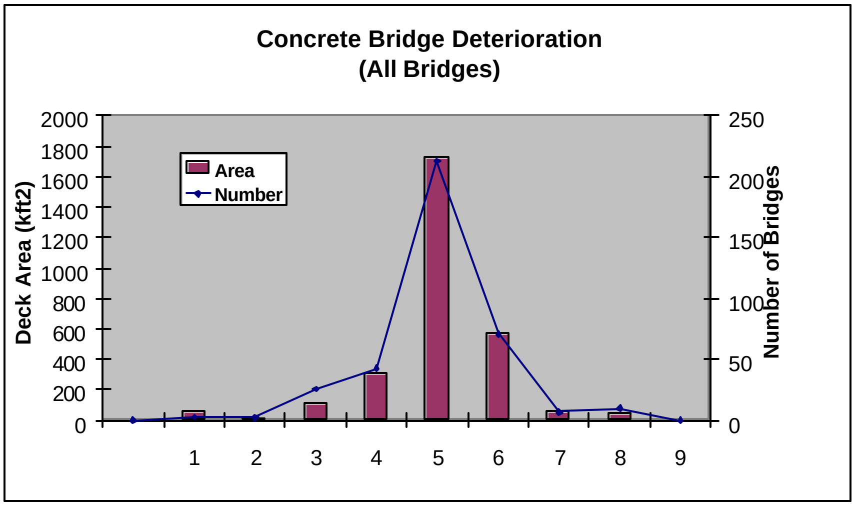


Figure A. 5
The concrete deck deterioration with original rating of 5

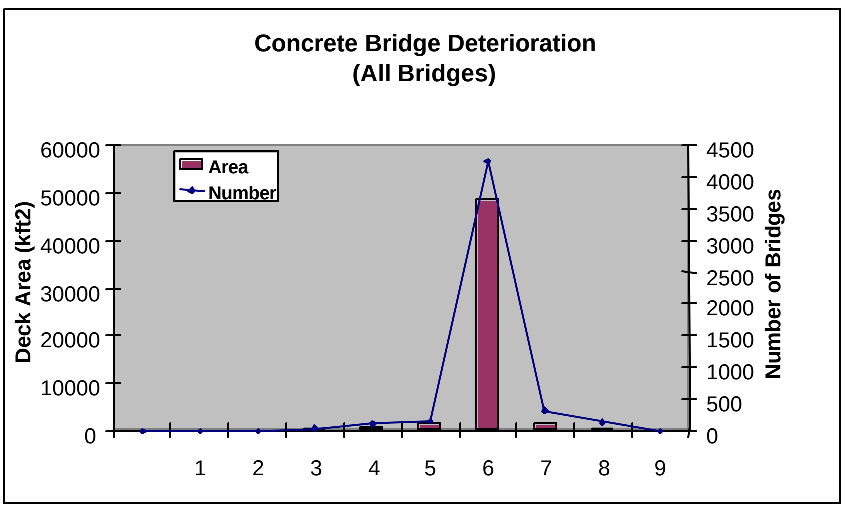


Figure A. 6
The concrete deck deterioration with original rating of 6

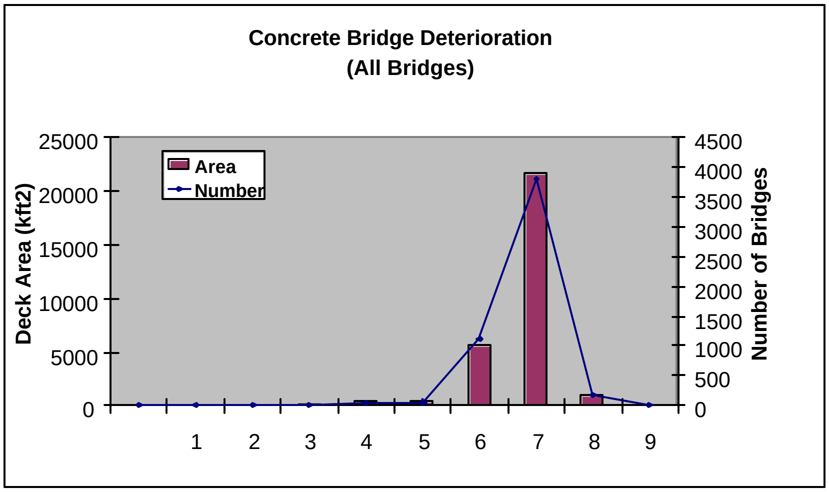


Figure A. 7
The concrete deck deterioration with original rating of 7

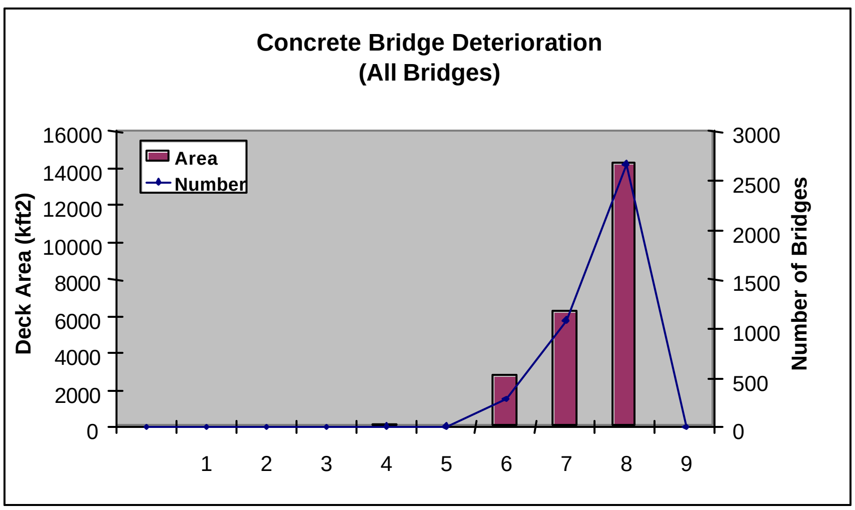


Figure A. 8
The concrete deck deterioration with original rating of 8

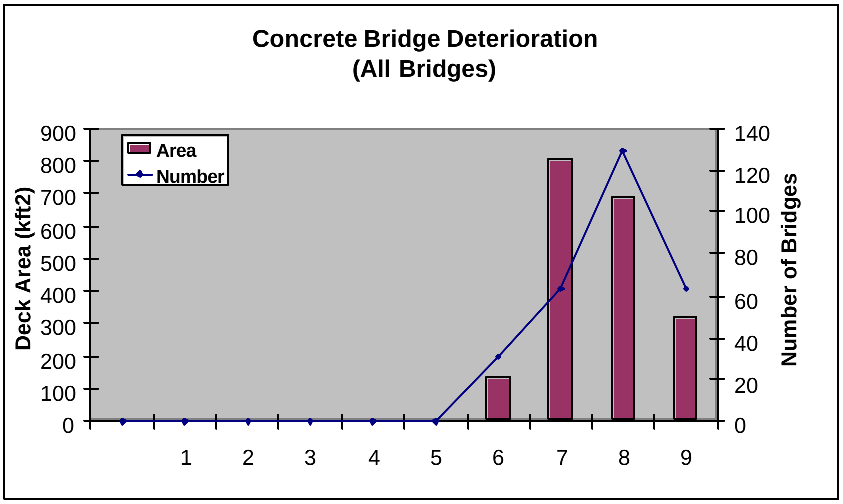


Figure A. 9
The concrete deck deterioration with original rating of 9

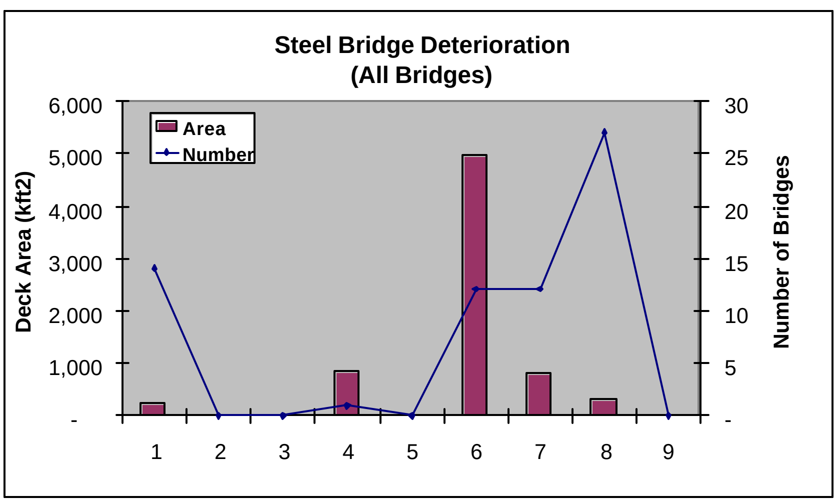
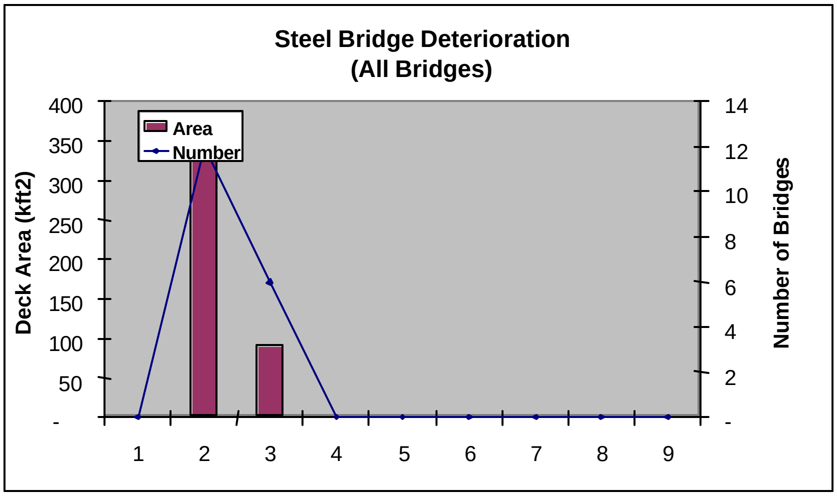


Figure A. 10
The steel deck deterioration with original rating of 1



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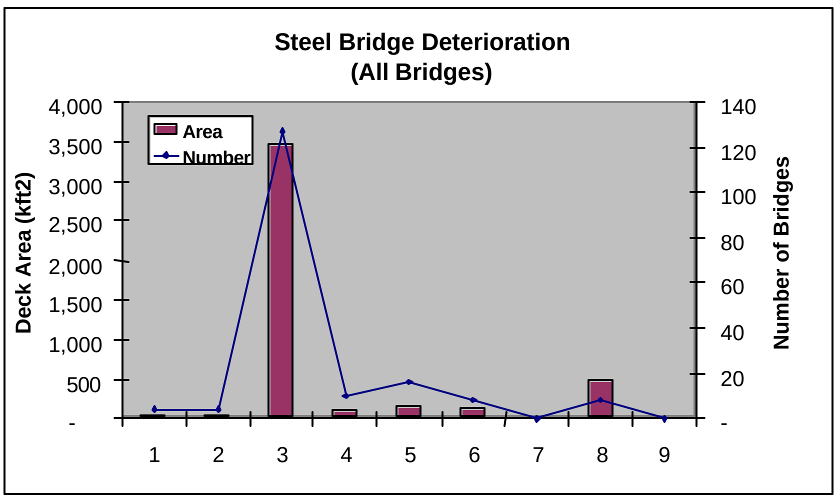

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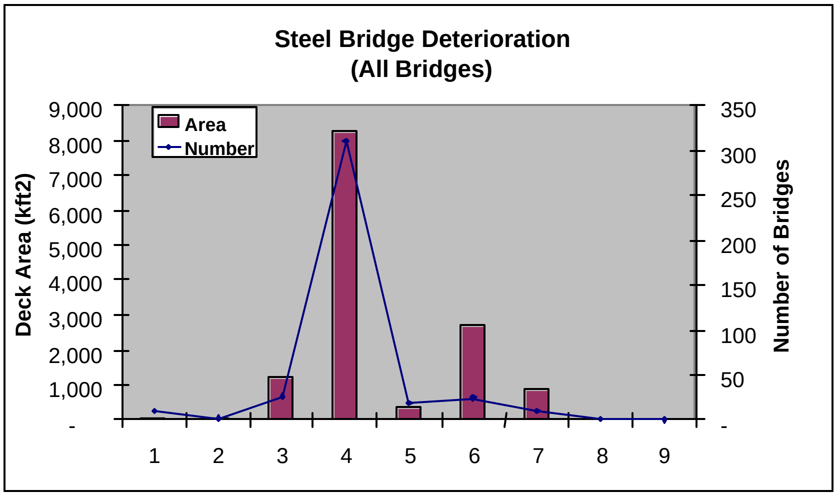
The steel deck deterioration with original rating of 3



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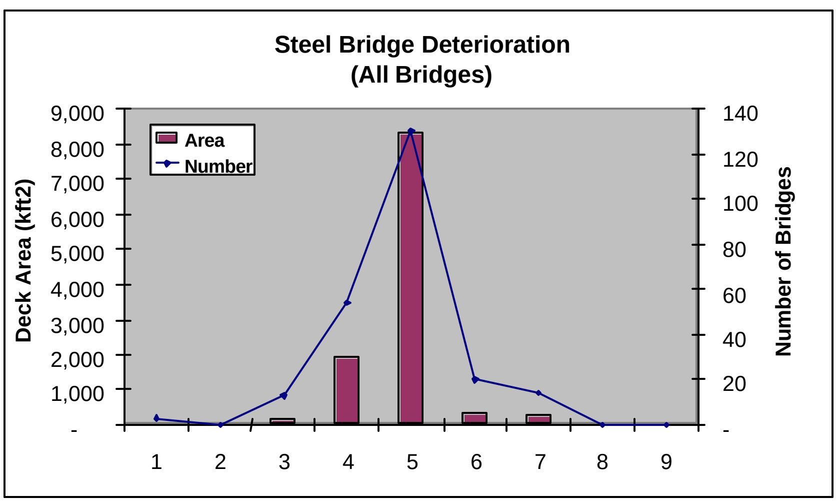
The steel deck deterioration with original rating of 4



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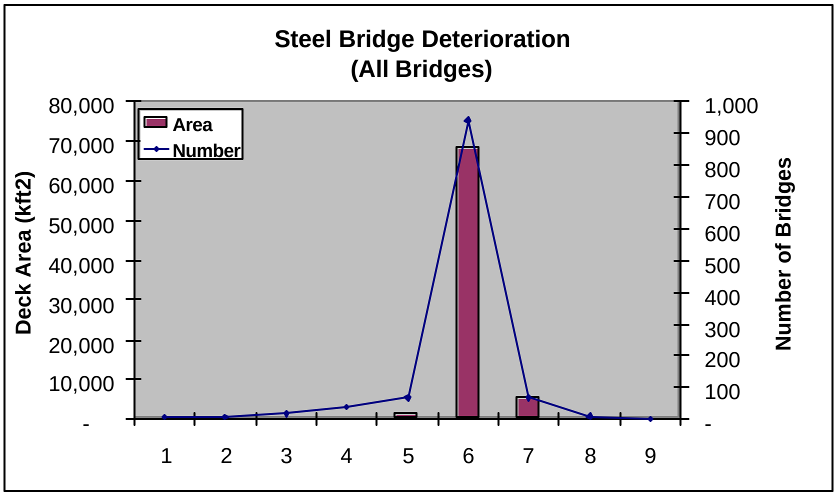
The steel deck deterioration with original rating of 5



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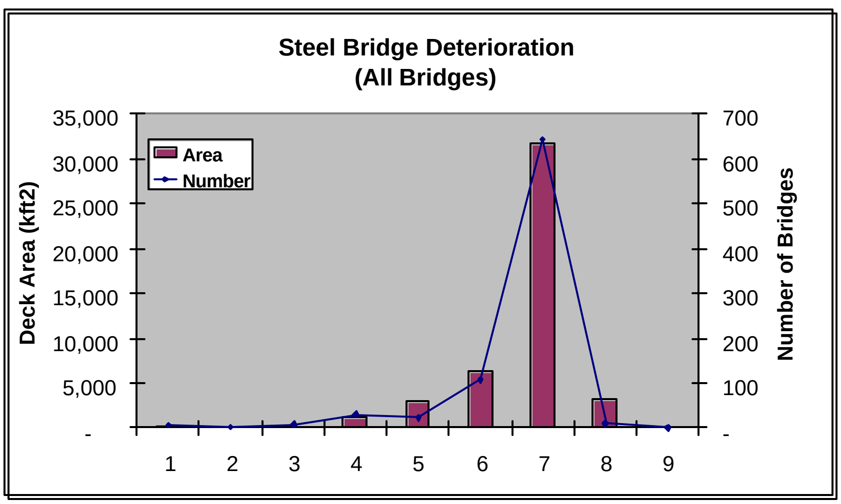
The steel deck deterioration with original rating of 6



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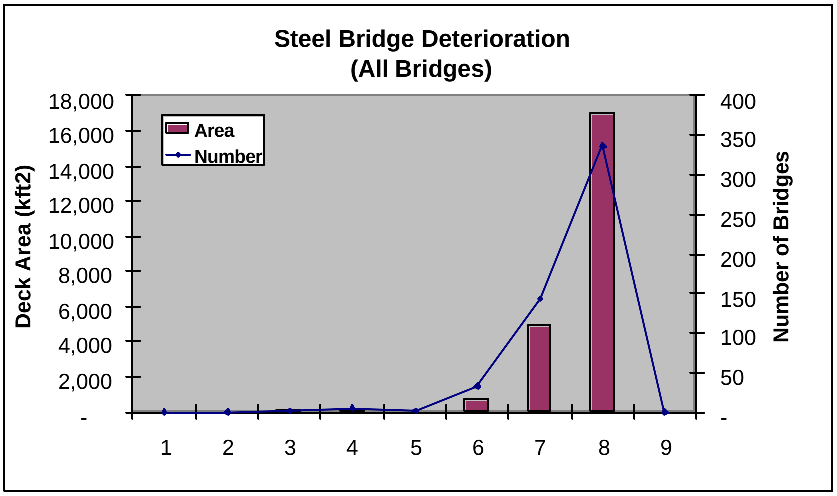
The steel deck deterioration with original rating of 7



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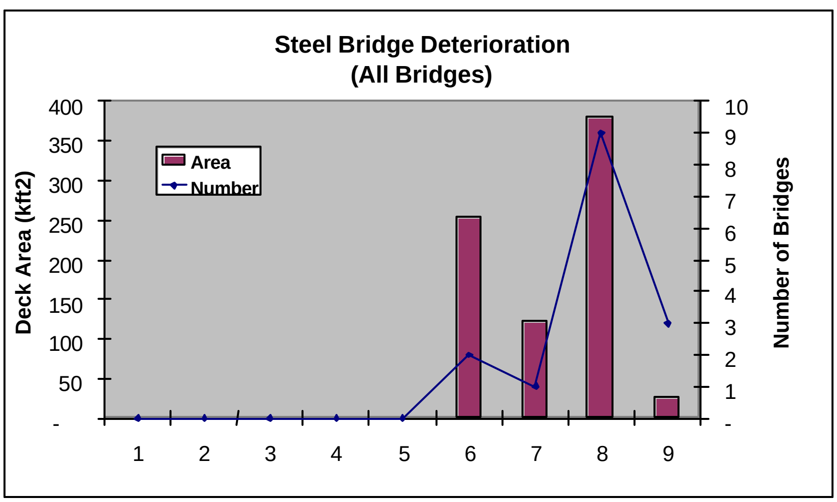
The steel deck deterioration with original rating of 8



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The steel deck deterioration with original rating of 9

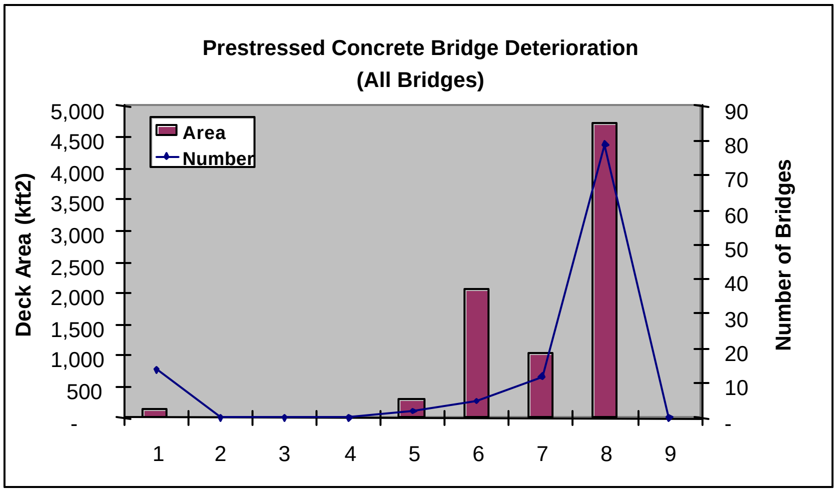
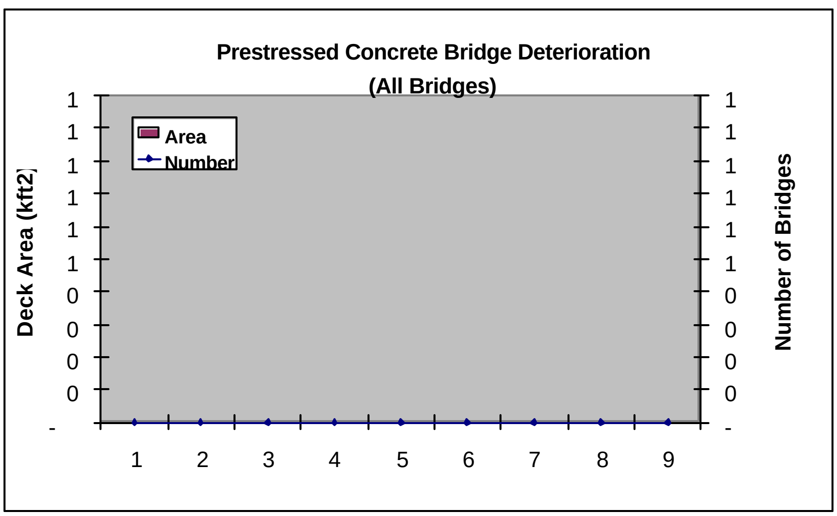


Figure A. 19
The prestressed concrete deck deterioration with original rating of 1



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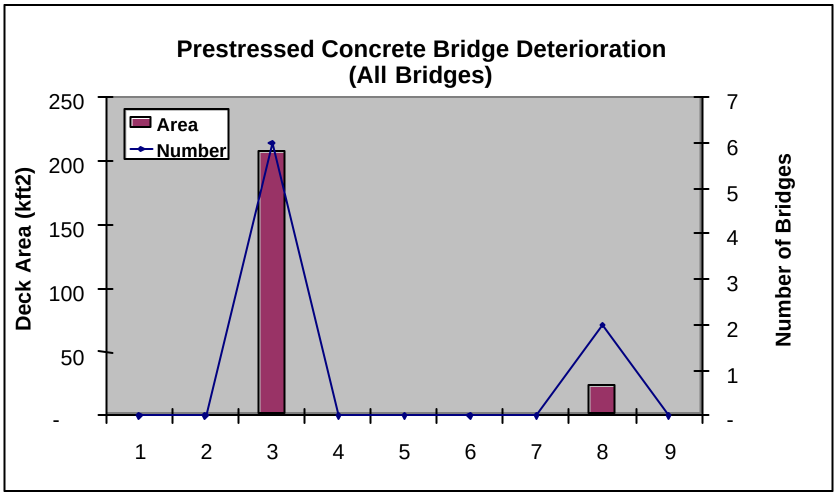

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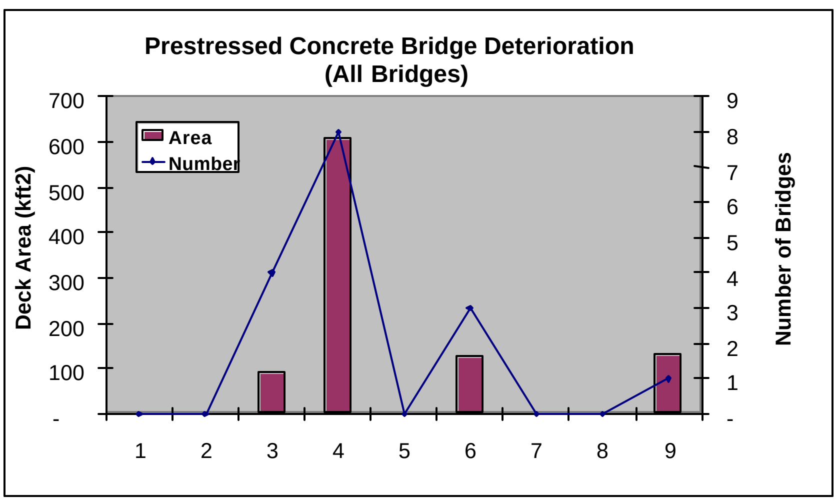

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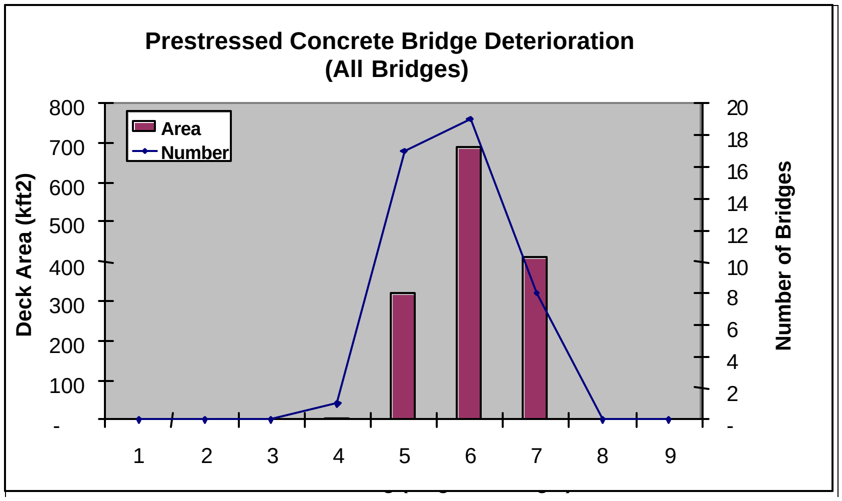
The prestressed concrete deck deterioration with original rating of 4



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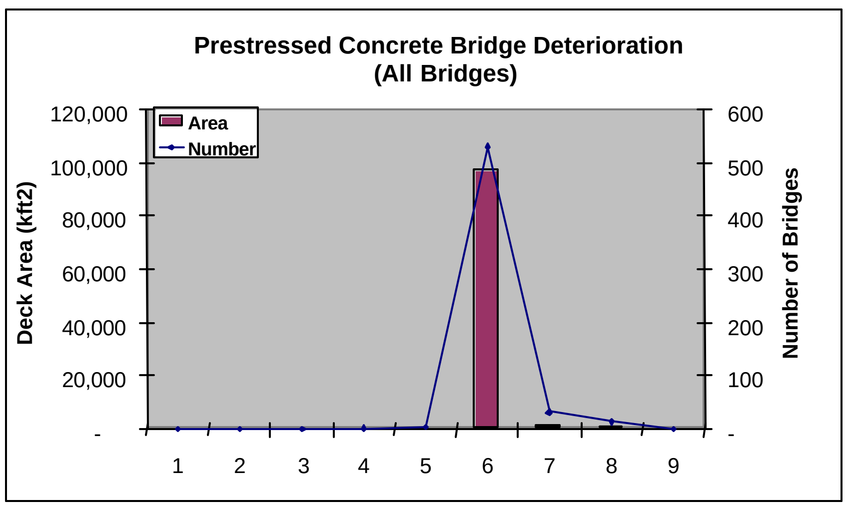

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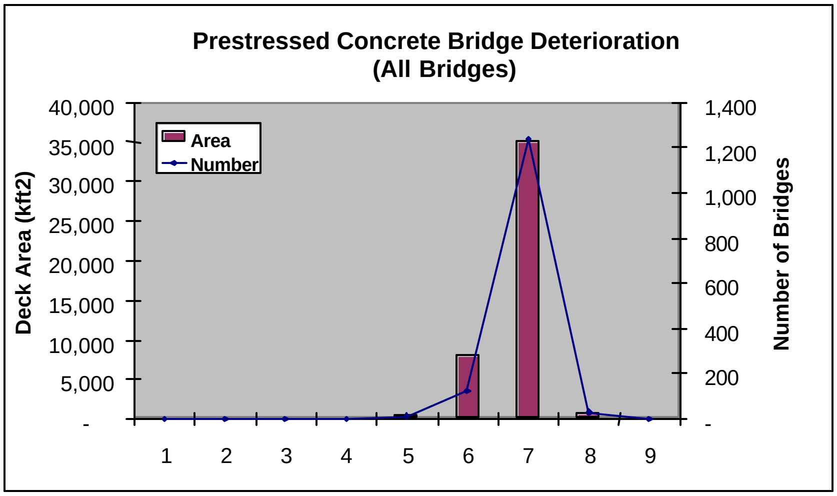

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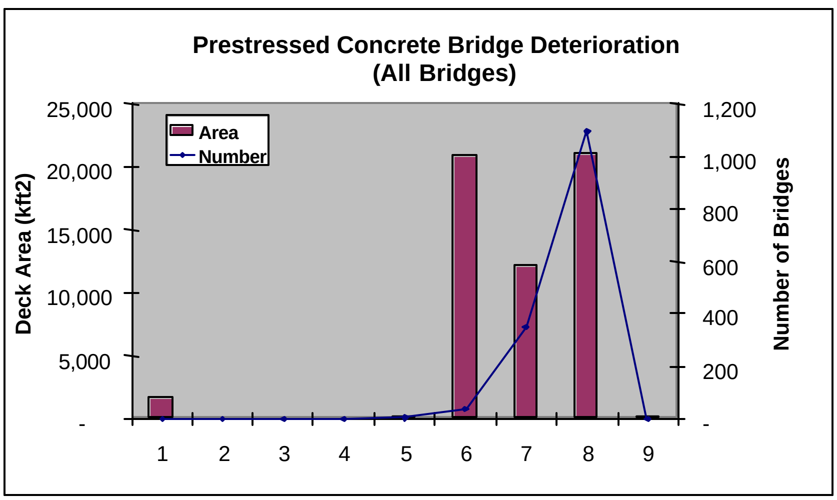

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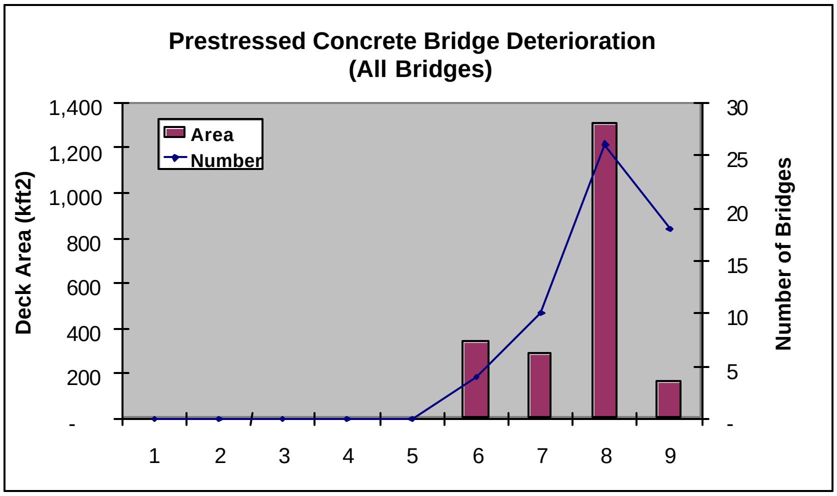
The prestressed concrete deck deterioration with original rating of 8



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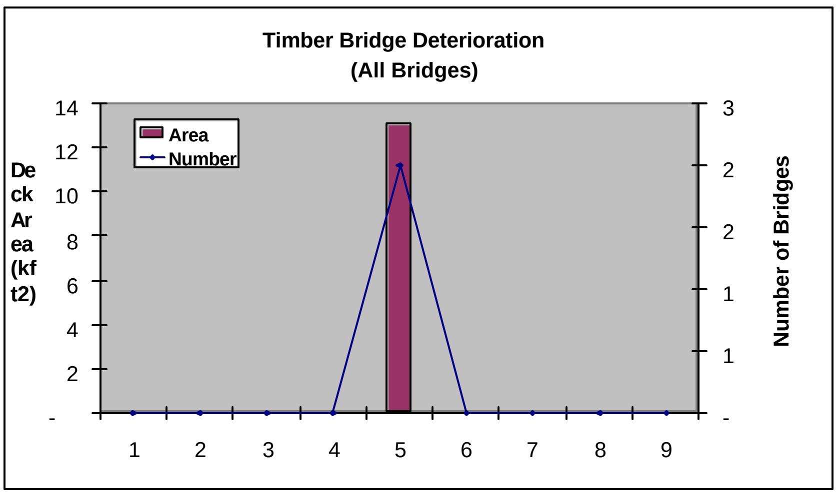

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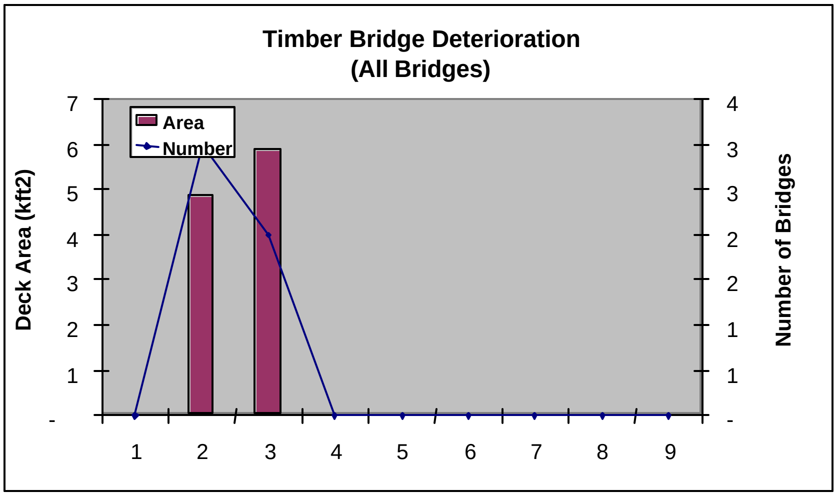
The timber deck deterioration with original rating of 1



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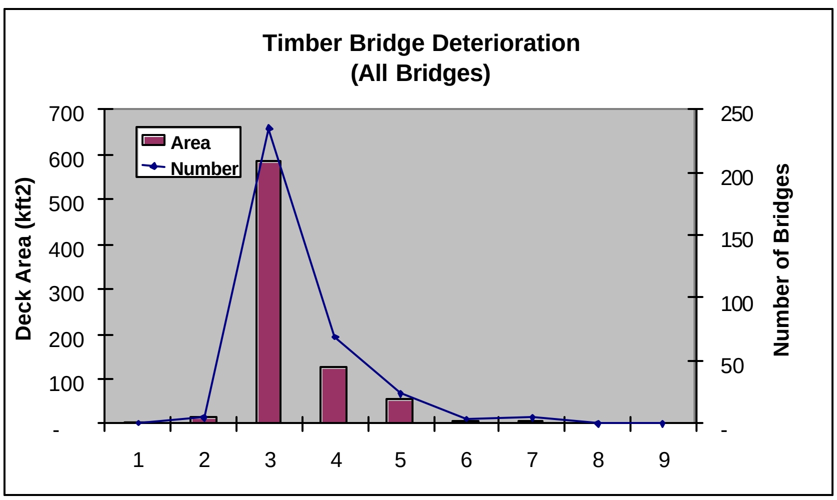

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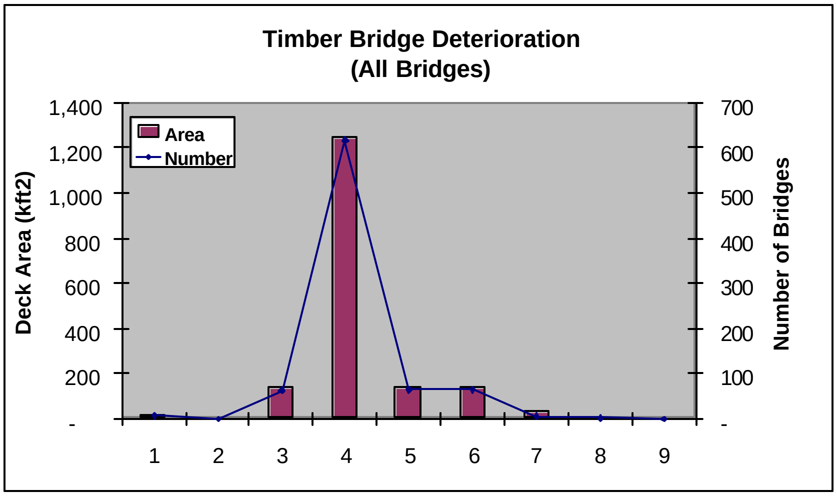

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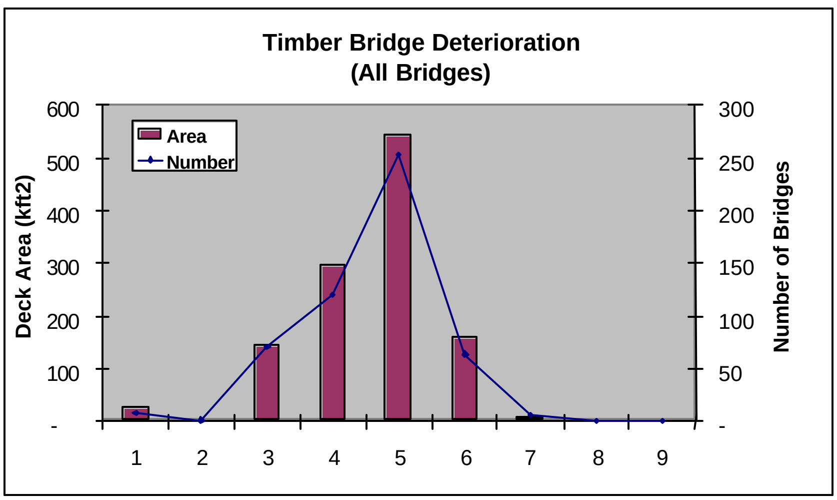

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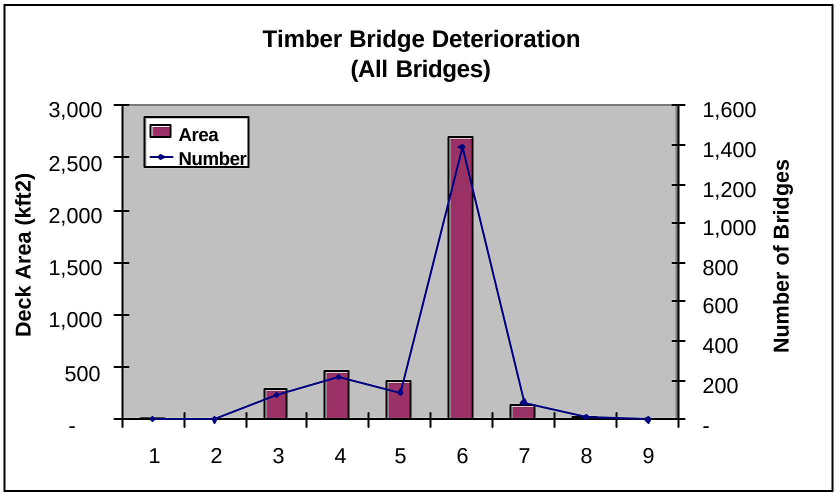

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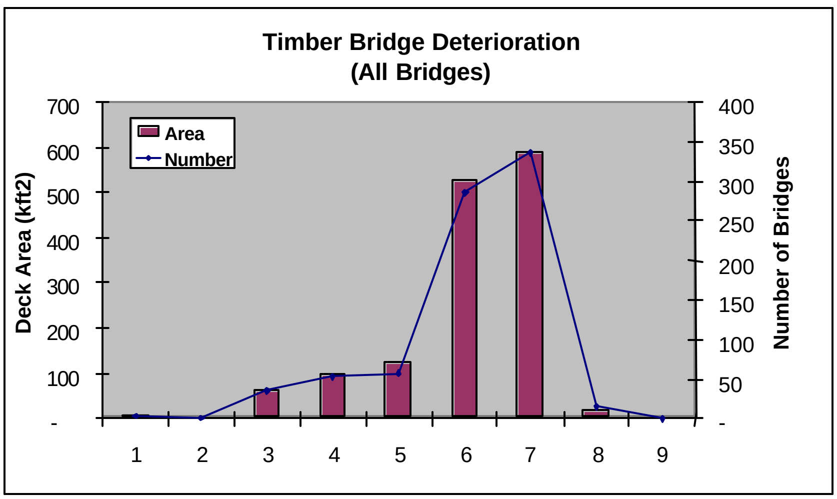

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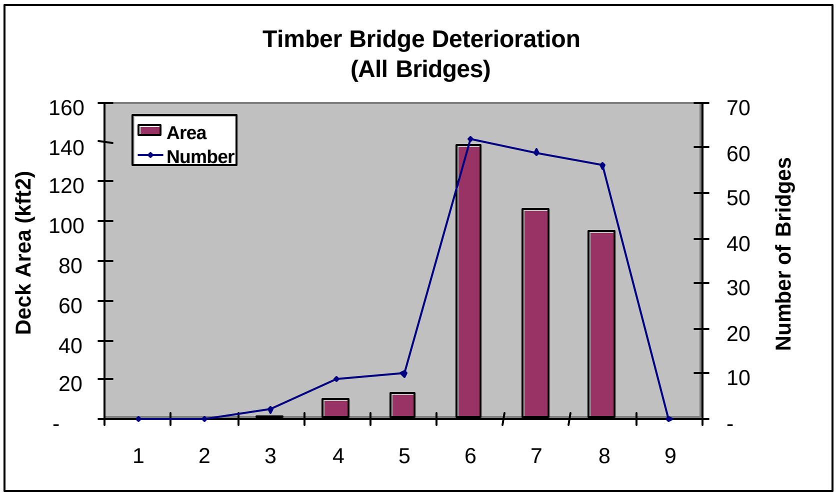

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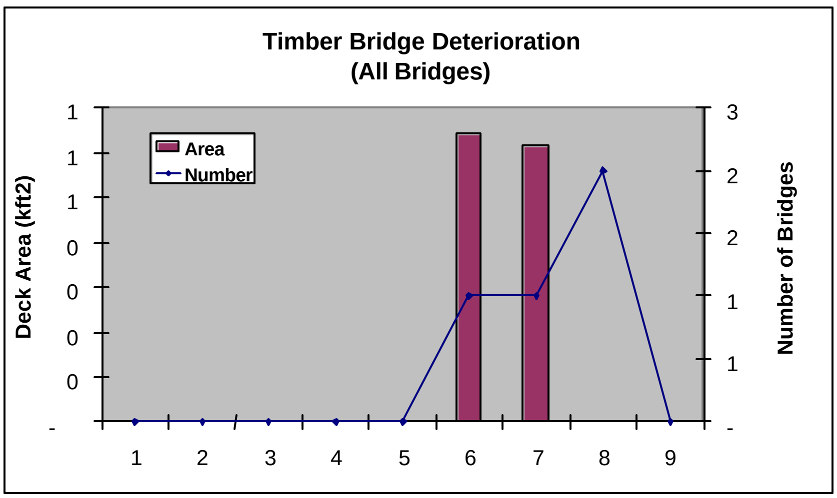

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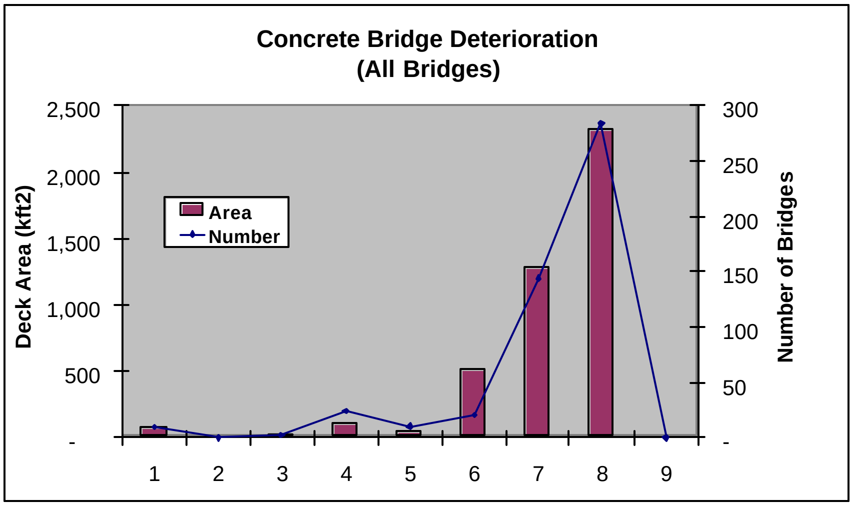
The timber deck deterioration with original rating of 9



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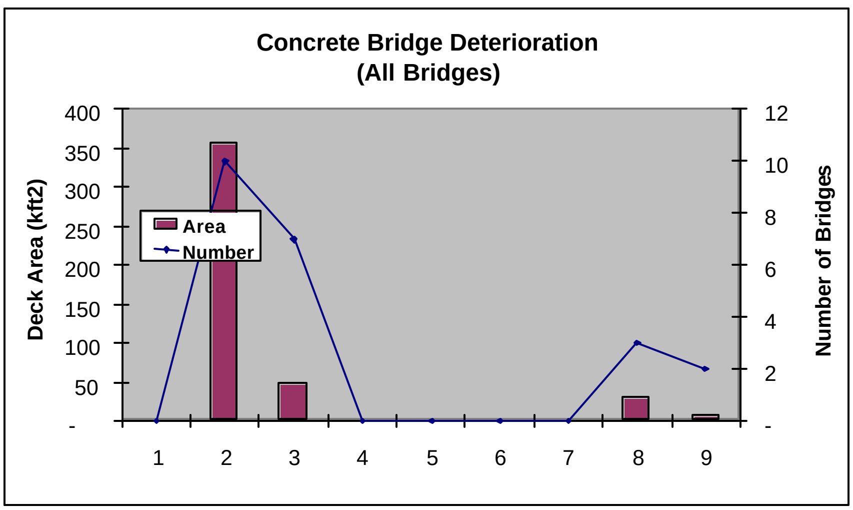
The concrete superstructure deterioration with original rating of 1



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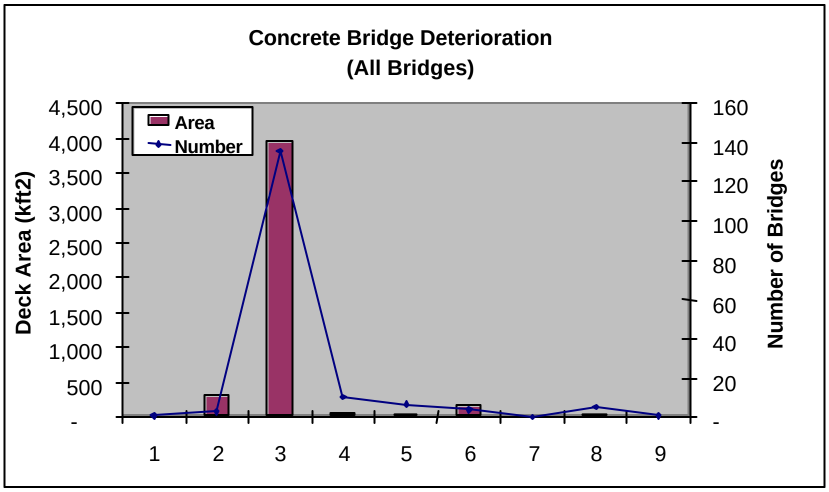

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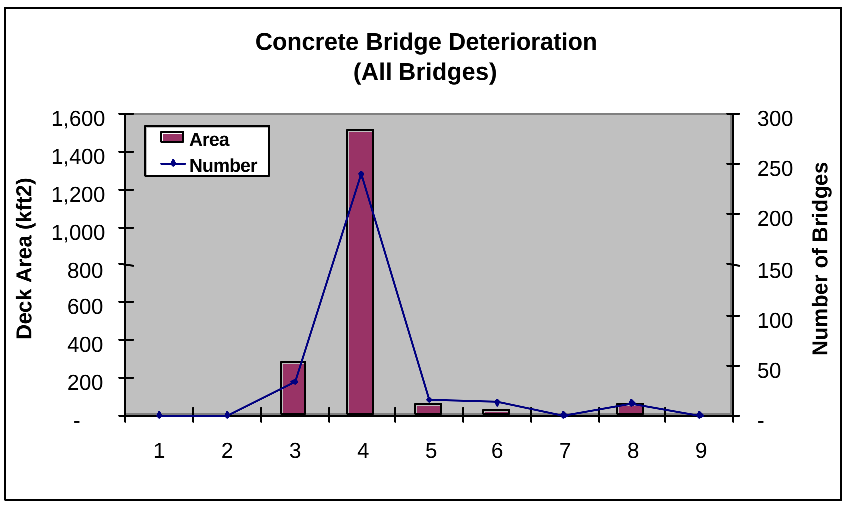
The concrete superstructure deterioration with original rating of 3



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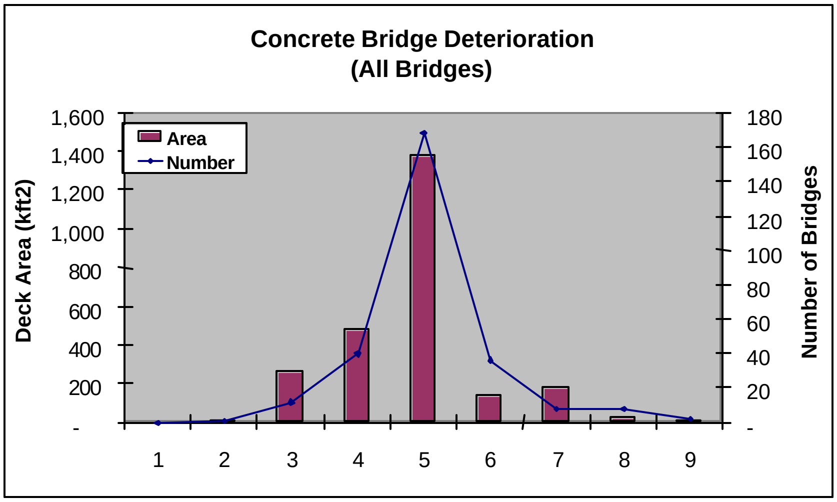
The concrete superstructure deterioration with original rating of 4



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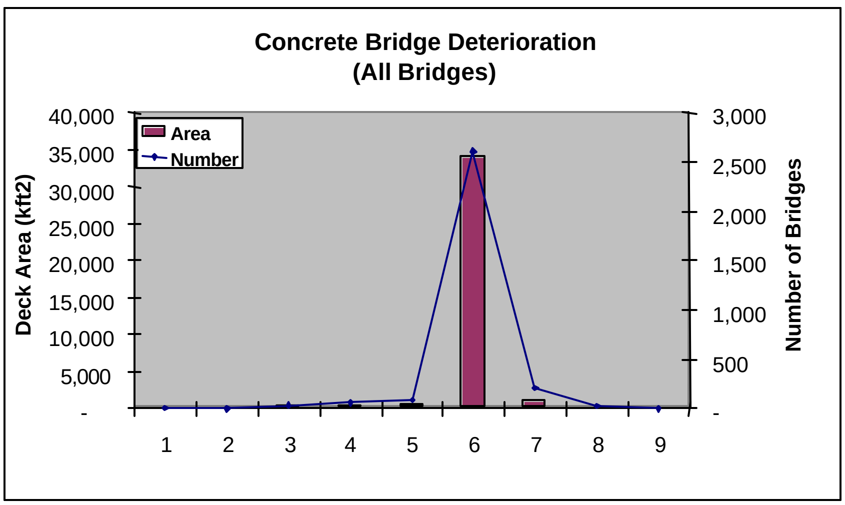

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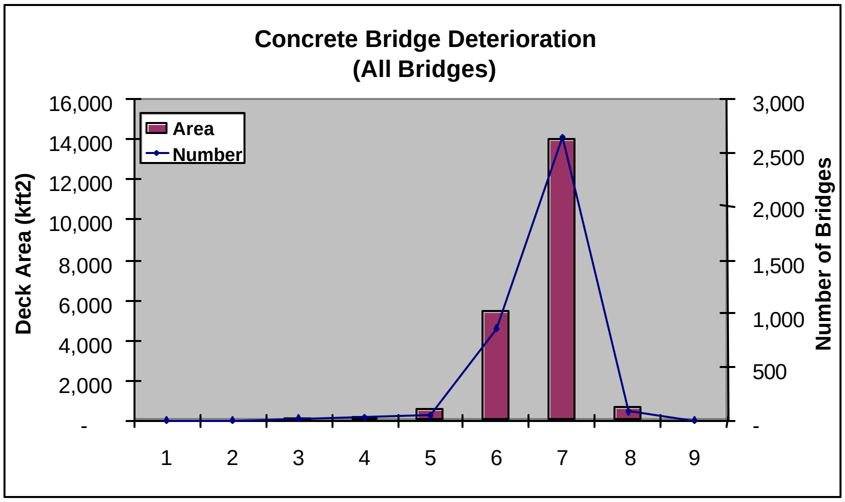

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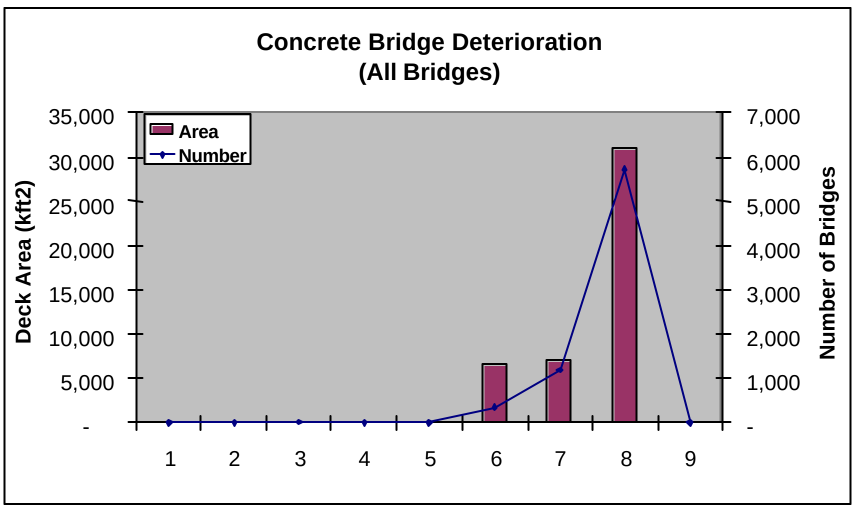

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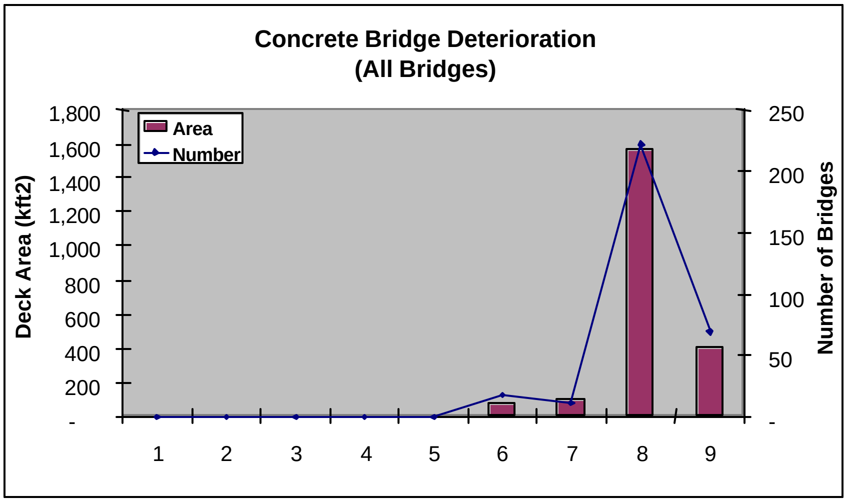

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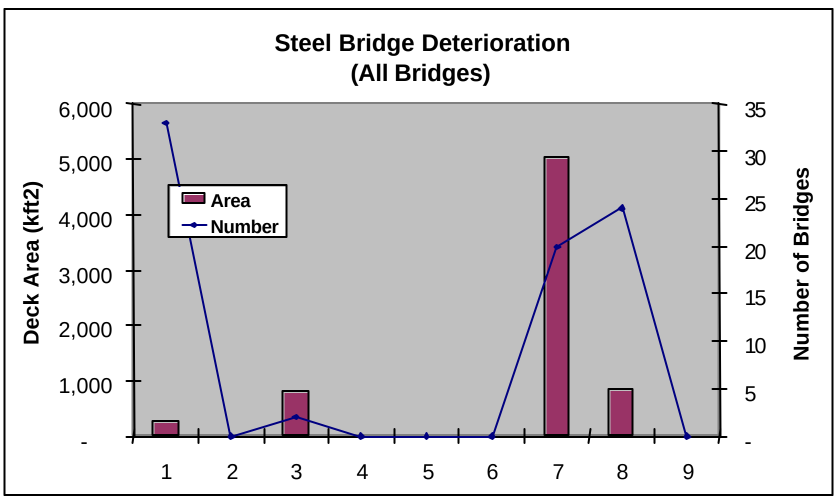
The concrete superstructure deterioration with original rating of 9



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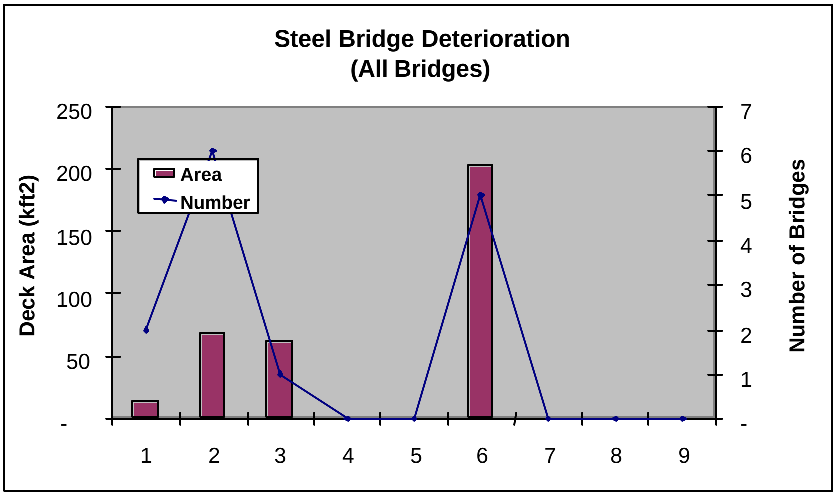

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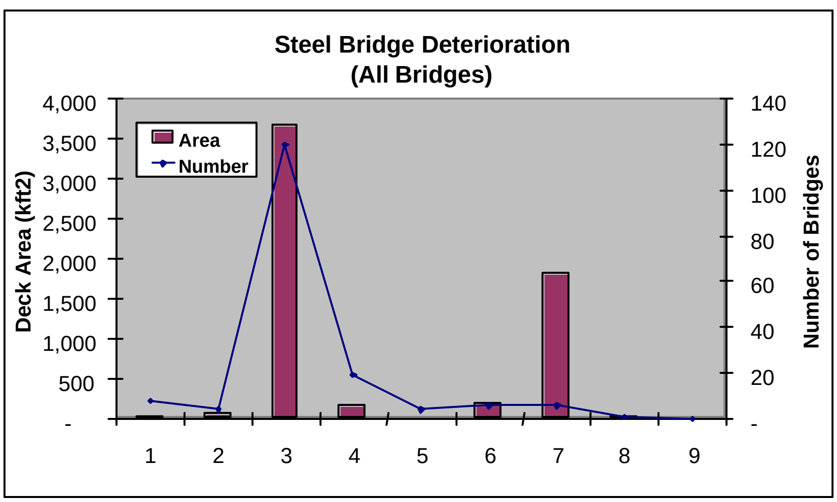

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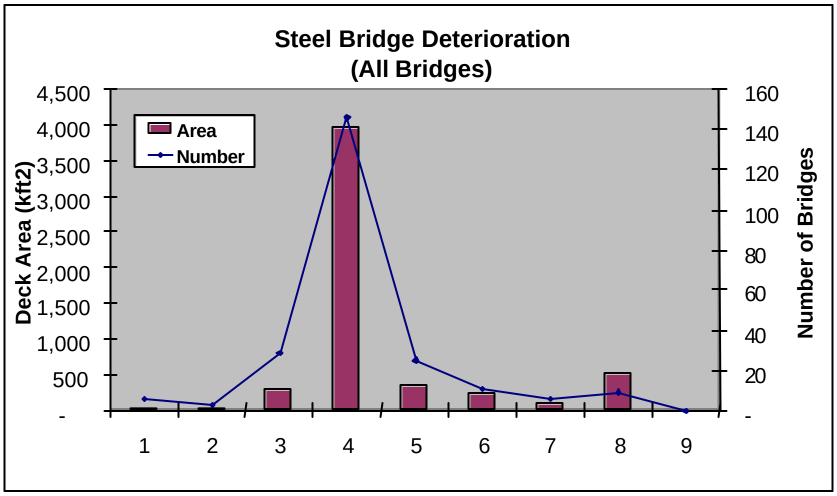
The steel superstructure deterioration with original rating of 3



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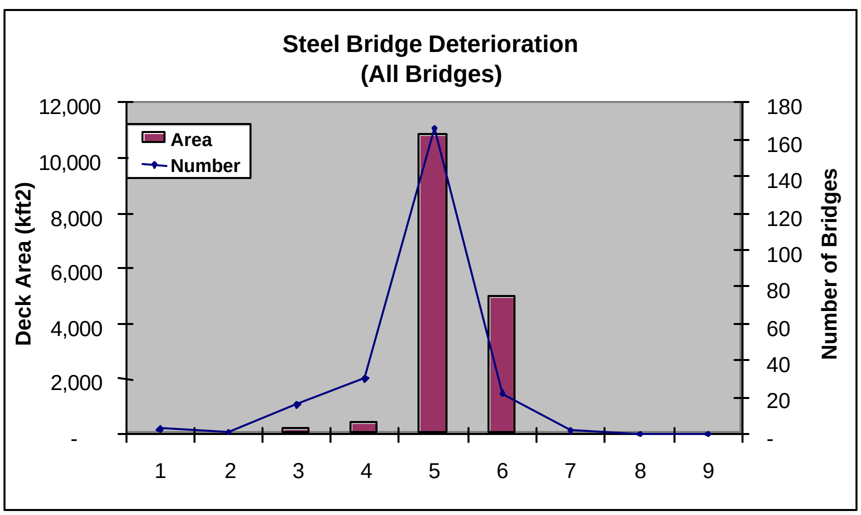

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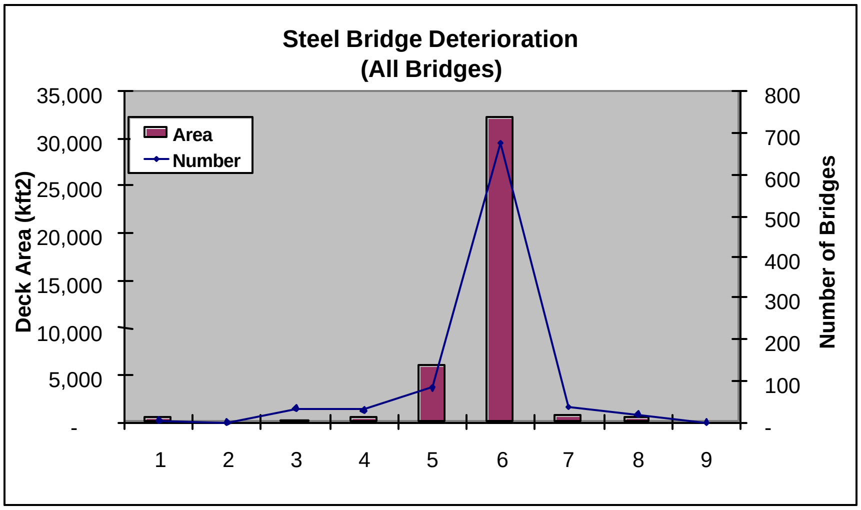

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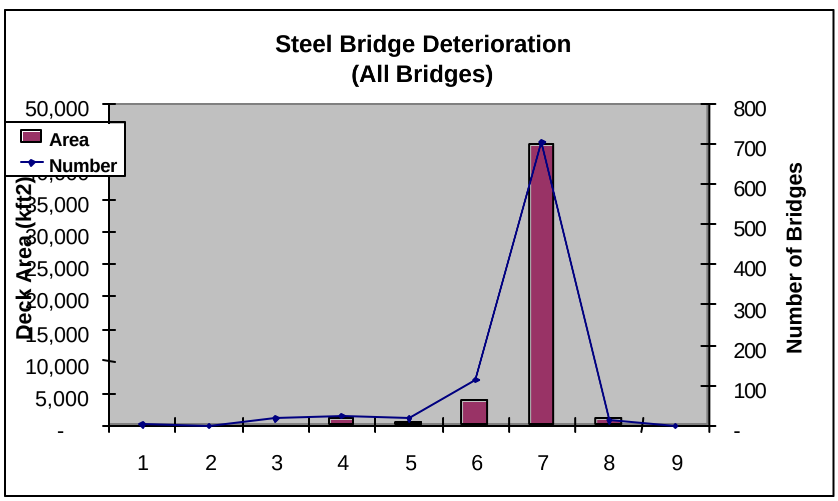

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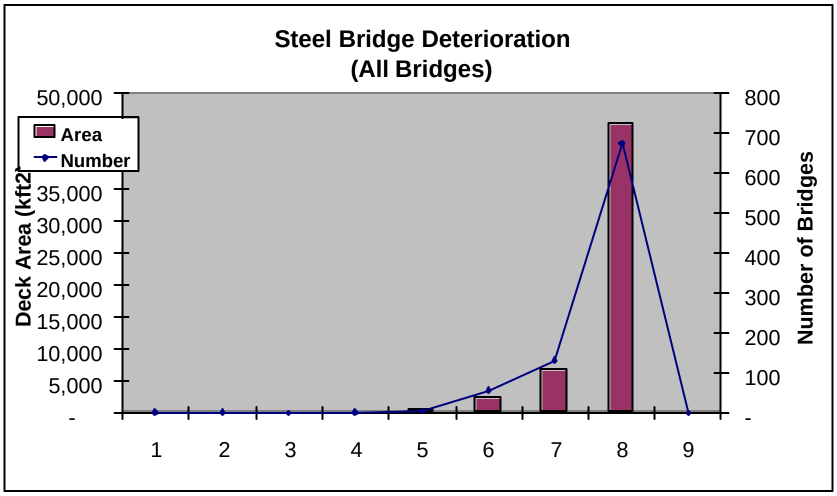


Figure A. 53
The steel superstructure deterioration with original rating of 8

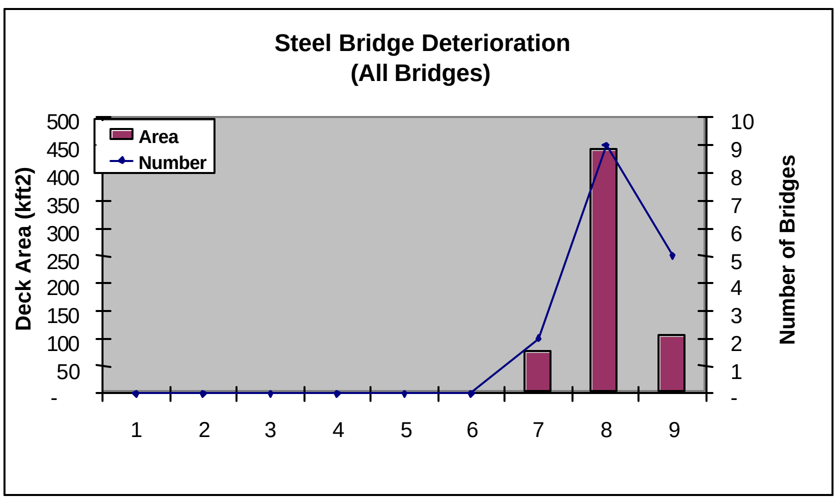


Figure A. 54
The steel superstructure deterioration with original rating of 9

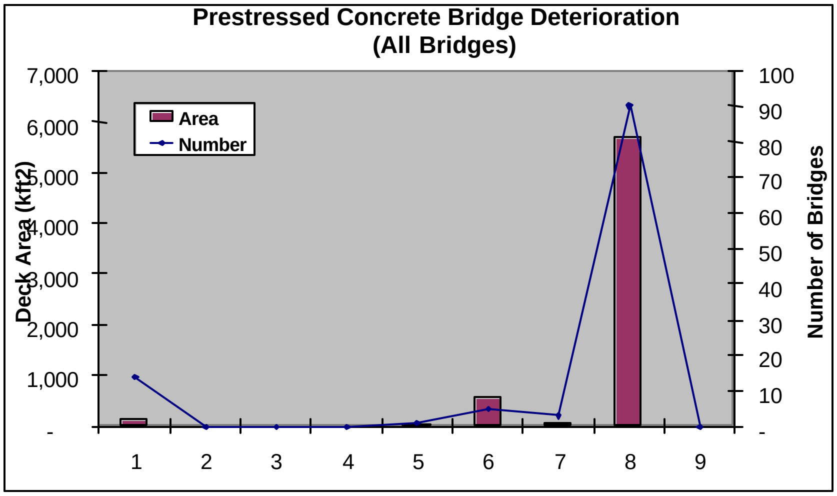
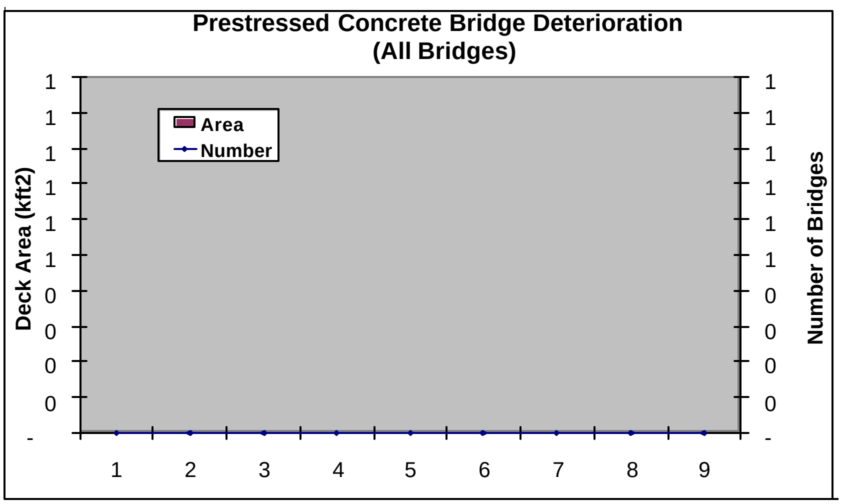


Figure A. 55
The prestressed concrete superstructure deterioration with original rating of 1



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The prestressed concrete superstructure deterioration with original rating of 2
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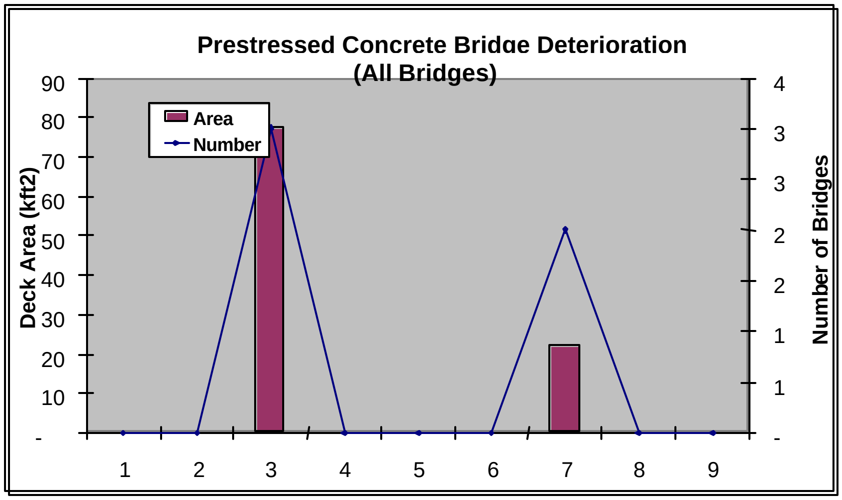

Figure A. 57
The prestressed concrete superstructure deterioration with original rating of

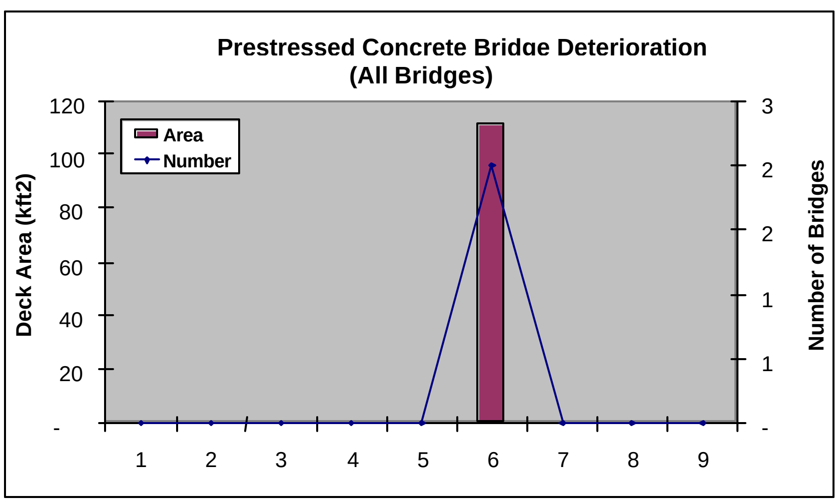

Figure A. 58
The prestressed concrete superstructure deterioration with original rating of 4

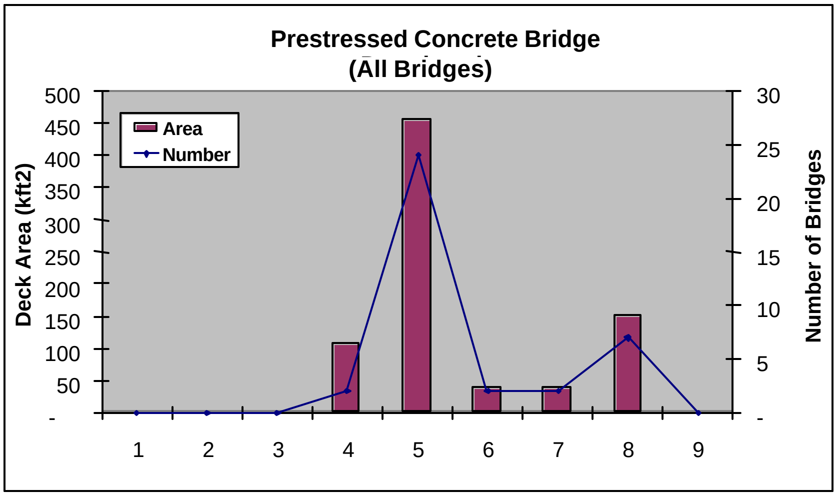

Figure A. 59
The prestressed concrete superstructure deterioration with original rating of 5

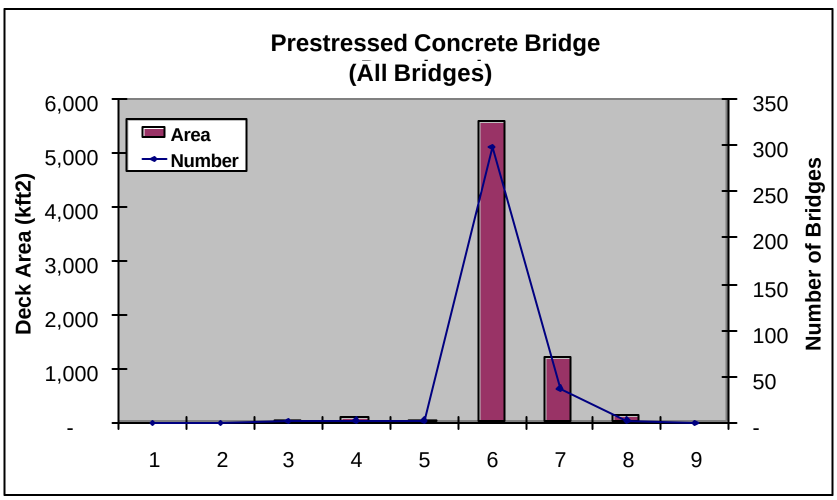

Figure A. 60
The prestressed concrete superstructure deterioration with original rating of 6

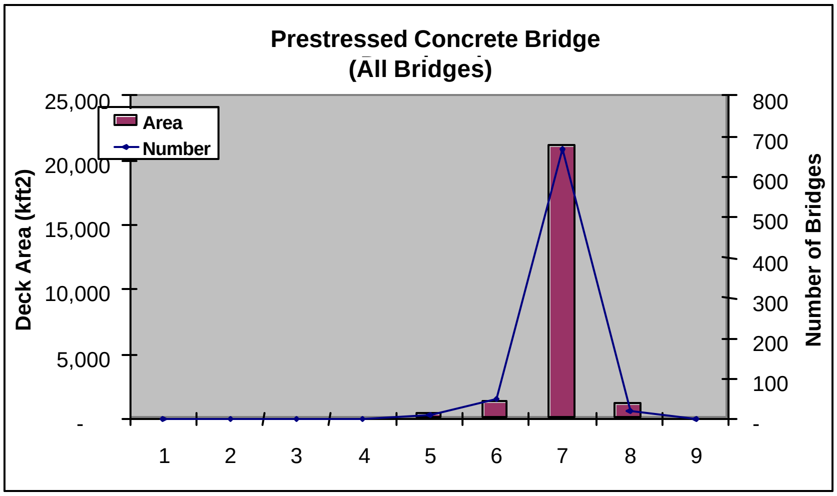

Figure A. 61
The prestressed concrete superstructure deterioration with original rating of 7

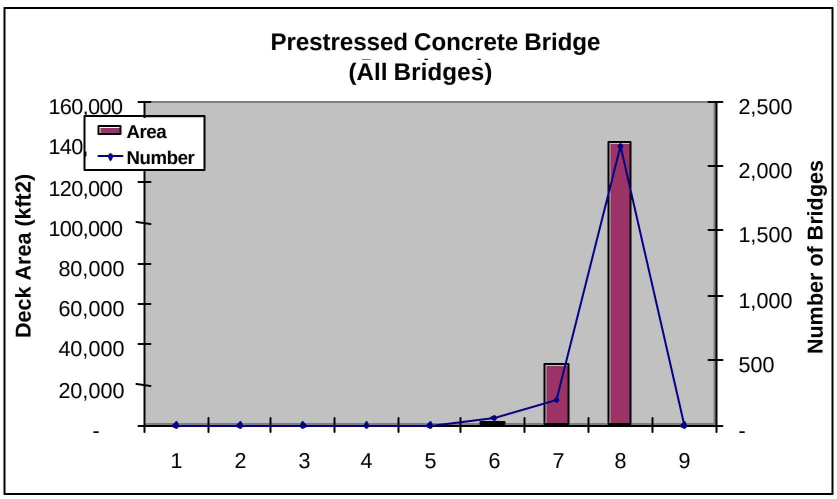

Figure A. 62
The prestressed concrete superstructure deterioration with original rating of 8

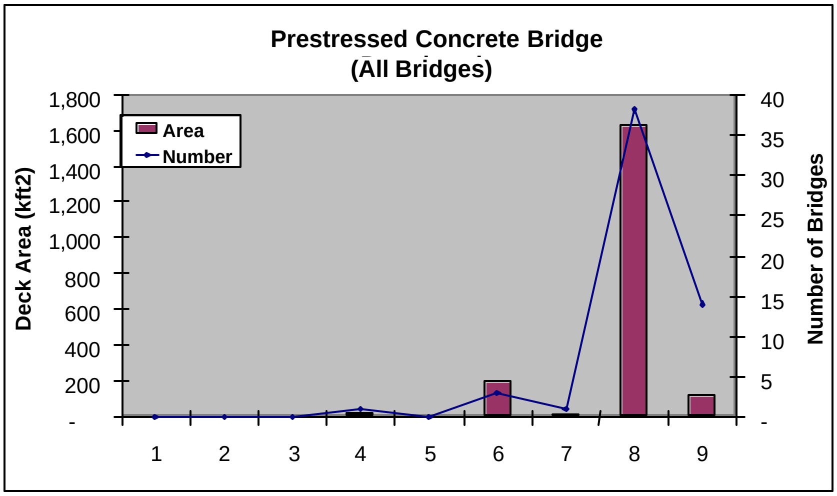

Figure A. 63
The prestressed concrete superstructure deterioration with original rating of 9

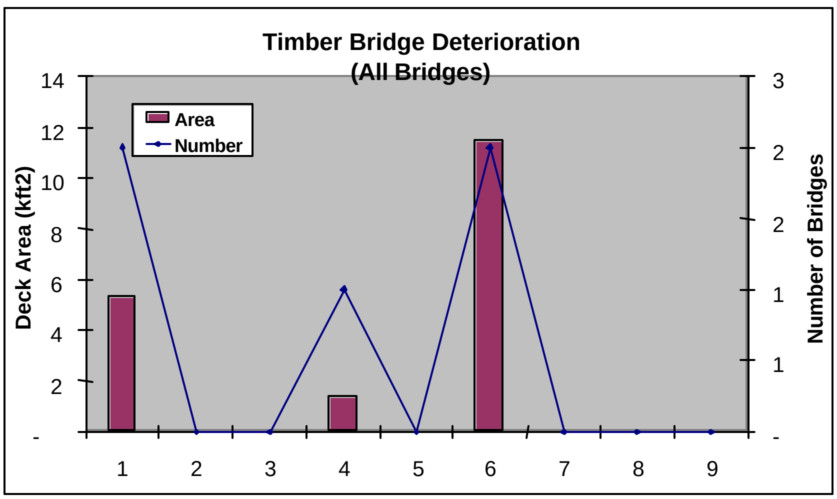

Figure A. 64
The timber superstructure deterioration with original rating of 1

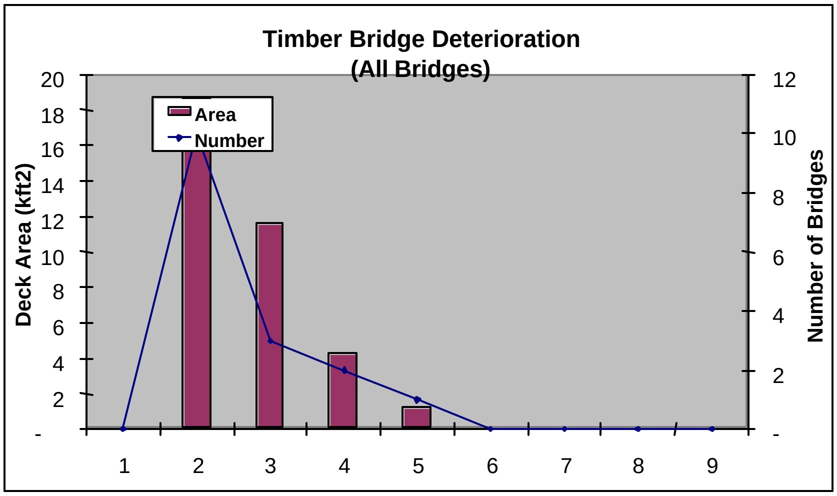

Figure A. 65
The timber superstructure deterioration with original rating of 2

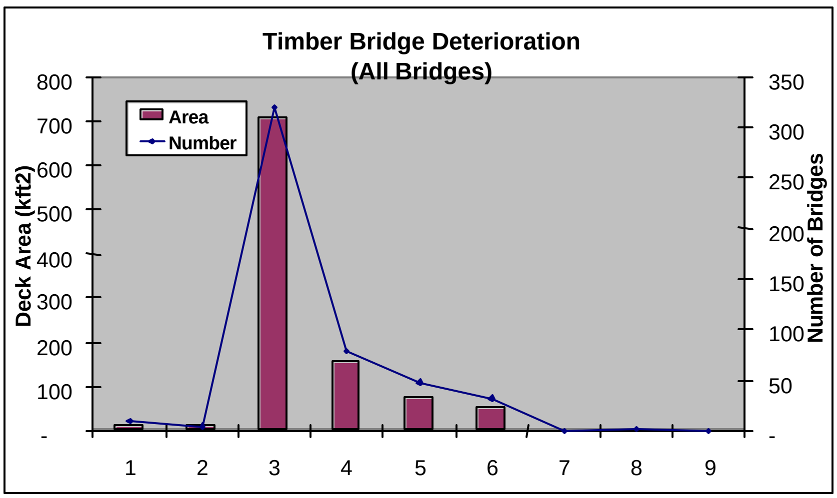

Figure A. 66
The timber superstructure deterioration with original rating of 3

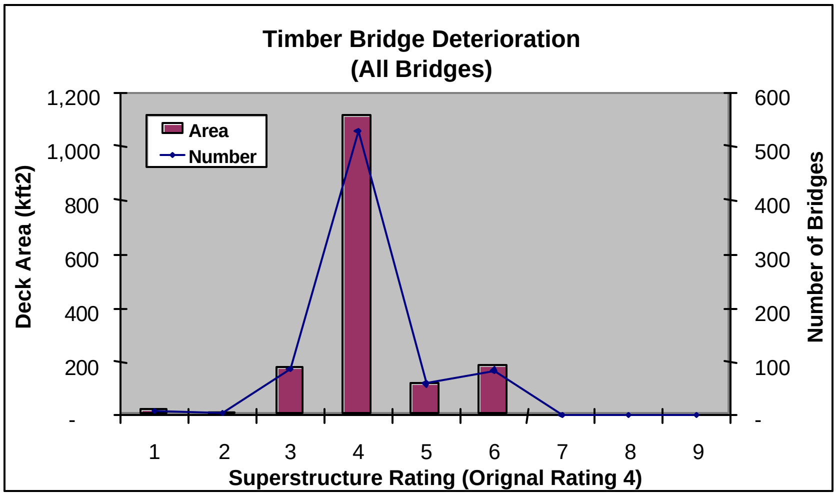

Figure A. 67
The timber superstructure deterioration with original rating of 4

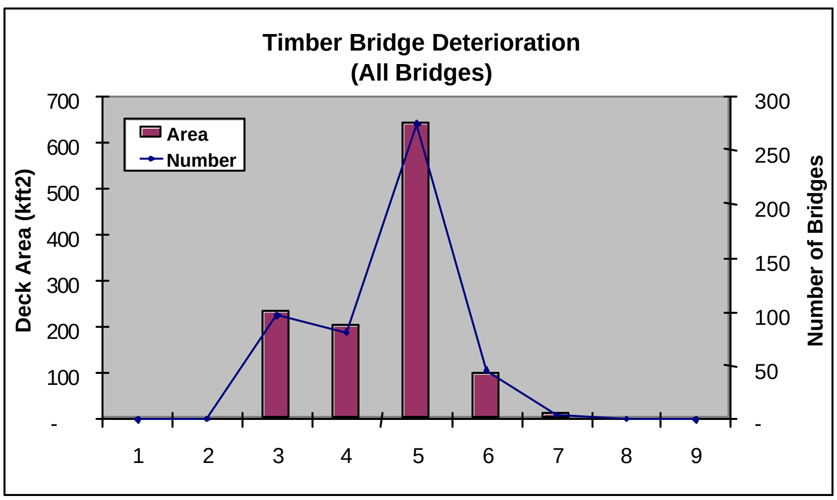

Figure A. 68
The timber superstructure deterioration with original rating of 5

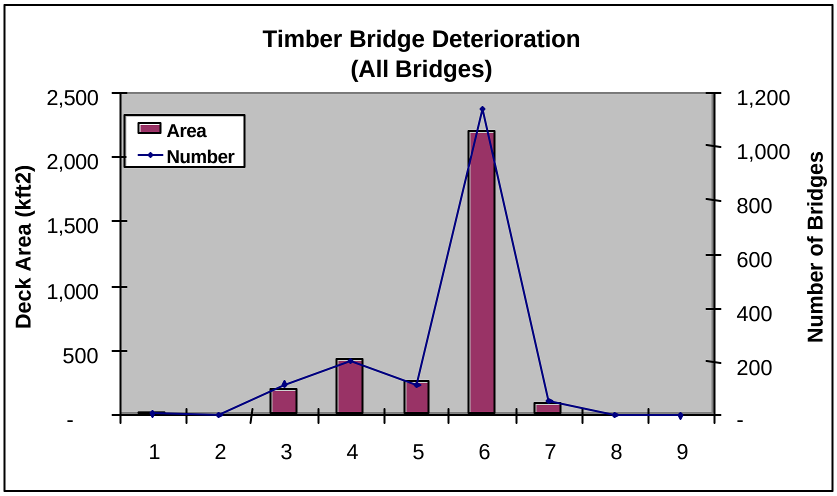

Figure A. 69
The timber superstructure deterioration with original rating of 6

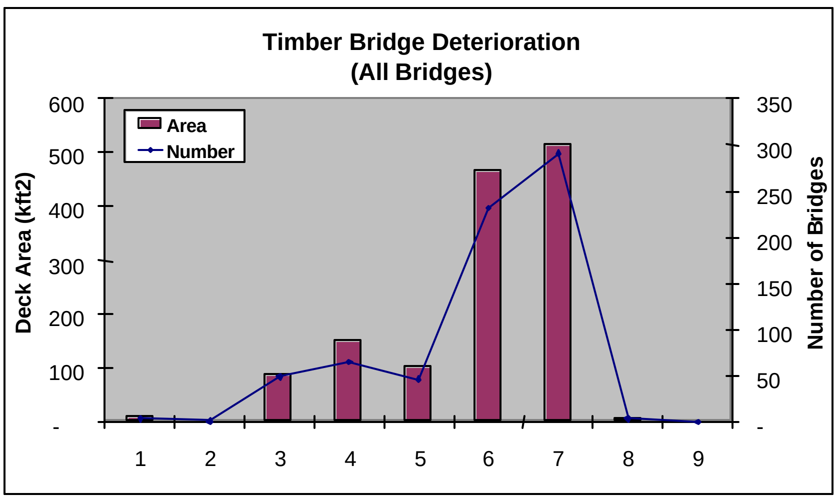

Figure A. 70
The timber superstructure deterioration with original rating of 7

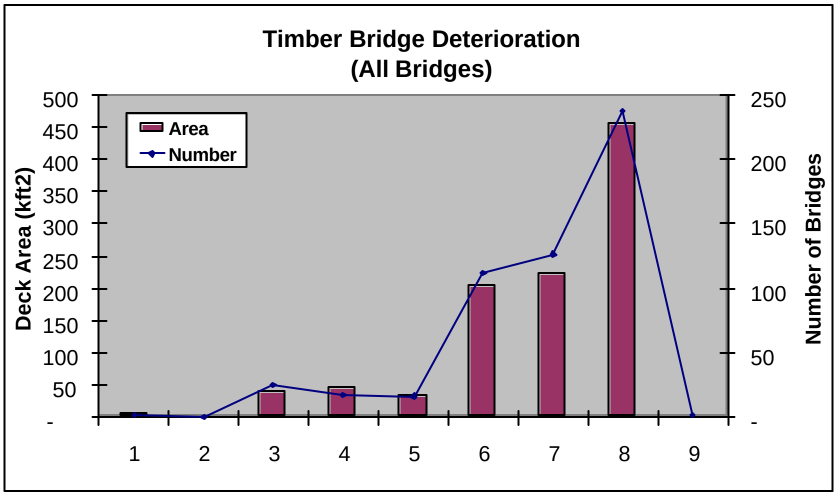

Figure A. 71
The timber superstructure deterioration with original rating of 8

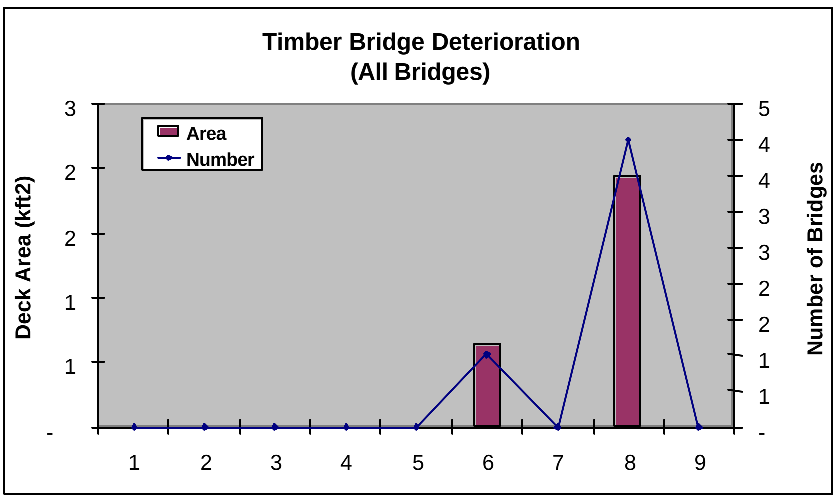

Figure A. 72
The timber superstructure deterioration with original rating of 9

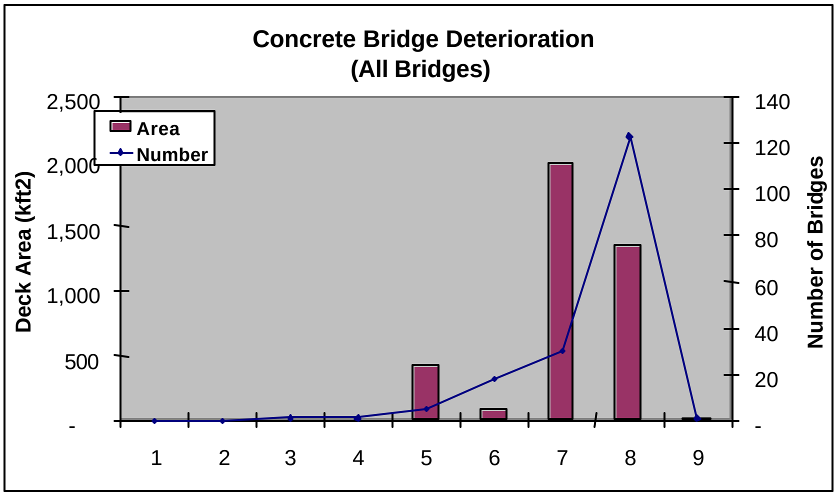

Figure A. 73
The concrete substructure deterioration with original rating of 1

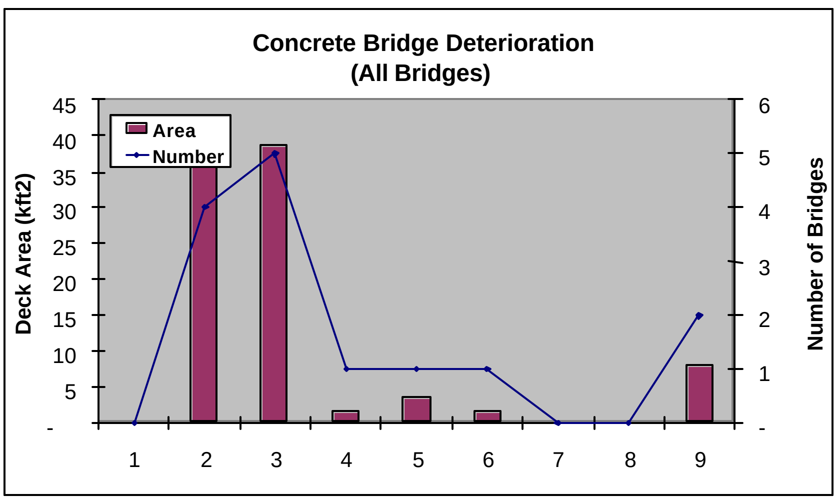

Figure A. 74
The concrete substructure deterioration with original rating of 2

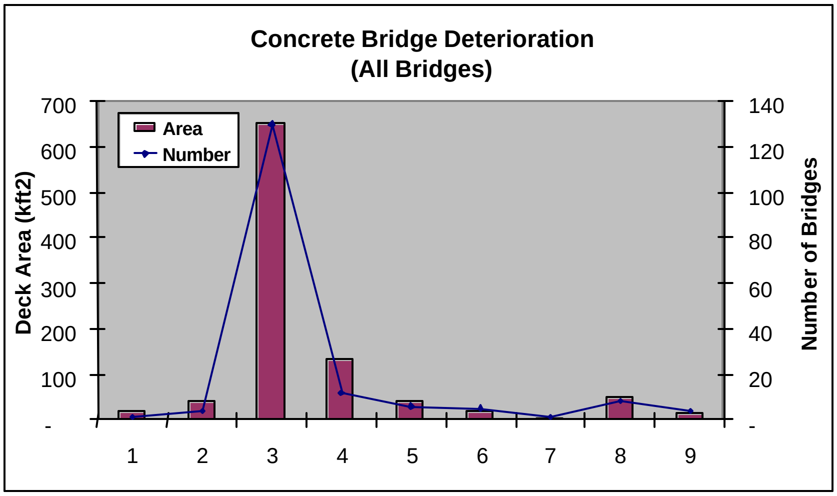

Figure A. 75
The concrete substructure deterioration with original rating of 3

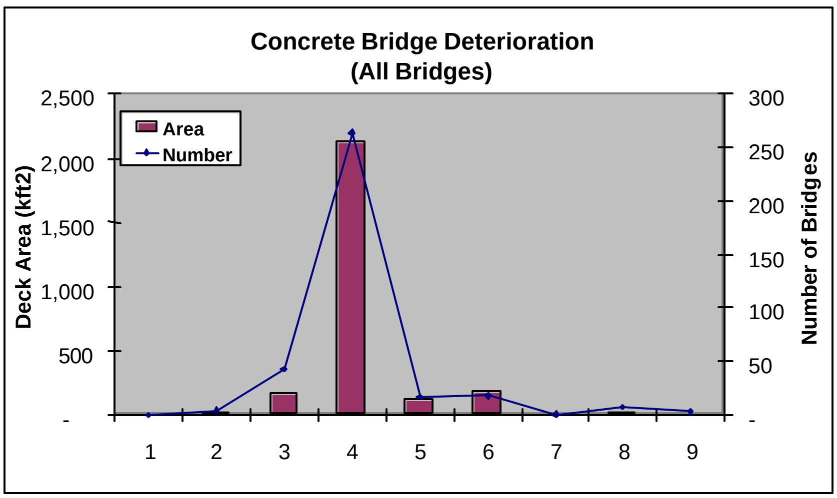

Figure A. 76
The concrete substructure deterioration with original rating of 4

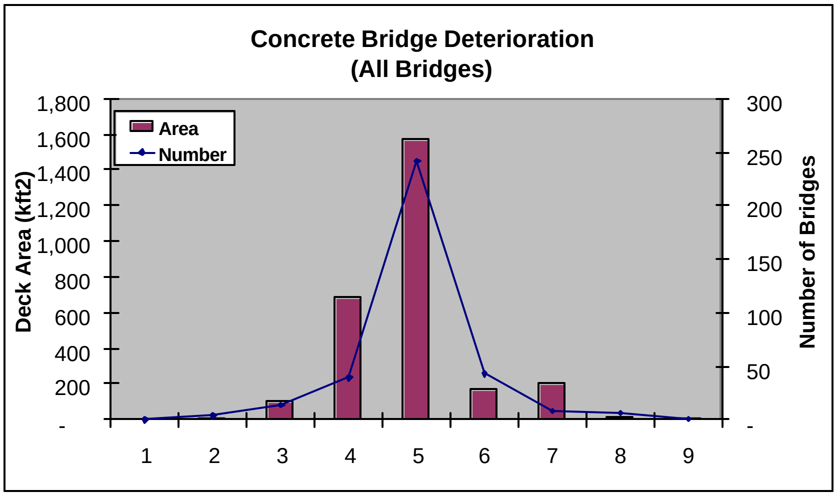

Figure A. 77
The concrete substructure deterioration with original rating of 5

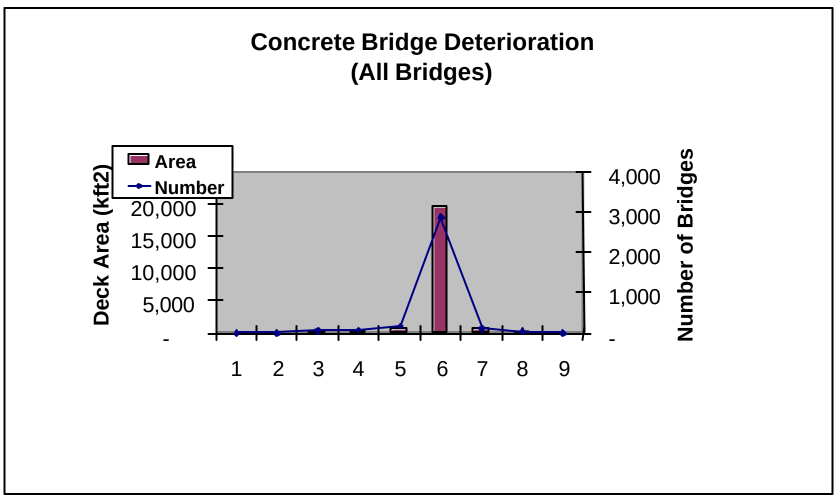

Figure A. 78
The concrete substructure deterioration with original rating of 6

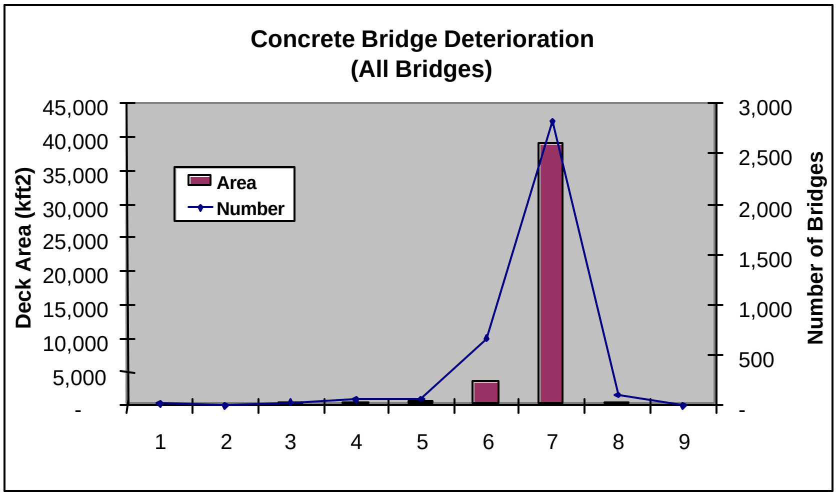

Figure A. 79
The concrete substructure deterioration with original rating of 7

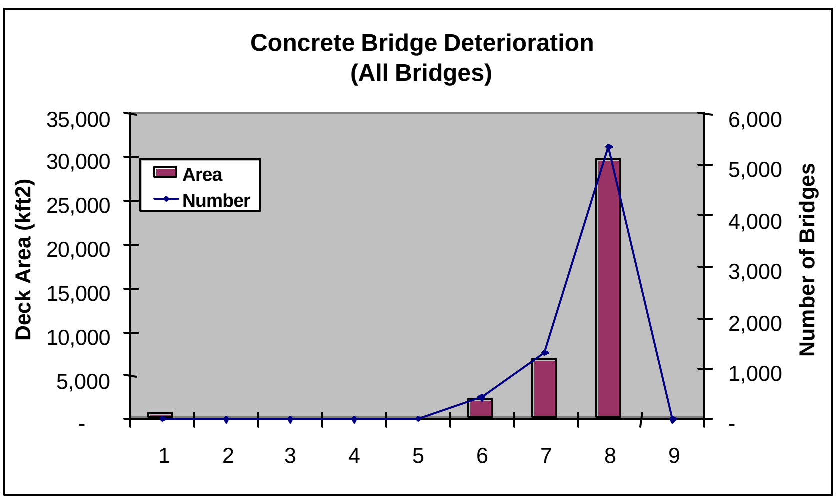

Figure A. 80
The concrete substructure deterioration with original rating of 8

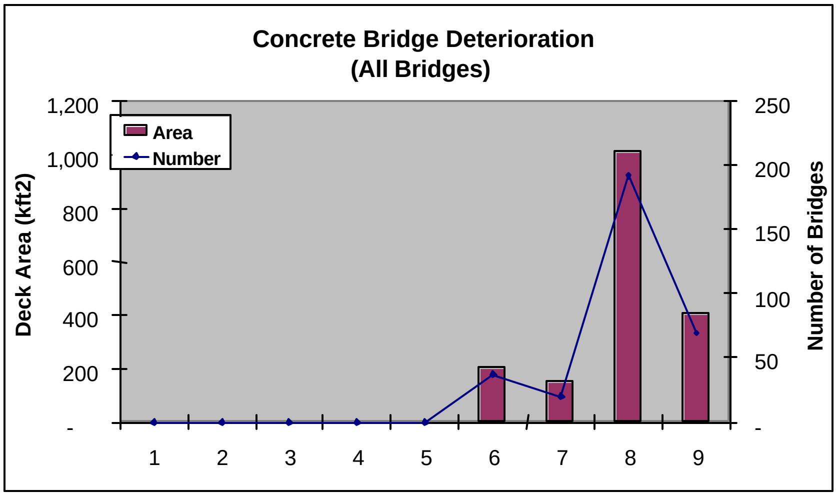

Figure A. 81
The concrete substructure deterioration with original rating of 9

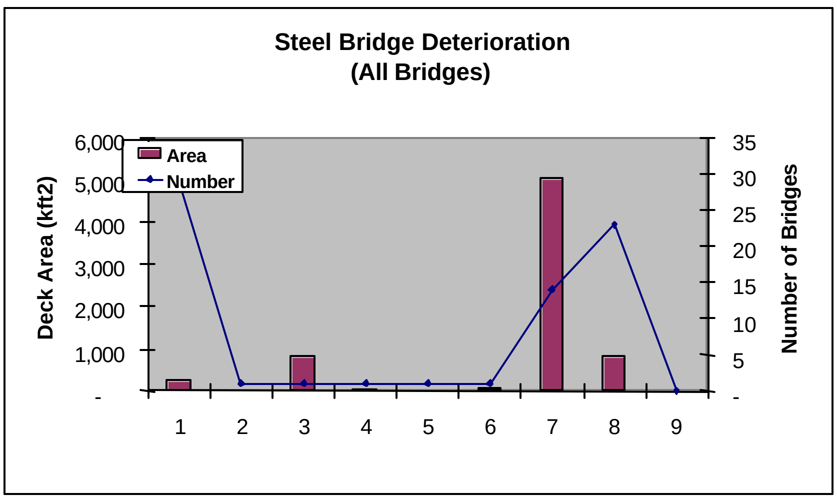

Figure A. 82
The steel substructure deterioration with original rating of 1

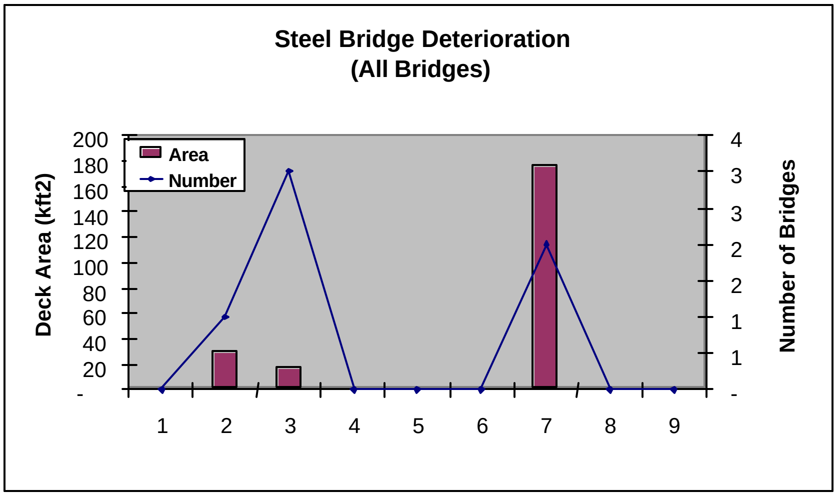

Figure A. 83
The steel substructure deterioration with original rating of 2

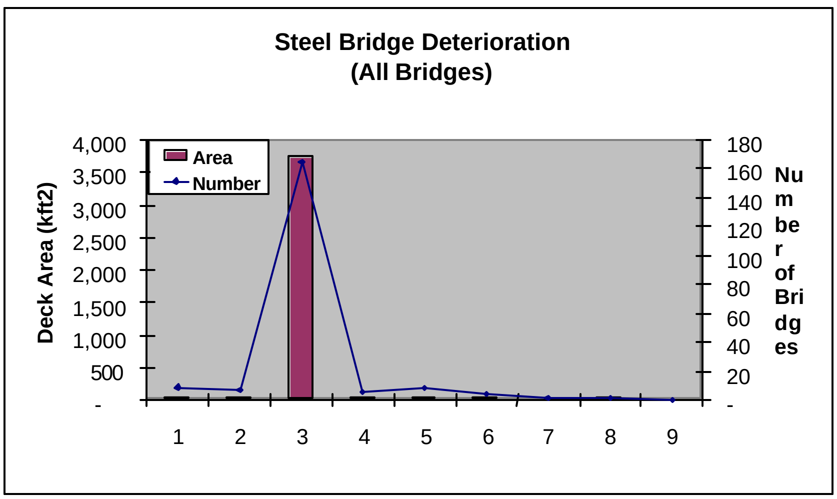

Figure A. 84
The steel substructure deterioration with original rating of 3

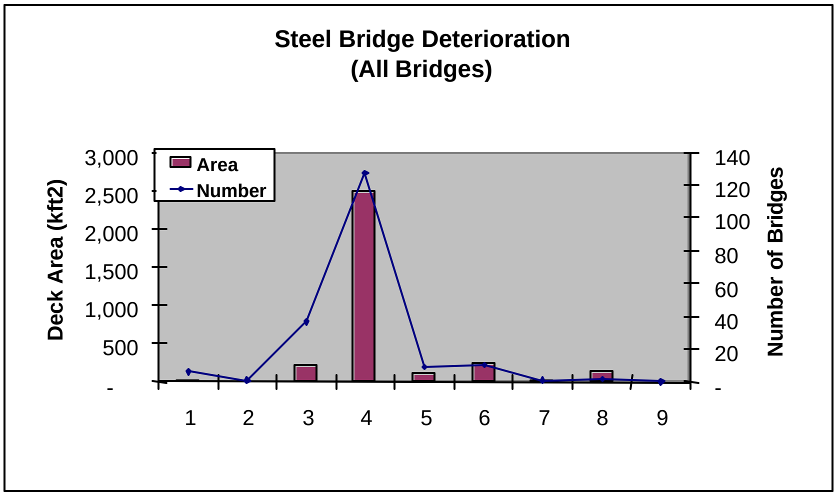

Figure A. 85
The steel substructure deterioration with original rating of 4

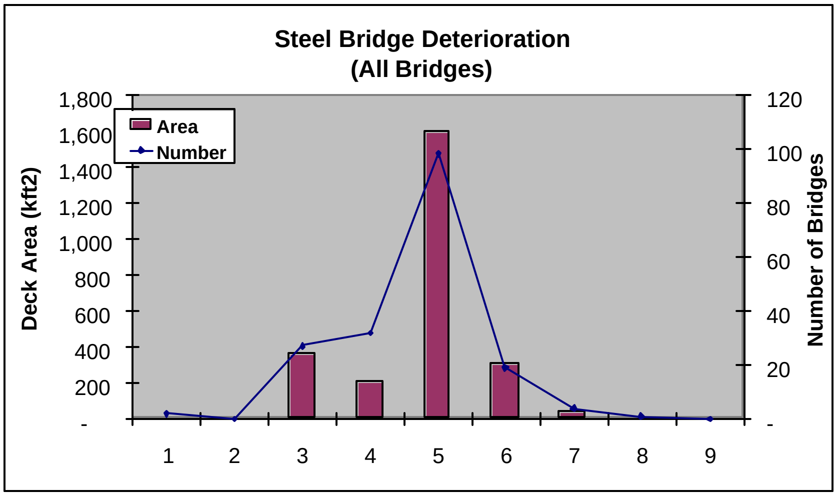

Figure A. 86
The steel substructure deterioration with original rating of 5

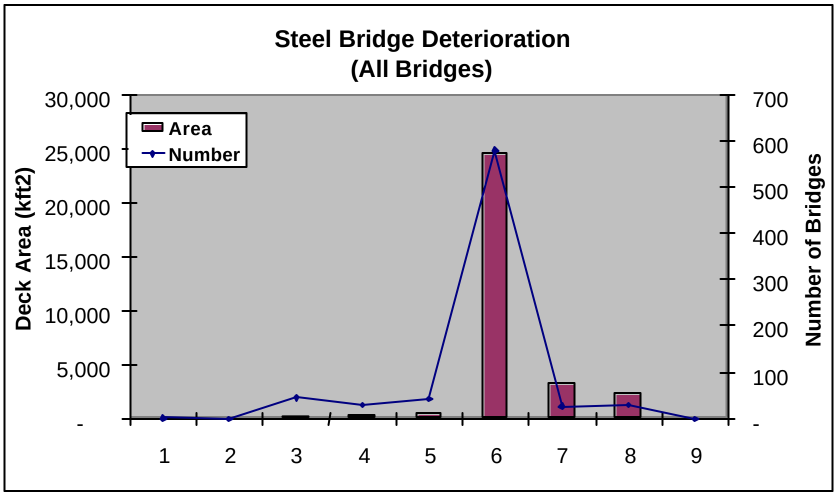

Figure A. 87
The steel substructure deterioration with original rating of 6

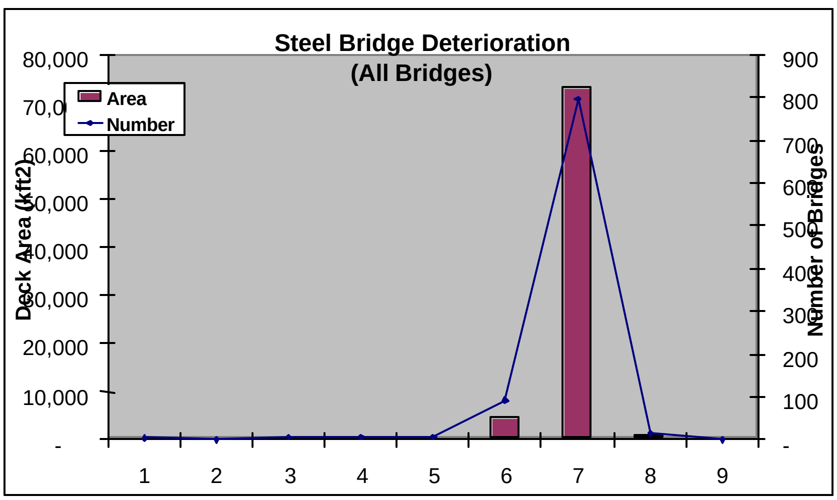

Figure A. 88
The steel substructure deterioration with original rating of 7

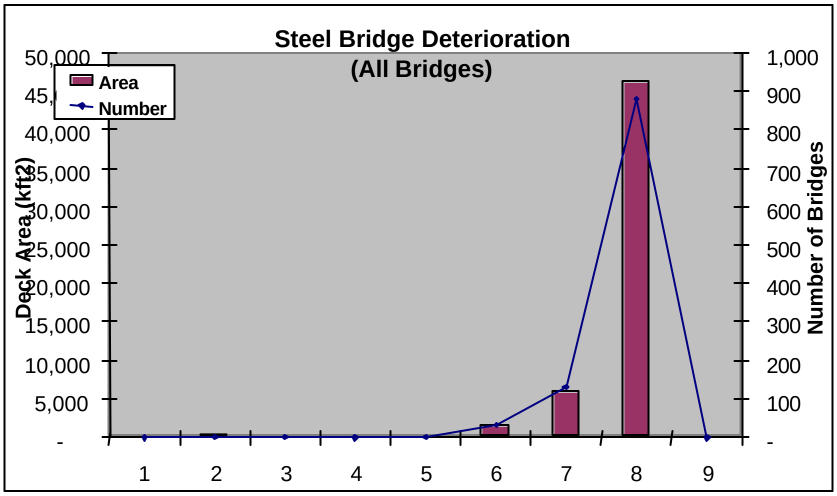

Figure A. 89
The steel substructure deterioration with original rating of 8

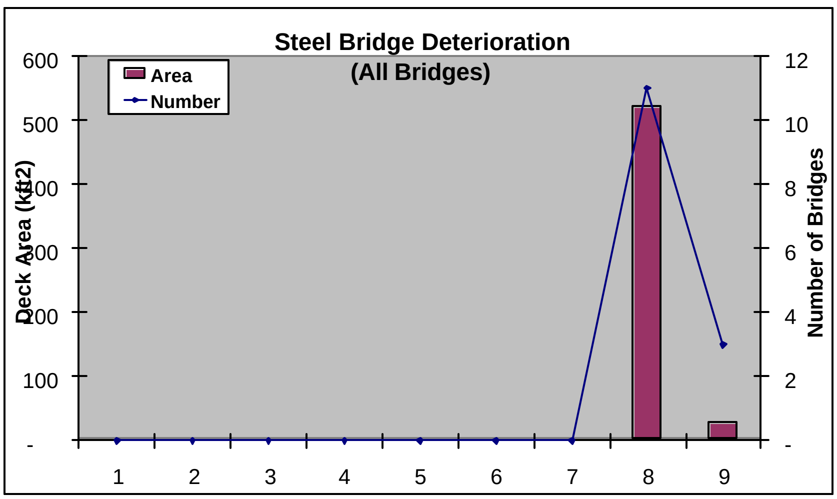

Figure A. 90
The steel substructure deterioration with original rating of 9

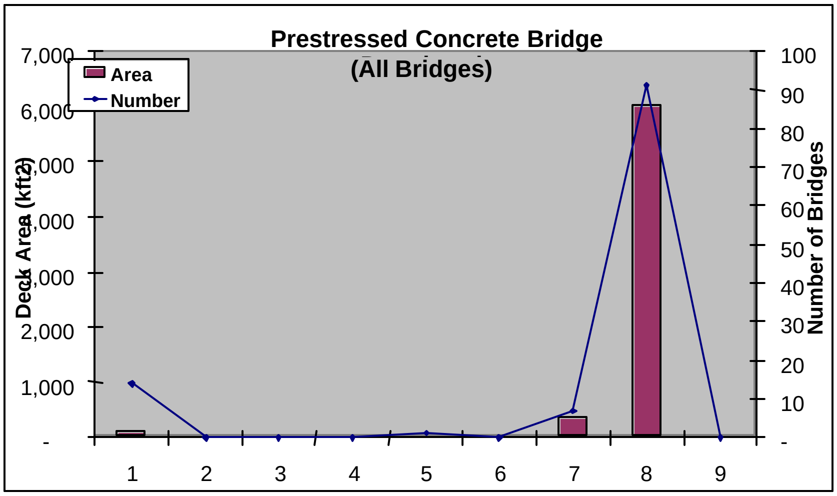

Figure A. 91
The prestressed concrete substructure deterioration with original rating of 1

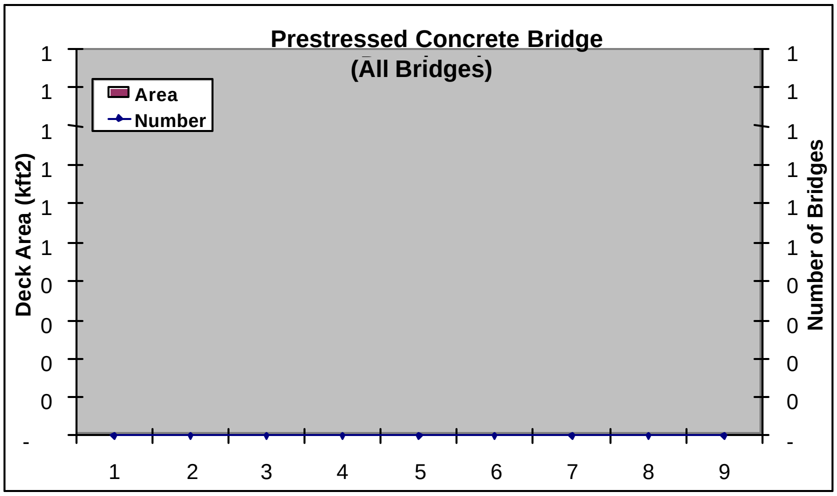

Figure A. 92
The prestressed concrete substructure deterioration with original rating of 2

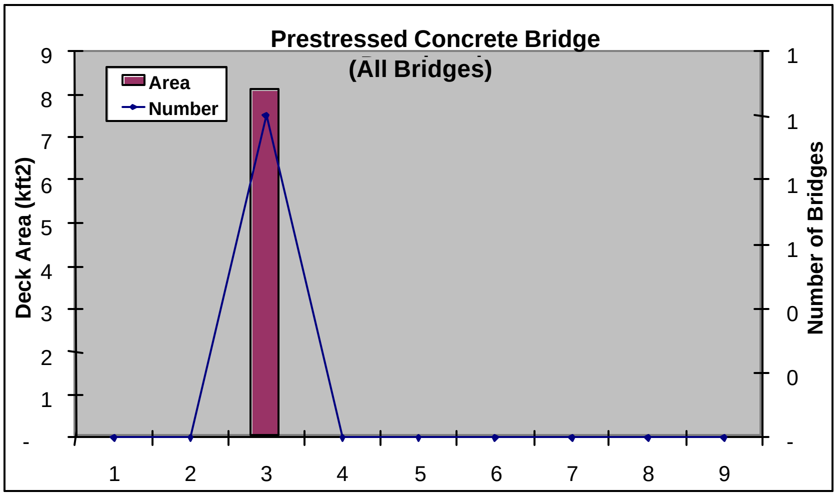

Figure A. 93
The prestressed concrete substructure deterioration with original rating of 3

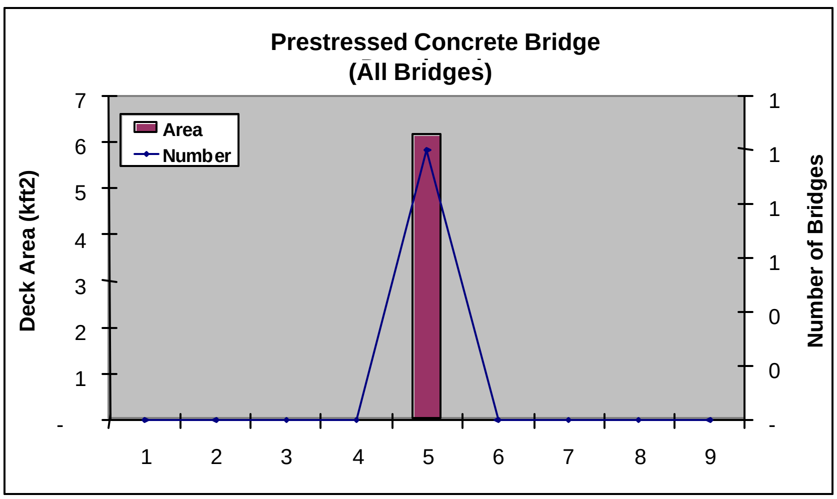

Figure A. 94
The prestressed concrete substructure deterioration with original rating of 4

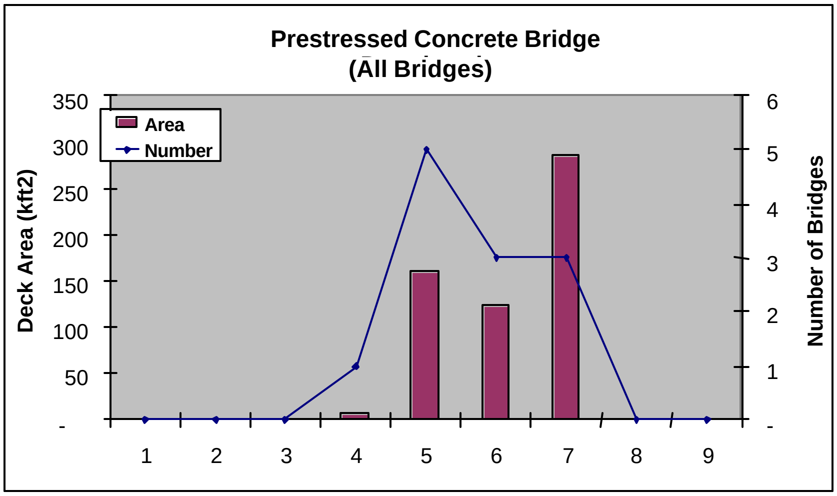

Figure A. 95
The prestressed concrete substructure deterioration with original rating of 5

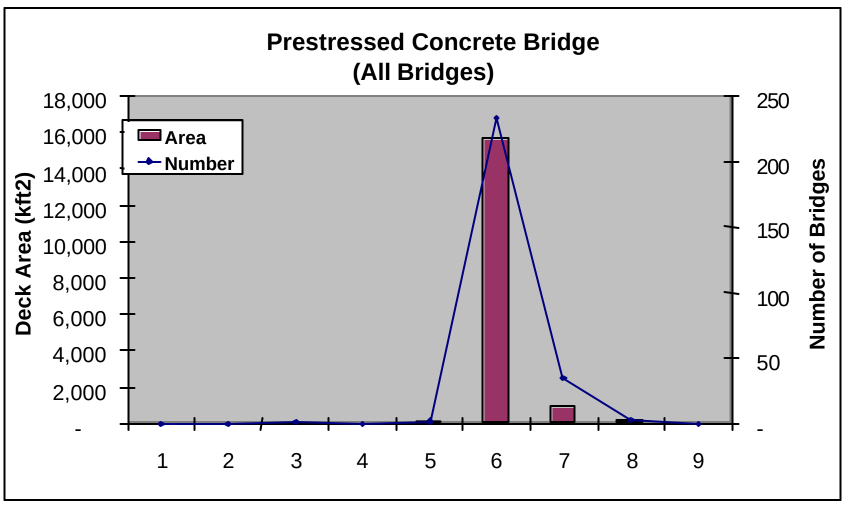

Figure A. 96
The prestressed concrete substructure deterioration with original rating of 6

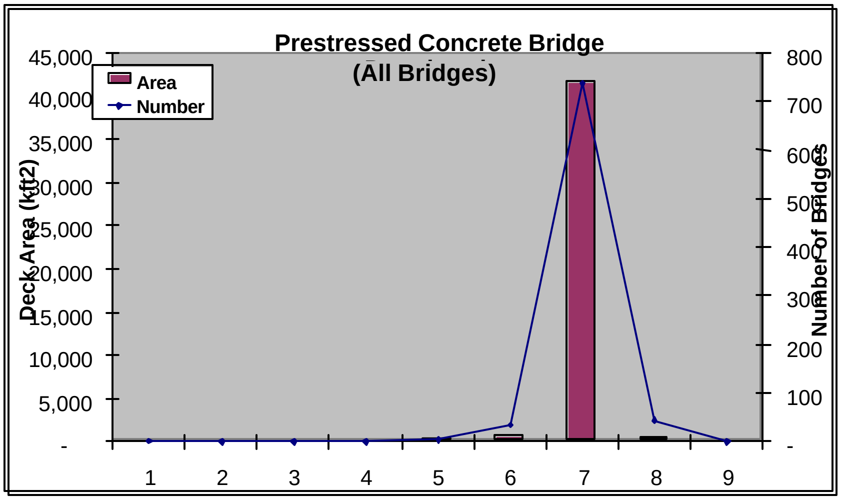

Figure A. 97
The prestressed concrete substructure deterioration with original rating of 7

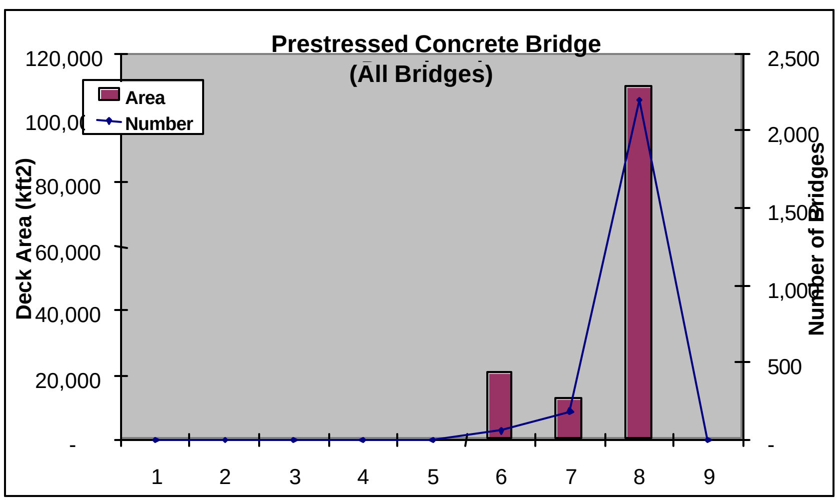

Figure A. 98
The prestressed concrete substructure deterioration with original rating of 8

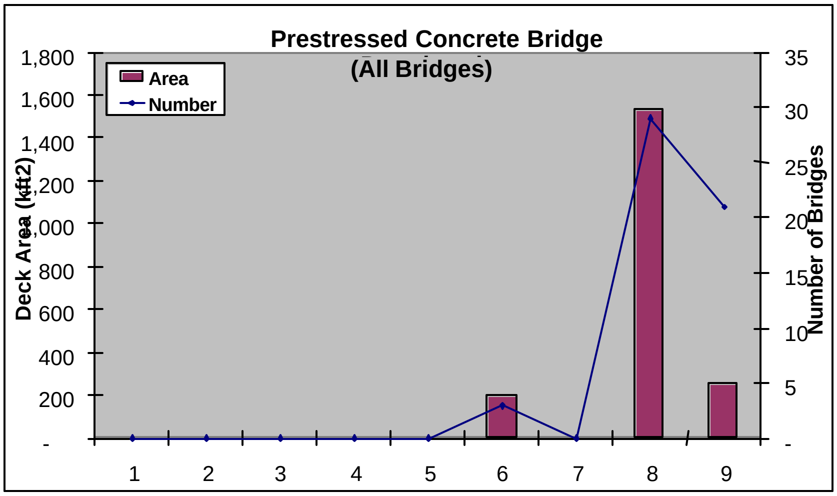

Figure A. 99
The prestressed concrete substructure deterioration with original rating of 9

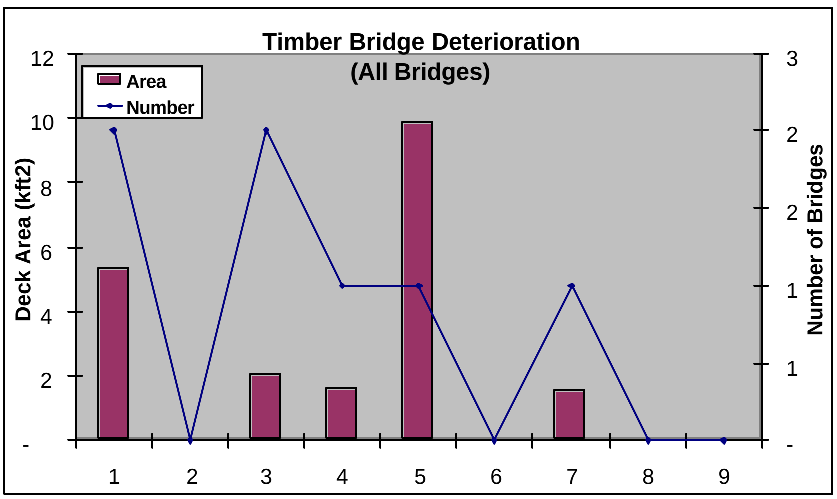

Figure A. 100
The timber substructure deterioration with original rating of 1

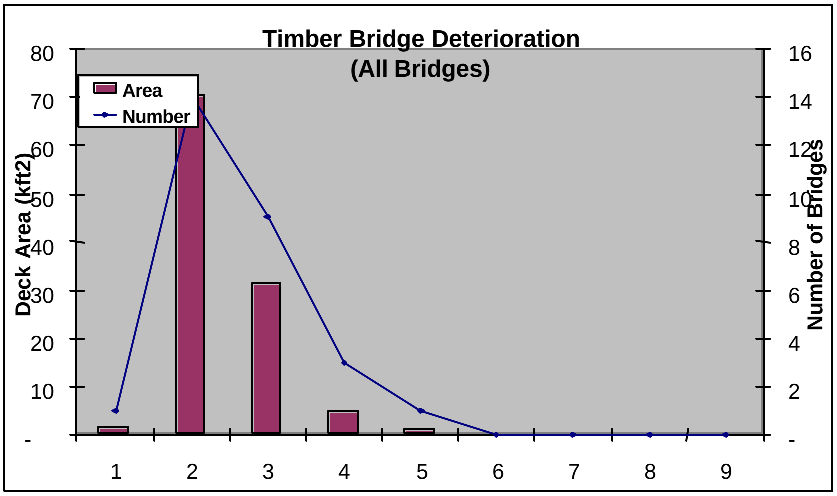

Figure A. 101
The timber substructure deterioration with original rating of 2

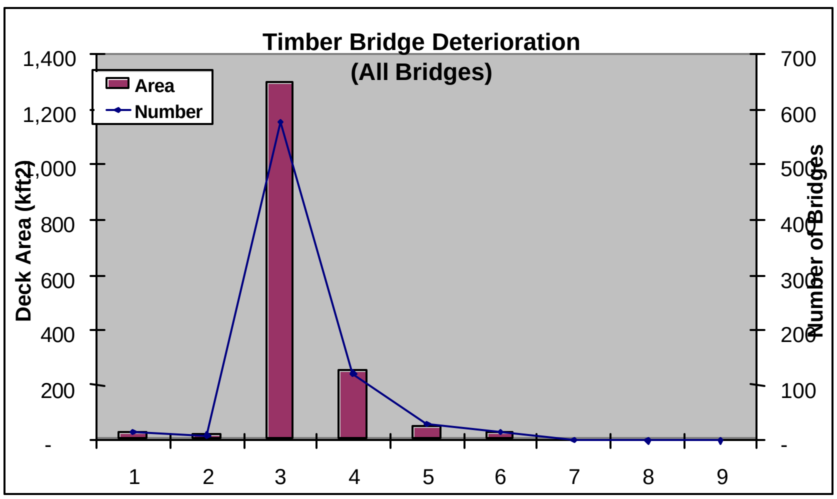

Figure A. 102
The timber substructure deterioration with original rating of 3

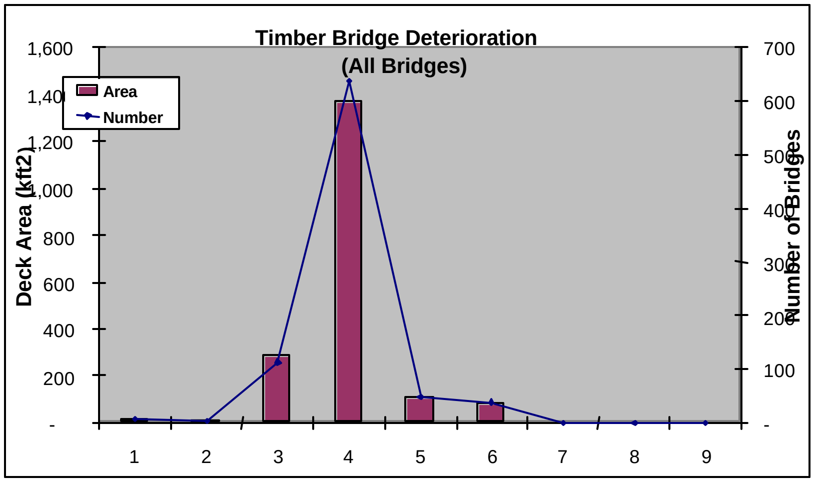

Figure A. 103
The timber substructure deterioration with original rating of 4

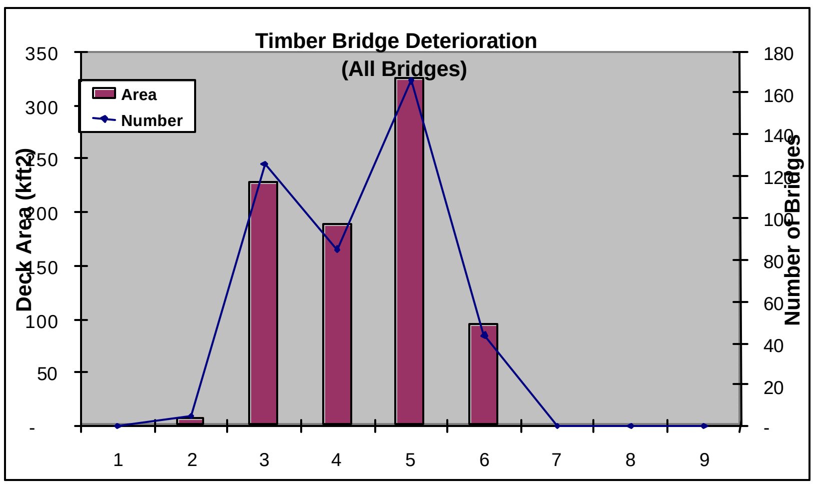

Figure A. 104
The timber substructure deterioration with original rating of 5

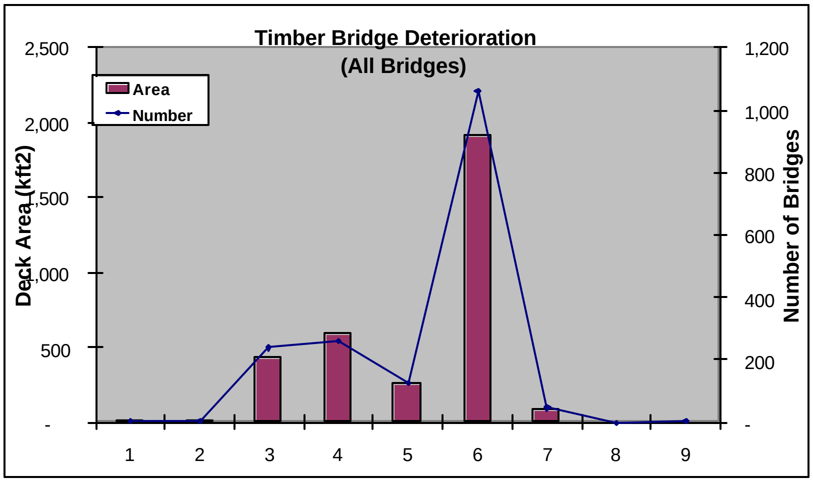

Figure A. 105
The timber substructure deterioration with original rating of 6

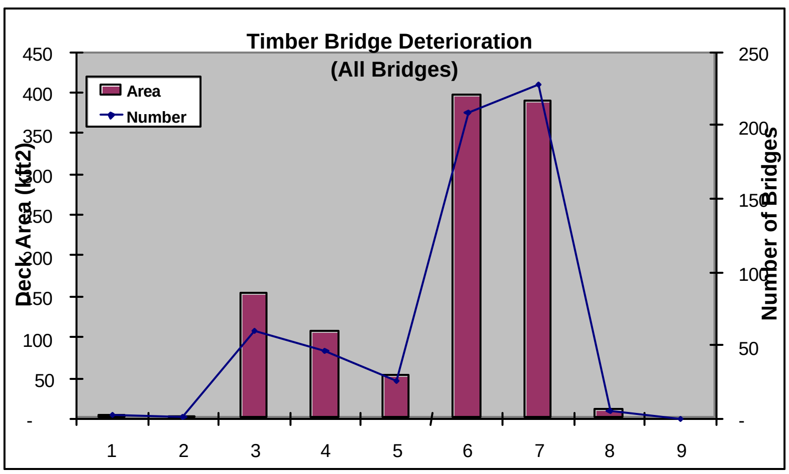

Figure A. 106
The timber substructure deterioration with original rating of 7

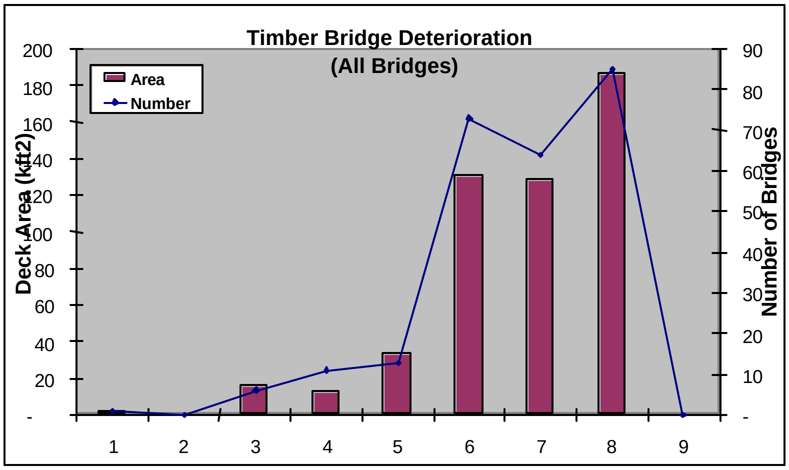

Figure A. 107
The timber substructure deterioration with original rating of 8

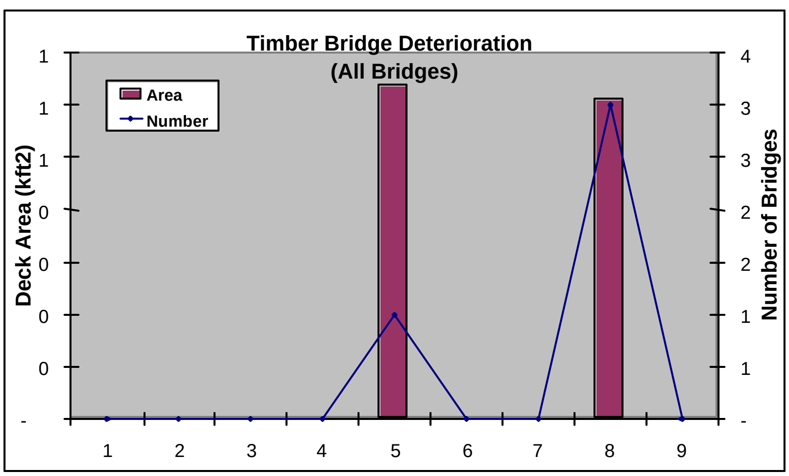

Figure A. 108
The timber substructure deterioration with original rating of 9

LIST OF FIGURES FOR APPENDIX B

LIST OF TABLES FOR APPENDIX B

APPENDIX B: PONTIS SETTINGS

The original PONTIS Working Database was chosen as the basic DB for the study. The Louisiana NBI database of year 2002 was used for data import. The procedure is described as below.

(1) Import bridge data

Change the default value of "strunitkey" in the table of *DATADICT* generated by Sybase/InfoMaker, which is the database software provided by PONTIS, to "*/101/*". Import the parameters of districts and county information at the *Configuration Parameter and Import* windows shown in Figure B1. Import NBI file in year 2002 from the Import window of Gateway module shown in Figure B2.

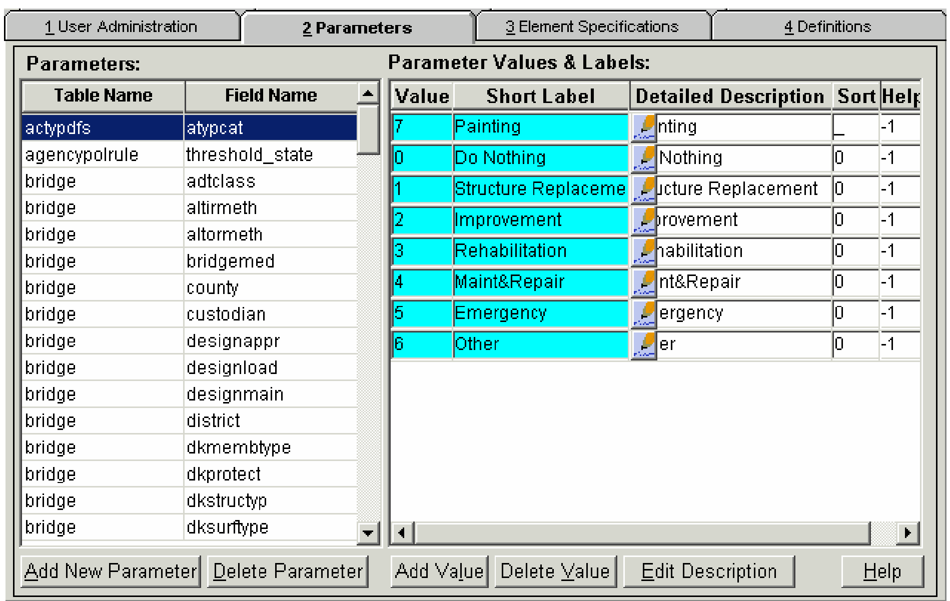

Figure B. 1
The PONTIS Configuration Parameter Window

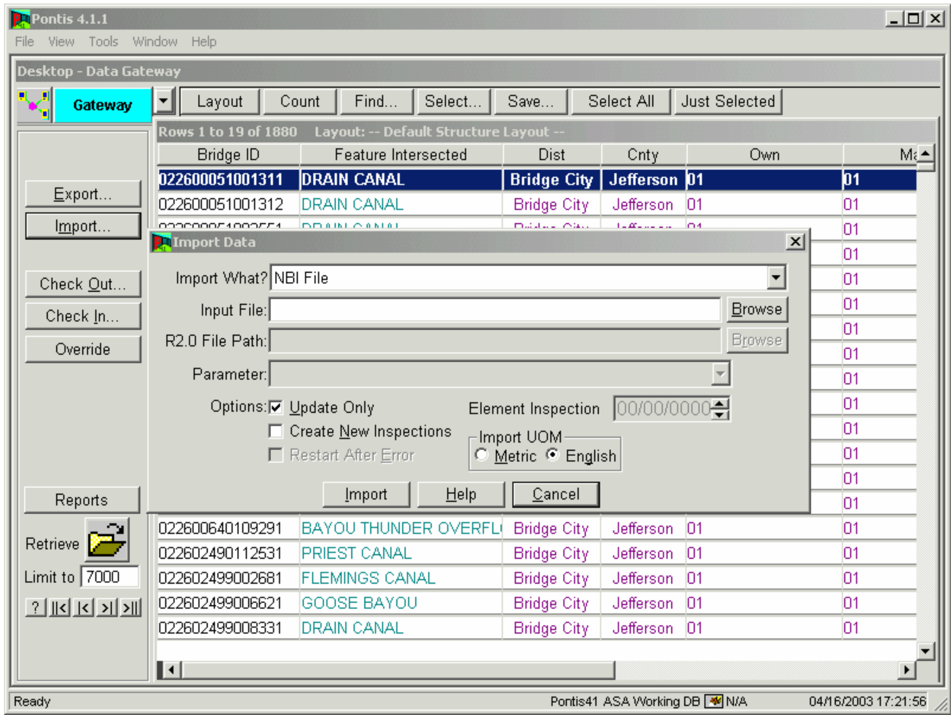

Figure B. 2
The PONTIS Gateway Module

(2) Import element data

Create twelve elements defined in Table B1 from the Configuration Element window (See Figure B.3).

Table B. 1
PONTIS Code Definition for NBI Elements

Group	Deck	Superstructure	Substructure	Culvert
Reinforced Concrete	364	365	366	367
Steel	368	369	370	371
Priestess Concrete	372	373	374	375
Timber	376	377	378	379

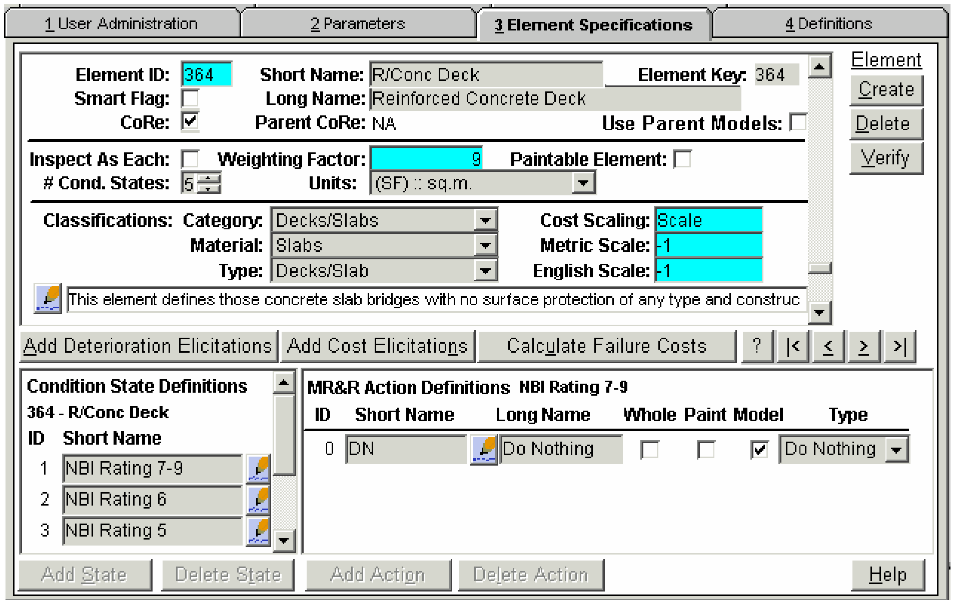

Figure B. 3
The PONTIS Element Specifications Window

Import element data from the Import window (?).

(3) Change parameters

From the *Configuration Element* window, set value of “weight” to 9, 10, and 15 to deck, superstructure, and substructure separately, “coreflag” to 1, “useparmdls” to 0, “paintflag” to 0, and “eachflag” to 0. Define actions for each condition state as in Table B2 with the default actions from PONTIS.

Table B. 2
The Action Plan in PONTIS

atypenum	atypeshort	atypelong	action plan
00	Do Nothing	Do Nothing	Do Nothing
11	Replace	Replace Structure	Replace Structure
21	Widen	Widen Structure	Functional Actions
22	Raise	Raise Structure	
23	Strengthen	Strengthen Structure	
31	Repl Elem	Replace Element	Replace Element
40	Pr Maint	Routine/Preventative	Major Maintenance
41	Min Repair	Element Repair	Minor Maintenance

Import the deterioration and cost models generated before in the *Preservation* module and calculate the failure cost as shown in Figures B4 and B5. Table B3 represents the parameter values changed for the Scenario Module.

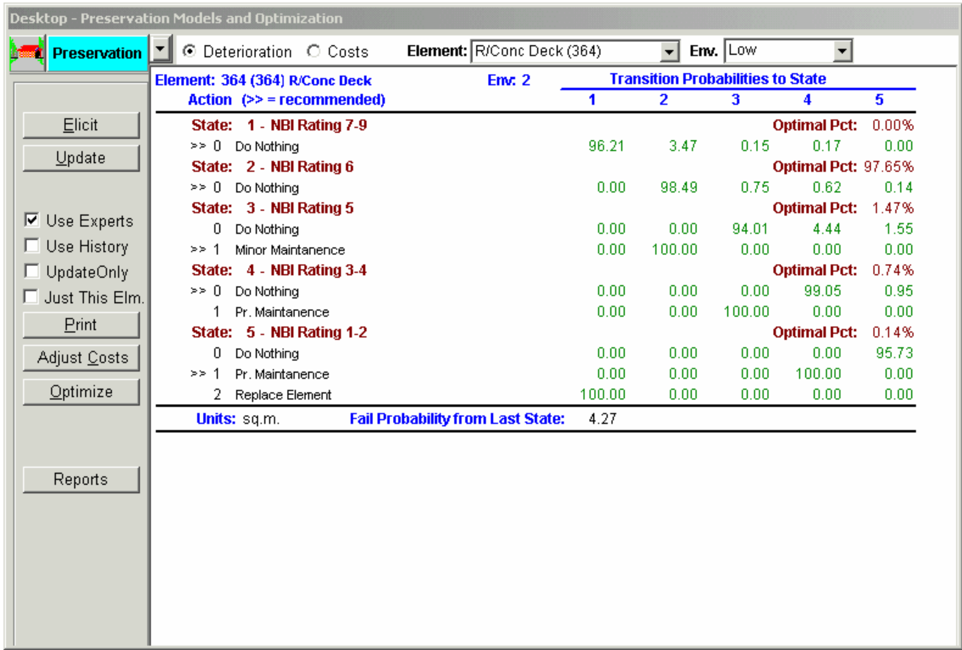

Figure B. 4
The PONTIS Preservation Module

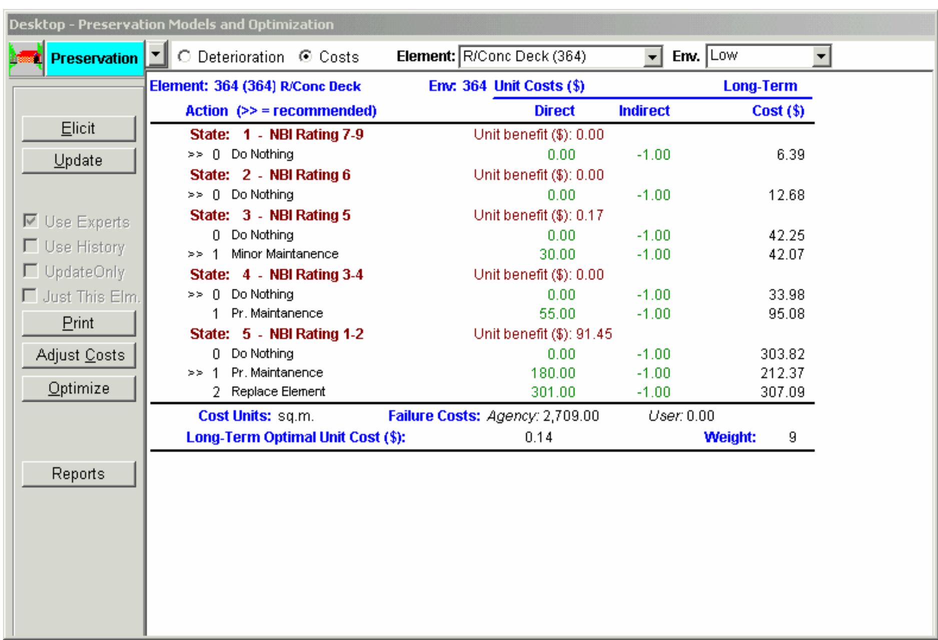

Figure B. 5
The PONTIS Costs Window of Preservation Module

Table B. 3
The Scenario Parameters Changed

scparam	value	scparamname	scparamdescr
BF	YES	Store bridge-level measure	YES to store bridge-level perf measures
DY	0	Deferment years	Min years between projects rec by PONTIS
F1	NO	Optimal projects only	YES to include only alts w/ greatest ben
F2	NO	Opt & user projects only	YES to inc user proj plus alt w/ max ben
HZ	30	Planning horizon	Length of simulation in years
PE	YES	Store future elem cond	YES to store future element conditions
PG	1	Percentage granularity	Granularity of percentage for NBI
RR	.05	Replacement B/C crit	Min B/C ratio for considering repl
Y1	2003	First simulation year	First simulation year
Y2	2003	First project year	First project year
Z1	5	Min super for improve	Improve infeas for lower super rating
Z2	5	Min sub for improve	Improve infeas for lower sub rating

(4) Enter the simulation rules:

A variety of simulation rules have been established in PONTIS to fine-tune the simulation steps to match with an agency practice for structure project development, and to improve the quality of the system's recommendations for bridge-level work. The ability to define these rules addresses the fact that while the system approach to determining preservation and improvement needs preservation optimization models is sufficient for addressing network-level needs, more careful consideration of a range of detailed factors is needed for making realistic bridge-level recommendations. (Cambridge Systematics, Inc., 2001)

Five different sets of simulation rules may be defined in PONTIS to control the behavior of the program simulation.

Scoping Rules allow you to ensure that when the preservation optimization model recommends a particular type of work, which related work is scheduled at the same time. Scoping rules help address issues created by the fact that the preservation optimization model considers each element independently of the others. (See Figure B.6)

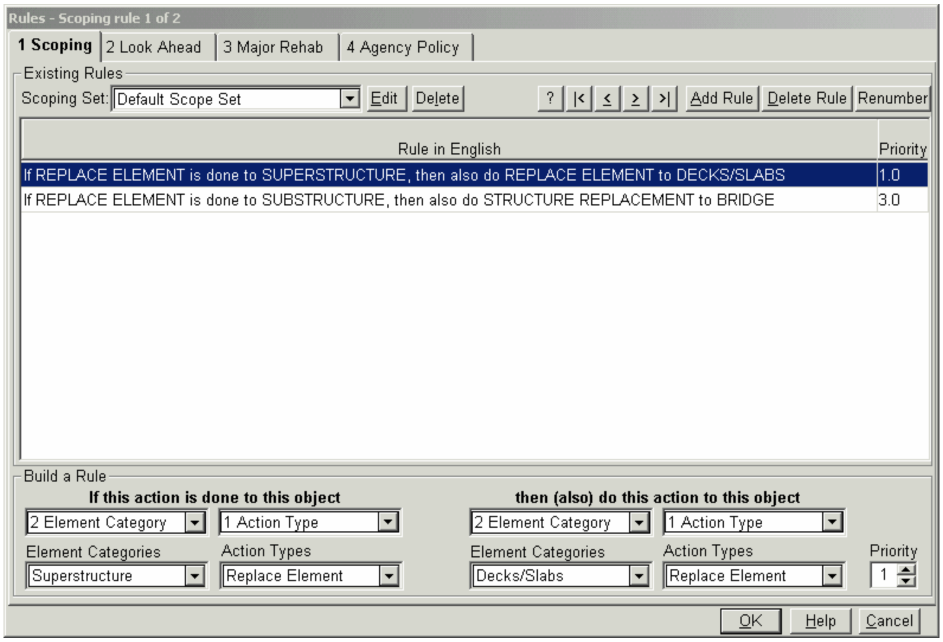

Figure B. 6
The PONTIS Scoping Rules

Look Ahead Rules allow you to control the timing of work so that if a major rehab or replacement is programmed within the timeframe of the simulation, minor maintenance or repair work will not be scheduled for a specified number of years prior to the major project. Look Ahead Rules help PONTIS make the best use of previously defined project data when performing a program simulation. (See Figure B.7)

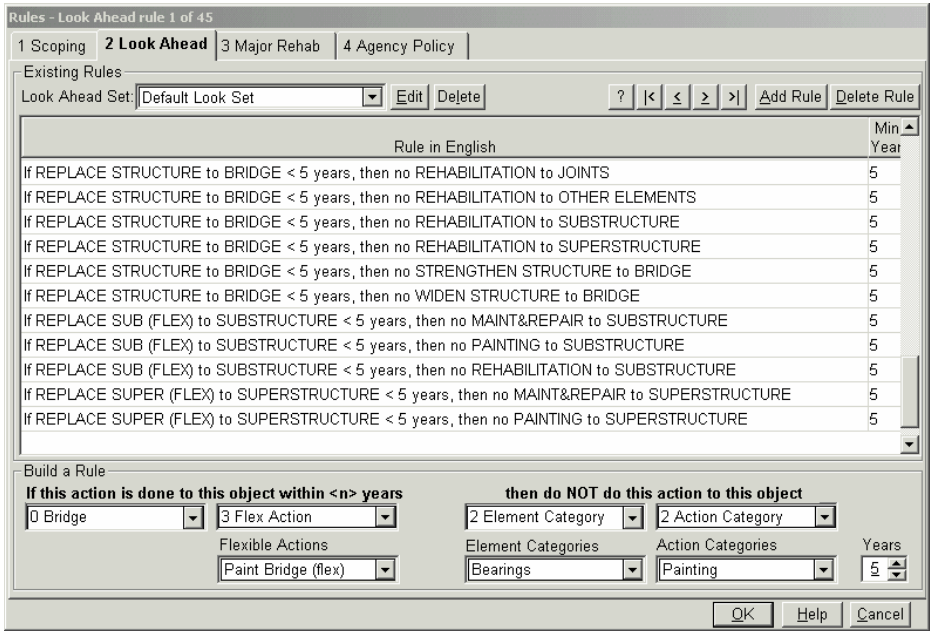

Figure B. 7
The PONTIS Look Ahead Rules

<u>Major Rehab Rules</u> allow you to force the simulation to schedule a major rehabilitation or replacement project based on the condition of the structure, or based on the cost of recommended work. Major rehab rules help account for the fact that performing a single rehabilitation or replacement project on a structure may be more cost effective than a series of smaller projects over time, once all relevant factors are considered. (See Figure B.8)

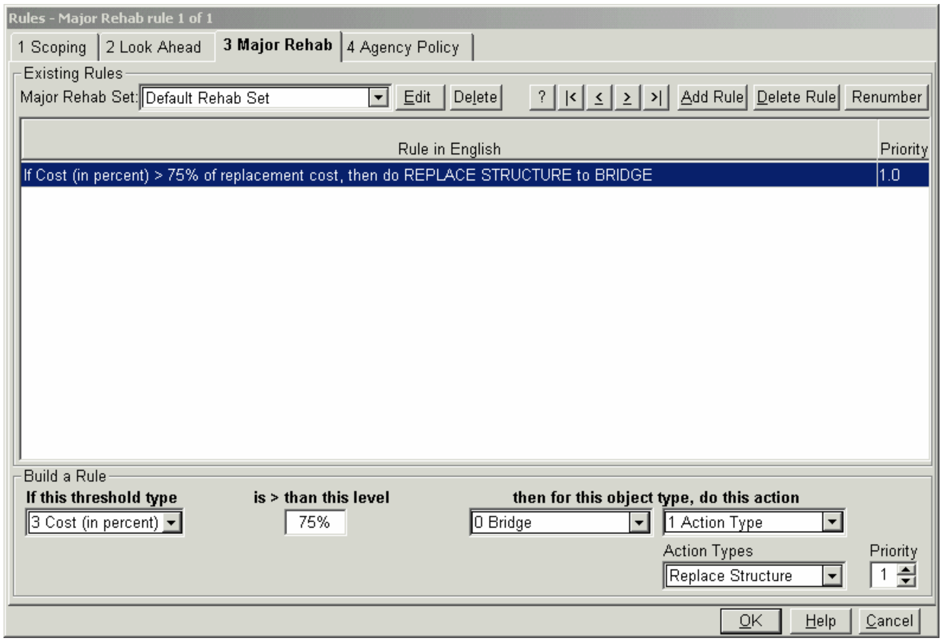

Figure B. 8
The PONTIS Major Rehabilitation Rules

Agency Policy Rules allow you to define detailed decision rules for what actions to schedule for specific elements, based on their condition, or on the condition of other elements or smart flags. These rules provide an extremely powerful tool more specifying agency policy and for modeling interactions between elements, as well as other factors.

Paint Rules allow you to set condition thresholds, below which a structure must be painted. The Agency Policy Rules and Paint Rules were not considered in the study.

After the modification of the scenario parameters described above, the next step is to input the annual budget in the Programming Module for each Scenario.

LIST OF TABLES FOR APPENDIX C

APPENDIX C. THE PRESERVATION MODEL DETAILS

The tables given in this appendix are direct printout of PONTIS. The double point-right arrow indicates the recommended action by the optimization model if more than one action is offered for a given condition state.

Table C. 1
The deterioration Model of Concrete Deck

LA DOTD

Bureau of Bridges and Structures
Bridge Maintenance

Preservation Model Details

Element (Environment): 364 (2)

Reinforced Concrete Deck (Low)

Long-Term Optimal Unit Cost($): 0.21
Failure Probability (%): 4.27

Element Failure Unit Costs($)
Agency Cost: 2,709.00
User Cost: 0.00

Metric Units: sq.m.
English Units: (SF)

Action (>> = recommended)	Direct Unit Cost($)	Transition Probabilities (%) 1	2	3	4	5	Long-Term Cost($)
State: 1 NBI Rating 7-9	Optimal Percent in State:			10.96	Unit Benefit:		0.00
>> 0 Do Nothing	0.00	96.21	3.47	0.15	0.17	0.00	6.39
State: 2 NBI Rating 6	Optimal Percent in State:			52.19	Unit Benefit:		0.00
>> 0 Do Nothing	0.00	0.00	98.49	0.75	0.62	0.14	12.68
State: 3 NBI Rating 5	Optimal Percent in State:			0.41	Unit Benefit:		0.17
0 Do Nothing	0.00	0.00	0.00	94.01	4.44	1.55	42.25
>> 1 Minor Maintanence	30.00	0.00	100.00	0.00	0.00	0.00	42.07
State: 4 NBI Rating 3-4	Optimal Percent in State:			36.02	Unit Benefit:		0.00
>> 0 Do Nothing	0.00	0.00	0.00	0.00	99.05	0.95	33.98
1 Pr. Maintanence	180.00	0.00	0.00	100.00	0.00	0.00	220.08
State: 5 NBI Rating 1-2	Optimal Percent in State:			0.42	Unit Benefit:		91.45
0 Do Nothing	0.00	0.00	0.00	0.00	0.00	95.73	303.82
>> 1 Pr. Maintanence	180.00	0.00	0.00	0.00	100.00	0.00	212.37
2 Replace Element	301.00	100.00	0.00	0.00	0.00	0.00	307.09

Table C. 2
The deterioration Model of Concrete Superstructure

LA DOTD

Bureau of Bridges and Structures
Bridge Maintenance

Preservation Model Details

Element (Environment): 365 (2)

Reinforced Concrete Superstructure (Low)

Long-Term Optimal Unit Cost($): 0.53
Failure Probability (%): 9.86

Element Failure Unit Costs($)
Agency Cost: 6,890.00
User Cost: 0.00

Metric Units: m.
English Units: (LF)

Action (>> = recommended)	Direct Unit Cost($)	Transition Probabilities (%) 1	2	3	4	5	Long-Term Cost($)
State: 1 NBI Rating 7-9	Optimal Percent in State:			0.00	Unit Benefit:		0.00
>> 0 Do Nothing	0.00	95.76	4.01	0.16	0.07		27.85
State: 2 NBI Rating 6	Optimal Percent in State:			98.56	Unit Benefit:		0.00
>> 0 Do Nothing	0.00	0.00	98.99	0.56	0.45		50.26
State: 3 NBI Rating 5	Optimal Percent in State:			1.00	Unit Benefit:		26.23
0 Do Nothing	0.00	0.00	0.00	91.81	8.19		143.10
>> 1 Minor Maintanence	69.00	0.00	100.00	0.00	0.00		116.87
State: 4 NBI Rating 1-4	Optimal Percent in State:			0.44	Unit Benefit:		572.94
0 Do Nothing	0.00	0.00	0.00	0.00	90.14		1,097.26
>> 1 Pr. Maintanence	413.00	0.00	0.00	100.00	0.00		524.32
2 Replace Element	689.00	100.00	0.00	0.00	0.00		715.52

Table C. 3
The deterioration Model of Concrete Substructure

LA DOTD — *Bureau of Bridges and Structures*
Bridge Maintenance

Preservation Model Details

Element (Environment): 366 (2)

Reinforced Concrete Substructure (Low)

Long-Term Optimal Unit Cost($): 14.46
Failure Probability (%): 15.64

Element Failure Unit Costs($)
Agency Cost: 180,000.00
User Cost: 0.00

Metric Units: ea.
English Units: (EA)

Action (>> = recommended)		Direct Unit Cost($)	Transition Probabilities (%) 1	2	3	4	5	Long-Term Cost($)
State: 1 NBI Rating 7-9		Optimal Percent in State:			0.00	Unit Benefit:		0.00
>> 0	Do Nothing	0.00	97.98	1.52	0.18	0.32		799.83
State: 2 NBI Rating 6		Optimal Percent in State:			97.49	Unit Benefit:		0.00
>> 0	Do Nothing	0.00	0.00	98.09	1.25	0.66		1,371.79
State: 3 NBI Rating 5		Optimal Percent in State:			1.86	Unit Benefit:		404.32
0	Do Nothing	0.00	0.00	0.00	92.24	7.76		2,910.95
>> 1	Minor Maintanence	1,200.00	0.00	100.00	0.00	0.00		2,506.63
State: 4 NBI Rating 1-4		Optimal Percent in State:			0.64	Unit Benefit		24,931.10
0	Do Nothing	0.00	0.00	0.00	0.00	84.36		34,518.67
>> 1	Pr. Maintanence	7,200.00	0.00	0.00	100.00	0.00		9,587.57
2	Replace Element	12,000.00	100.00	0.00	0.00	0.00		12,761.84

Table C. 4
The deterioration Model of Steel Deck

LA DOTD

Bureau of Bridges and Structures
Bridge Maintenance

Preservation Model Details

Element (Environment): 368 (2)

Steel Deck (Low)

Long-Term Optimal Unit Cost($): 0.24
Failure Probability (%): 3.98

Element Failure Unit Costs($)
Agency Cost: 2,709.00
User Cost: 0.00

Metric Units: sq.m.
English Units: (SF)

Action (>> = recommended)		Direct Unit Cost($)	Transition Probabilities (%) 1	2	3	4	5	Long-Term Cost($)
State: 1 NBI Rating 7-9		Optimal Percent in State:			11.78		Unit Benefit:	0.00
>> 0	Do Nothing	0.00	96.35	2.35	1.00	0.30	0.00	10.80
State: 2 NBI Rating 6		Optimal Percent in State:			74.47		Unit Benefit:	0.00
>> 0	Do Nothing	0.00	0.00	98.73	0.74	0.26	0.27	17.08
State: 3 NBI Rating 5		Optimal Percent in State:			0.67		Unit Benefit:	0.00
>> 0	Do Nothing	0.00	0.00	0.00	95.25	4.61	0.14	33.88
1	Minor Maintanence	30.00	0.00	100.00	0.00	0.00	0.00	46.27
State: 4 NBI Rating 3-4		Optimal Percent in State:			12.65		Unit Benefit:	0.00
>> 0	Do Nothing	0.00	0.00	0.00	0.00	98.19	1.81	64.22
1	Pr. Maintanence	180.00	0.00	0.00	100.00	0.00	0.00	212.27
State: 5 NBI Rating 1-2		Optimal Percent in State:			0.43		Unit Benefit:	82.10
0	Do Nothing	0.00	0.00	0.00	0.00	0.00	96.02	323.27
>> 1	Pr. Maintanence	180.00	0.00	0.00	0.00	100.00	0.00	241.17
2	Replace Element	301.00	100.00	0.00	0.00	0.00	0.00	311.29

Table C. 5
The deterioration Model of Steel Superstructure

LA DOTD *Bureau of Bridges and Structures*
Bridge Maintenance

Preservation Model Details

Element (Environment): 369 (2)

Steel Superstructure (Low)

Long-Term Optimal Unit Cost($):	0.91
Failure Probability (%):	12.85
Element Failure Unit Costs($)	
Agency Cost:	6,890.00
User Cost:	0.00

Metric Units: m.
English Units: (LF)

Action (>> = recommended)		Direct Unit Cost($)	Transition Probabilities (%) 1	2	3	4	5	Long-Term Cost($)
State: 1 NBI Rating 7-9		Optimal Percent in State:			29.37		Unit Benefit:	0.00
>> 0	Do Nothing	0.00	98.32	1.31	0.12	0.25		44.81
State: 2 NBI Rating 6		Optimal Percent in State:			67.73		Unit Benefit:	0.00
>> 0	Do Nothing	0.00	0.00	95.87	3.51	0.62		103.43
State: 3 NBI Rating 5		Optimal Percent in State:			2.41		Unit Benefit:	2.73
0	Do Nothing	0.00	0.00	0.00	97.23	2.77		170.25
>> 1	Minor Maintanence	69.00	0.00	100.00	0.00	0.00		167.52
State: 4 NBI Rating 1-4		Optimal Percent in State:			0.49		Unit Benefit:	746.03
0	Do Nothing	0.00	0.00	0.00	0.00	87.15		1,318.60
>> 1	Pr. Maintanence	413.00	0.00	0.00	100.00	0.00		572.56
2	Replace Element	689.00	100.00	0.00	0.00	0.00		731.68

Table C. 6
The deterioration Model of Steel Substructure

LA DOTD

Bureau of Bridges and Structures
Bridge Maintenance

Preservation Model Details

Element (Environment): 370 (2)

Steel Substructure (Low)

Long-Term Optimal Unit Cost($): 11.87
Failure Probability (%): 11.78

Element Failure Unit Costs($)
Agency Cost: 180,000.00
User Cost: 0.00

Metric Units: ea.
English Units: (EA)

Action (>> = recommended)		Direct Unit Cost($)	Transition Probabilities (%) 1	2	3	4	5	Long-Term Cost($)
State: 1 NBI Rating 7-9		Optimal Percent in State:			48.66	Unit Benefit:		0.00
>> 0	Do Nothing	0.00	98.98	0.95	0.03	0.04		372.81
State: 2 NBI Rating 6		Optimal Percent in State:			50.19	Unit Benefit:		0.00
>> 0	Do Nothing	0.00	0.00	97.77	1.28	0.95		1,842.34
State: 3 NBI Rating 5		Optimal Percent in State:			0.66	Unit Benefit:		269.16
0	Do Nothing	0.00	0.00	0.00	93.91	6.09		3,223.98
>> 1	Minor Maintanence	1,200.00	0.00	100.00	0.00	0.00		2,954.83
State: 4 NBI Rating 1-4		Optimal Percent in State:			0.50	Unit Benefit:		18,597.45
0	Do Nothing	0.00	0.00	0.00	0.00	88.22		28,611.93
>> 1	Pr. Maintanence	7,200.00	0.00	0.00	100.00	0.00		10,014.47
2	Replace Element	12,000.00	100.00	0.00	0.00	0.00		12,355.10

Table C. 7
The deterioration Model of Prestressed Concrete Deck

LA DOTD

Bureau of Bridges and Structures
Bridge Maintenance

Preservation Model Details

Element (Environment): 372 (2)

P/S Concrete Deck (Low)

Long-Term Optimal Unit Cost($): 0.04
Failure Probability (%): 4.29

Element Failure Unit Costs($)
Agency Cost: 2,709.00
User Cost: 0.00

Metric Units: sq.m.
English Units: (SF)

Action (>> = recommended)		Direct Unit Cost($)	Transition Probabilities (%) 1	2	3	4	5	Long-Term Cost($)
State: 1 NBI Rating 7-9		Optimal Percent in State:			0.83	Unit Benefit:		0.00
>> 0	Do Nothing	0.00	92.82	6.67	0.51	0.00	0.00	3.55
State: 2 NBI Rating 6		Optimal Percent in State:			98.89	Unit Benefit:		0.00
>> 0	Do Nothing	0.00	0.00	99.78	0.10	0.06	0.06	3.90
State: 3 NBI Rating 5		Optimal Percent in State:			0.16	Unit Benefit:		5.52
0	Do Nothing	0.00	0.00	0.00	92.84	3.70	3.46	39.23
>> 1	Minor Maintanence	30.00	0.00	100.00	0.00	0.00	0.00	33.71
State: 4 NBI Rating 3-4		Optimal Percent in State:			0.06	Unit Benefit:		0.00
>> 0	Do Nothing	0.00	0.00	0.00	0.00	98.53	1.47	52.33
1	Pr. Maintanence	180.00	0.00	0.00	100.00	0.00	0.00	212.11
State: 5 NBI Rating 1-2		Optimal Percent in State:			0.06	Unit Benefit:		90.39
0	Do Nothing	0.00	0.00	0.00	0.00	0.00	95.71	320.23
>> 1	Pr. Maintanence	180.00	0.00	0.00	0.00	100.00	0.00	229.84
2	Replace Element	301.00	100.00	0.00	0.00	0.00	0.00	304.38

Table C. 8
The deterioration Model of Prestressed Concrete Superstructure

LA DOTD

Bureau of Bridges and Structures
Bridge Maintenance

Preservation Model Details

Element (Environment): 373 (2)

P/S Concrete Superstructure (Low)

Long-Term Optimal Unit Cost($): 0.38
Failure Probability (%): 50.24

Element Failure Unit Costs($)
Agency Cost: 6,890.00
User Cost: 0.00

Metric Units: m.
English Units: (LF)

Action (>> = recommended)	Direct Unit Cost($)	Transition Probabilities (%) 1	2	3	4	5	Long-Term Cost($)
State: 1 NBI Rating 7-9	Optimal Percent in State:			75.74		Unit Benefit:	0.00
>> 0 Do Nothing	0.00	99.64	0.31	0.05	0.00		8.71
State: 2 NBI Rating 6	Optimal Percent in State:			23.71		Unit Benefit:	0.00
>> 0 Do Nothing	0.00	0.00	97.85	1.00	1.15		120.51
State: 3 NBI Rating 5	Optimal Percent in State:			0.27		Unit Benefit:	10.29
0 Do Nothing	0.00	0.00	0.00	95.06	4.94		194.08
>> 1 Minor Maintanence	69.00	0.00	100.00	0.00	0.00		183.78
State: 4 NBI Rating 1-4	Optimal Percent in State:			0.27		Unit Benefit:	2,987.78
0 Do Nothing	0.00	0.00	0.00	0.00	49.76		3,575.83
>> 1 Pr. Maintanence	413.00	0.00	0.00	100.00	0.00		588.05
2 Replace Element	689.00	100.00	0.00	0.00	0.00		697.29

Table C. 9
The deterioration Model of Prestressed Concrete Substructure

LA DOTD | *Bureau of Bridges and Structures*
Bridge Maintenance

Preservation Model Details

Element (Environment): 374 (2)

P/S Concrete Substructure (Low)

Long-Term Optimal Unit Cost($): 5.40
Failure Probability (%): 53.84

Element Failure Unit Costs($)
Agency Cost: 180,000.00
User Cost: 0.00

Metric Units: ea.
English Units: (EA)

Action		Direct	Transition Probabilities (%)					Long-Term
(>> = recommended)		Unit Cost($)	1	2	3	4	5	Cost($)
State: 1 NBI Rating 7-9		Optimal Percent in State:			0.00		Unit Benefit:	0.00
>> 0	Do Nothing	0.00	97.53	2.47	0.00	0.00		169.72
State: 2 NBI Rating 6		Optimal Percent in State:			99.05		Unit Benefit:	0.00
>> 0	Do Nothing	0.00	0.00	99.28	0.48	0.24		512.39
State: 3 NBI Rating 5		Optimal Percent in State:			0.71		Unit Benefit:	255.51
0	Do Nothing	0.00	0.00	0.00	95.05	4.95		1,943.56
>> 1	Minor Maintanence	1,200.00	0.00	100.00	0.00	0.00		1,688.05
State: 4 NBI Rating 1-4		Optimal Percent in State:			0.24		Unit Benefit	87,373.40
0	Do Nothing	0.00	0.00	0.00	0.00	46.16		96,181.27
>> 1	Pr. Maintanence	7,200.00	0.00	0.00	100.00	0.00		8,807.87
2	Replace Element	12,000.00	100.00	0.00	0.00	0.00		12,161.66

Table C. 10
The deterioration Model of Timber Deck

LA DOTD

Bureau of Bridges and Structures
Bridge Maintenance

Preservation Model Details

Element (Environment): 376 (2)

Timber Deck (Low)

Long-Term Optimal Unit Cost($): 0.45
Failure Probability (%): 3.41

Element Failure Unit Costs($)
Agency Cost: 2,709.00
User Cost: 0.00

Metric Units: sq.m.
English Units: (SF)

Action (>> = recommended)	Direct Unit Cost($)	Transition Probabilities (%) 1	2	3	4	5	Long-Term Cost($)
State: 1 NBI Rating 7-9	Optimal Percent in State:			0.00	Unit Benefit:		0.00
>> 0 Do Nothing	0.00	85.26	11.71	1.88	1.14	0.00	21.56
State: 2 NBI Rating 6	Optimal Percent in State:			0.00	Unit Benefit:		0.00
>> 0 Do Nothing	0.00	0.00	93.05	2.84	4.05	0.06	25.49
State: 3 NBI Rating 5	Optimal Percent in State:			0.00	Unit Benefit:		0.00
>> 0 Do Nothing	0.00	0.00	0.00	88.51	10.42	1.07	41.42
1 Minor Maintanence	30.00	0.00	100.00	0.00	0.00	0.00	54.28
State: 4 NBI Rating 3-4	Optimal Percent in State:			98.81	Unit Benefit:		0.00
>> 0 Do Nothing	0.00	0.00	0.00	0.00	98.80	1.20	42.82
1 Pr. Maintanence	180.00	0.00	0.00	100.00	0.00	0.00	219.45
State: 5 NBI Rating 1-2	Optimal Percent in State:			1.19	Unit Benefit:		70.33
0 Do Nothing	0.00	0.00	0.00	0.00	0.00	96.59	291.12
>> 1 Pr. Maintanence	180.00	0.00	0.00	0.00	100.00	0.00	220.79
2 Replace Element	301.00	100.00	0.00	0.00	0.00	0.00	321.53

Table C. 11
The deterioration Model of Timber Superstructure

LA DOTD

Bureau of Bridges and Structures
Bridge Maintenance

Preservation Model Details

Element (Environment): 377 (2)

Timber Superstructure (Low)

Long-Term Optimal Unit Cost($): 4.26
Failure Probability (%): 3.60

Element Failure Unit Costs($)
Agency Cost: 6,890.00
User Cost: 0.00

Metric Units: m.
English Units: (LF)

Action (>> = recommended)	Direct Unit Cost($)	Transition Probabilities (%) 1	2	3	4	5	Long-Term Cost($)
State: 1 NBI Rating 7-9	Optimal Percent in State:			0.00	Unit Benefit:		0.00
>> 0 Do Nothing	0.00	87.40	8.57	1.38	2.65		361.32
State: 2 NBI Rating 6	Optimal Percent in State:			89.94	Unit Benefit:		0.00
>> 0 Do Nothing	0.00	0.00	93.11	2.59	4.30		406.12
State: 3 NBI Rating 5	Optimal Percent in State:			6.20	Unit Benefit:		14.21
0 Do Nothing	0.00	0.00	0.00	90.38	9.62		470.04
>> 1 Minor Maintanence	69.00	0.00	100.00	0.00	0.00		455.83
State: 4 NBI Rating 1-4	Optimal Percent in State:			3.87	Unit Benefit:		166.97
0 Do Nothing	0.00	0.00	0.00	0.00	96.40		1,014.15
>> 1 Pr. Maintanence	413.00	0.00	0.00	100.00	0.00		847.18
2 Replace Element	689.00	100.00	0.00	0.00	0.00		1,033.16

Table C. 12
The deterioration Model of Timber Substructure

LA DOTD

Bureau of Bridges and Structures
Bridge Maintenance

Preservation Model Details

Element (Environment): 378 (2)

Timber Substructure (Low)

Long-Term Optimal Unit Cost($): 113.69
Failure Probability (%): 1.66

Element Failure Unit Costs($)
Agency Cost: 180,000.00
User Cost: 0.00

Metric Units: ea.
English Units: (EA)

Action (>> = recommended)	Direct Unit Cost($)	Transition Probabilities (%) 1	2	3	4	5	Long-Term Cost($)
State: 1 NBI Rating 7-9	Optimal Percent in State:			0.00	Unit Benefit:		0.00
>> 0 Do Nothing	0.00	84.85	11.03	1.26	2.86		9,259.06
State: 2 NBI Rating 6	Optimal Percent in State:			85.40	Unit Benefit:		0.00
>> 0 Do Nothing	0.00	0.00	90.02	2.86	7.12		10,865.21
State: 3 NBI Rating 5	Optimal Percent in State:			8.52	Unit Benefit:		354.22
0 Do Nothing	0.00	0.00	0.00	85.75	14.25		11,903.33
>> 1 Minor Maintanence	1,200.00	0.00	100.00	0.00	0.00		11,549.11
State: 4 NBI Rating 1-4	Optimal Percent in State:			6.08	Unit Benefit:		1,693.77
0 Do Nothing	0.00	0.00	0.00	0.00	98.34		19,894.29
>> 1 Pr. Maintanence	7,200.00	0.00	0.00	100.00	0.00		18,200.53
2 Replace Element	12,000.00	100.00	0.00	0.00	0.00		20,819.26

LIST OF FIGURES FOR APPENDIX D

APPENDIX D. RESULTS FROM SCENARIOS WITHOUT ANNUAL BUDGET

As listed in Table 32 of the report, there are two scenarios, S-0-1 and S-0-4 under this budget level. This appendix contains the results from these scenarios in the following order:

1. Work vs. Need
2. PONTIS condition ratings (accumulated curves)
    a. Deck
    b. Superstructure
    c. Substructure
3. Sufficient ratings
4. Health index (accumulated)
    a. By number of bridges
    b. By deck areas

Results from S-0-1:

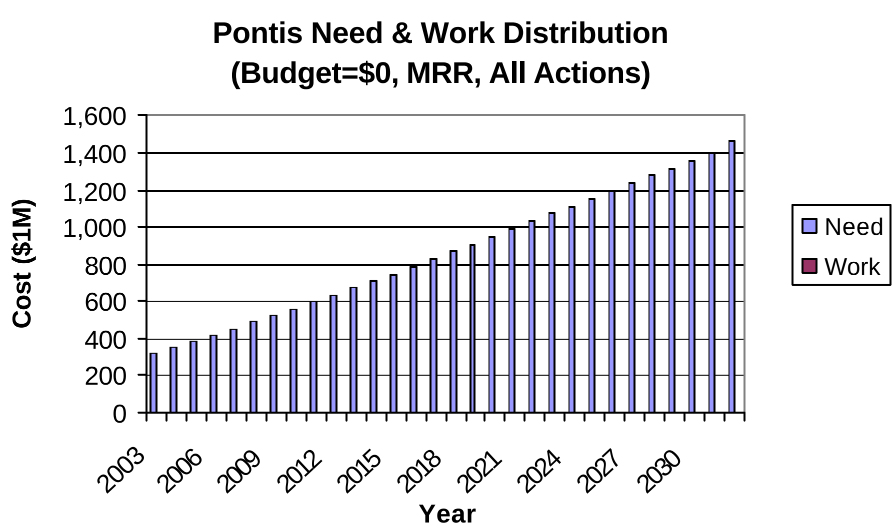

Figure D. 1
PONTIS need and work distribution (Budget = $0, MRR, all actions)

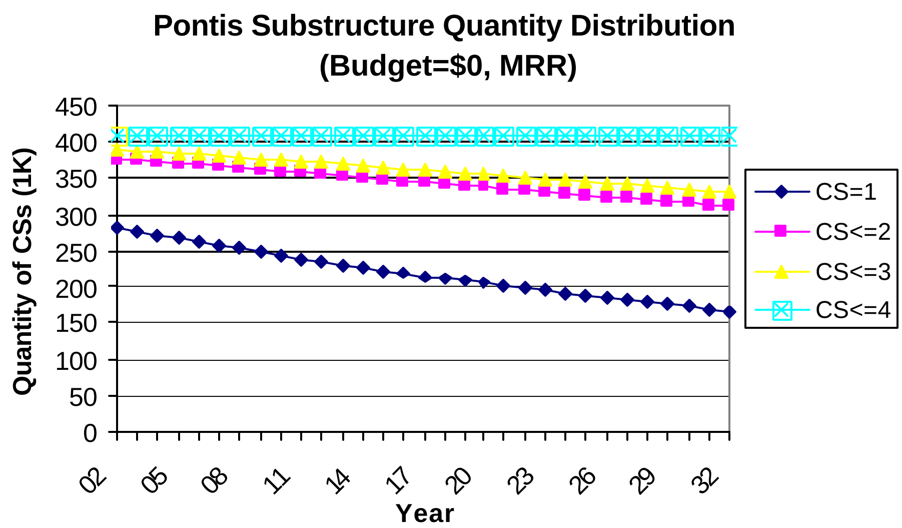

Figure D. 2
PONTIS substructure quantity distribution (Budget = $0, MRR)

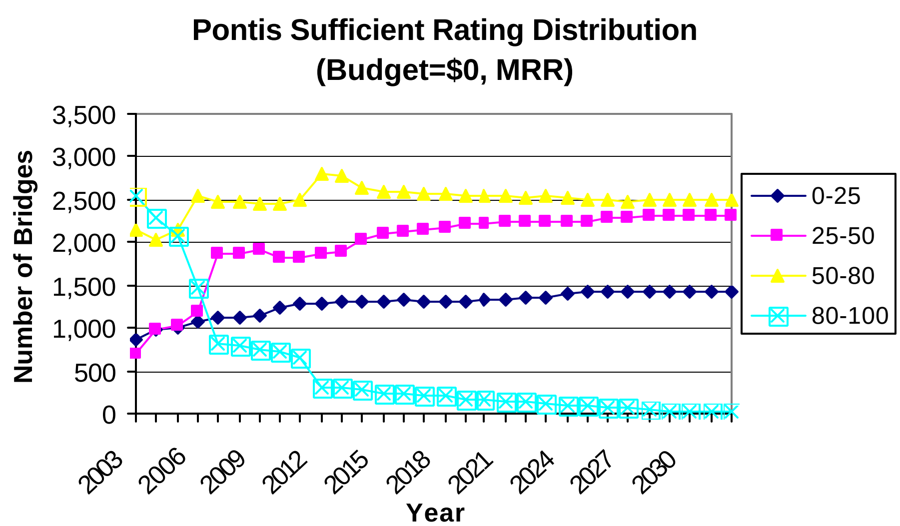

Figure D. 3
PONTIS sufficiency rating distribution (Budget = $0, MRR)

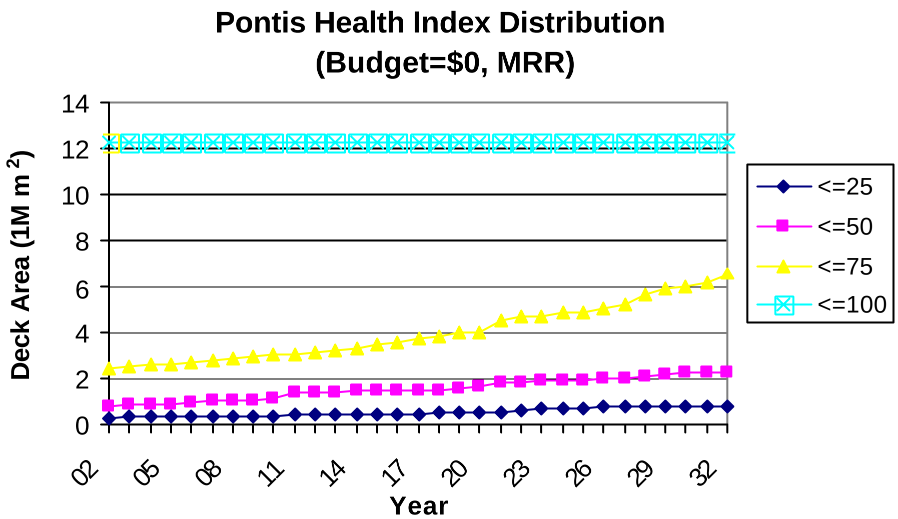

Figure D. 4
PONTIS health index distribution (Budget = $0, MRR)

Results from S-0-4

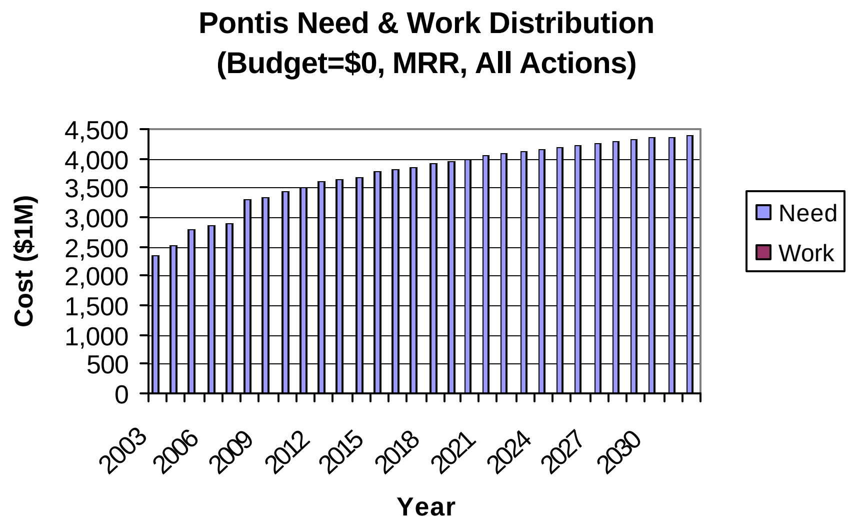

Figure D. 5
PONTIS need & work distribution (Budget =$0, MRR, all actions)

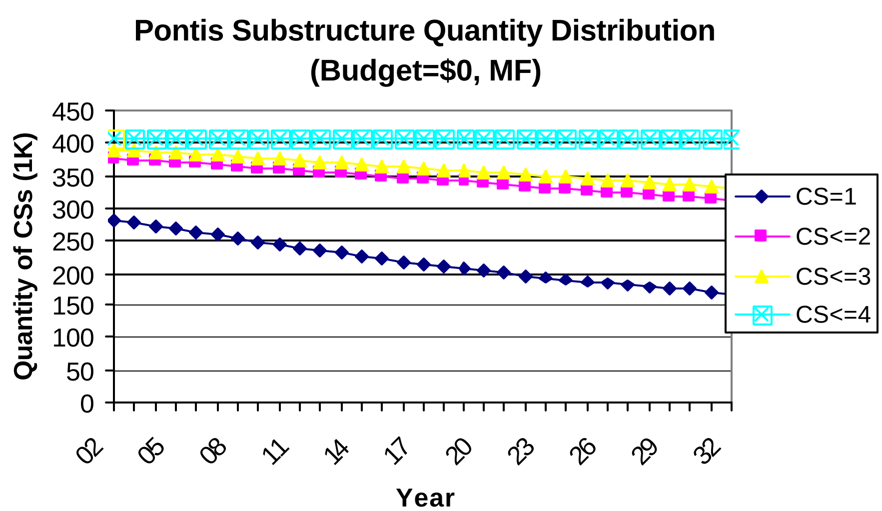

Figure D. 6
PONTIS substructure quantity distribution (Budget = $0, MF)

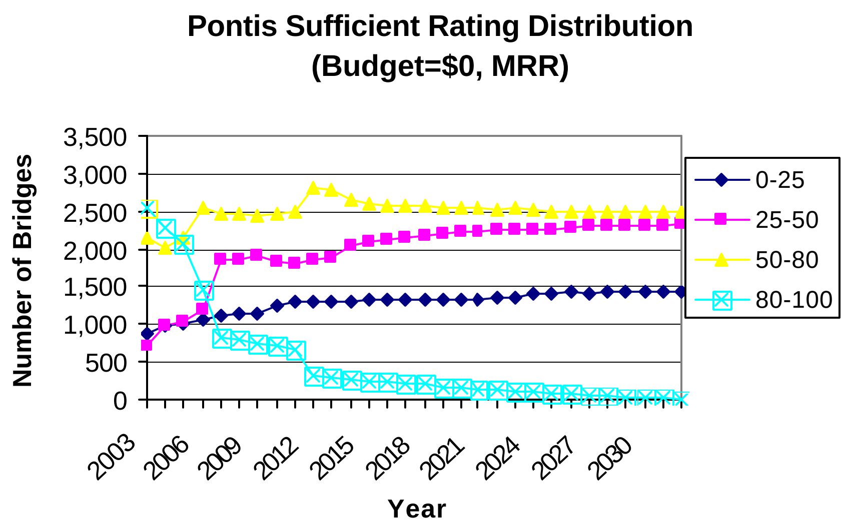

Figure D. 7
PONTIS sufficiency rating distribution (Budget = $0, MRR)

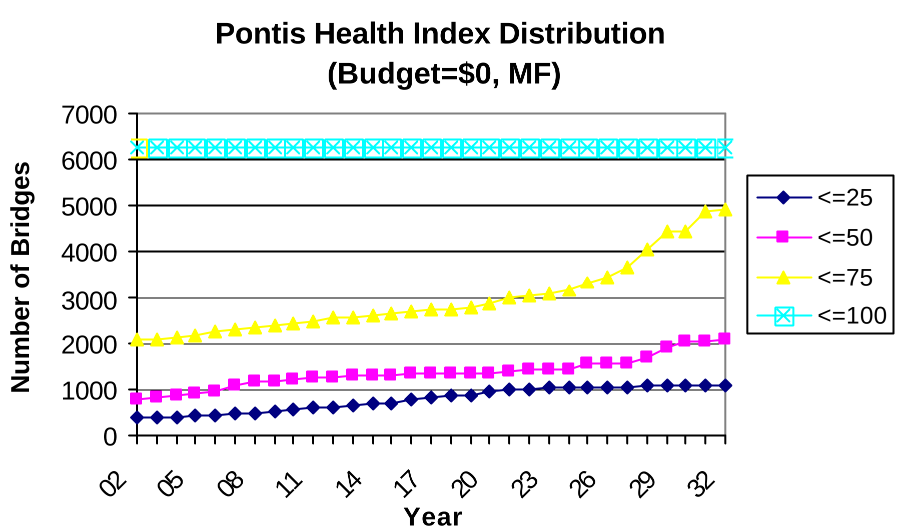

Figure D. 8
PONTIS health index distribution (Budget = $0, MF)

LIST OF FIGURES FOR APPENDIX E

APPENDIX E. RESULTS FROM AN ANNUAL BUDGET OF $70M

As listed in Table 32 of the report, there are four scenarios, S-70-1, S-70-2, S-70-3, and S-70-4, under this budget level. This appendix contains the results from these scenarios in the following order:

1. Work vs. Need
2. PONTIS condition ratings (accumulated curves)
    a. Deck
    b. Superstructure
    c. Substructure
3. Sufficient ratings
4. Health index (accumulated)
    a. By number of bridges
    b. By deck areas

<u>*Results from Scenario S-70-1:*</u>

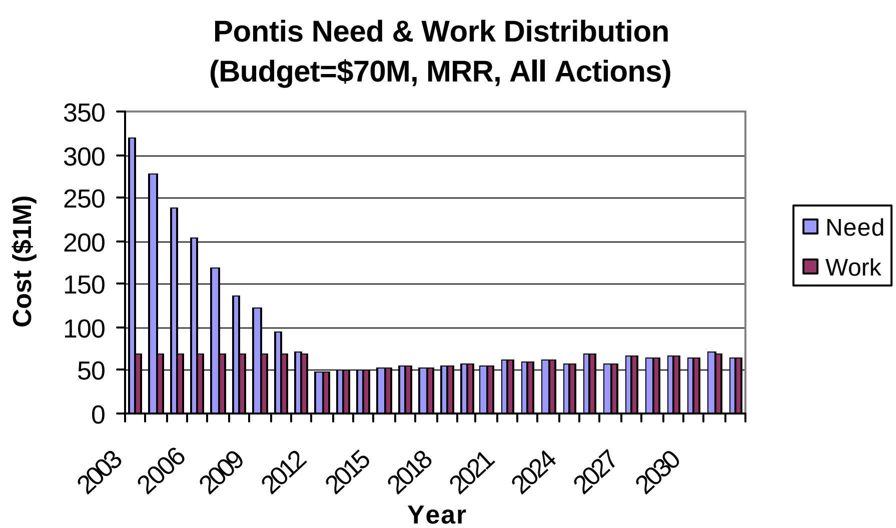

Figure E. 1
PONTIS need & work distribution (Budget = $0, MRR, all actions)

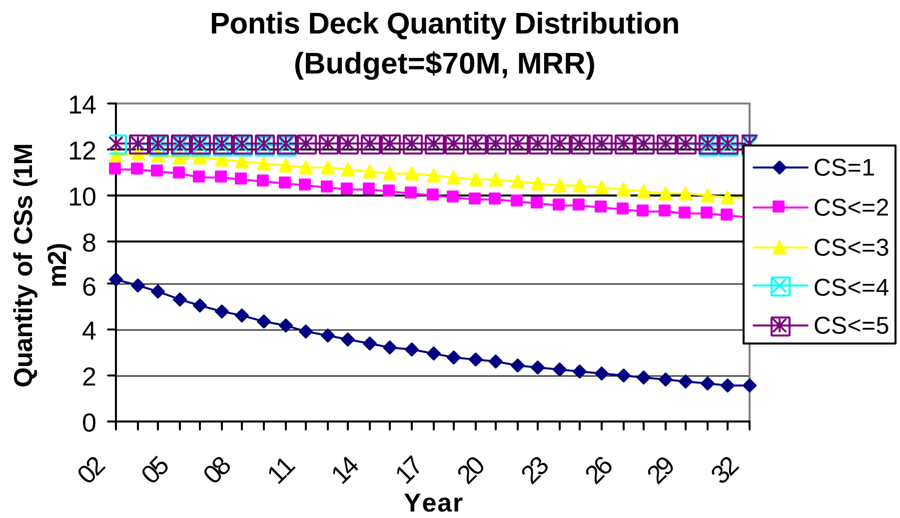

Figure E. 2
PONTIS deck quantity distribution (Budget =$70M, MRR)

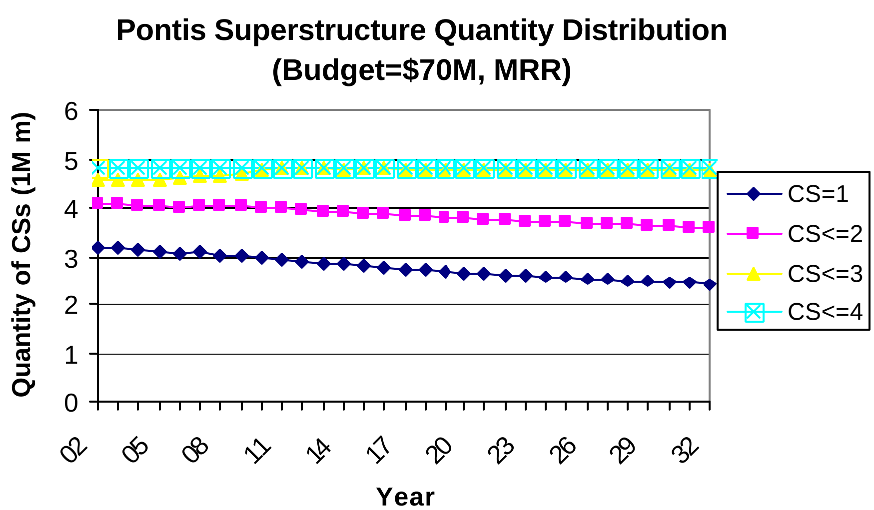

Figure E. 3
PONTIS superstructure quantity distribution (Budget =$70M, MRR)

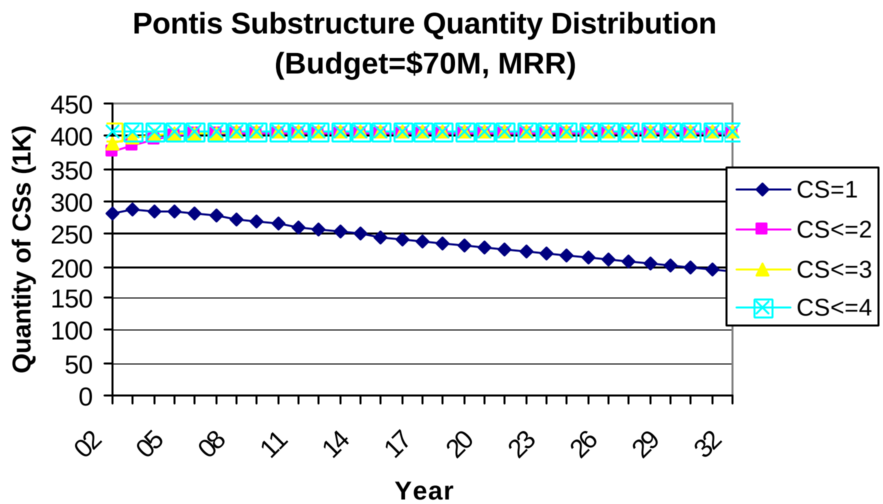

Figure E. 4
PONTIS substructure quantity distribution (Budget = 70M, MRR)

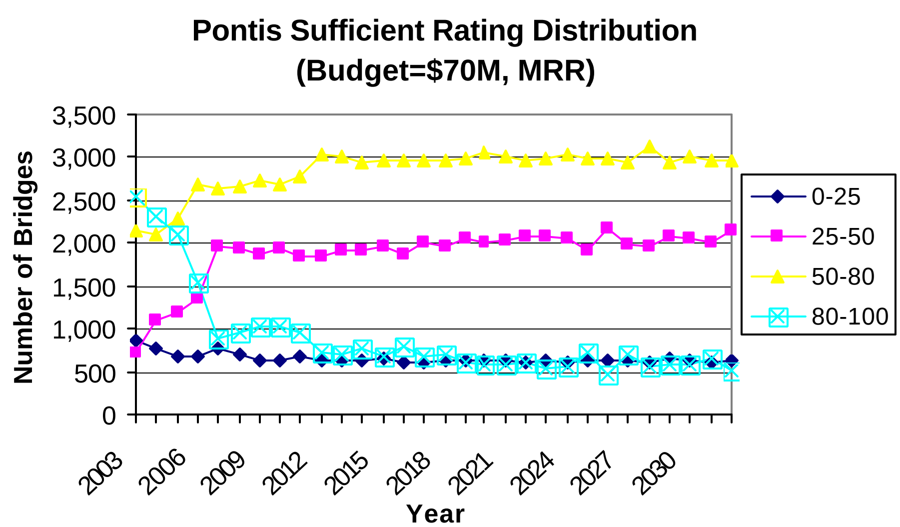

Figure E. 5
PONTIS sufficiency rating distribution (Budget = $70M, MRR)

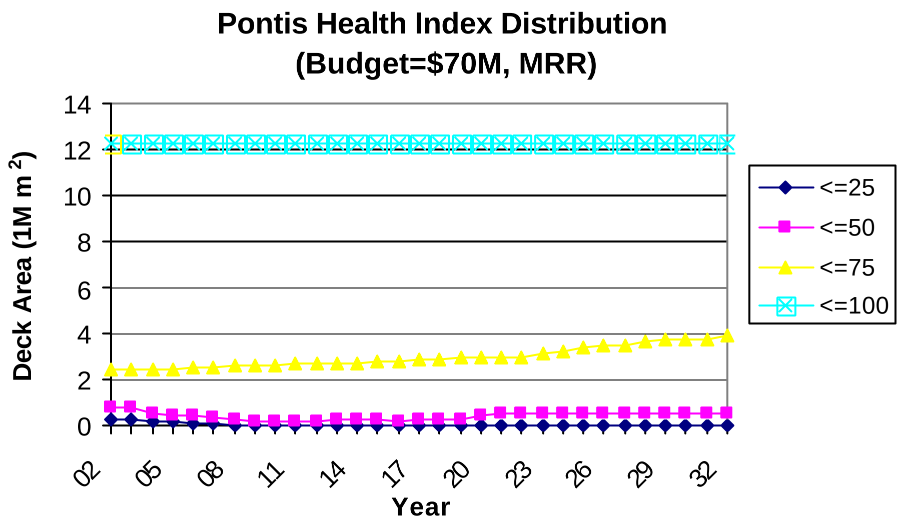

Figure E. 6
PONTIS health index distribution (Budget = $70M, MRR

Results from Scenario S-70-2:

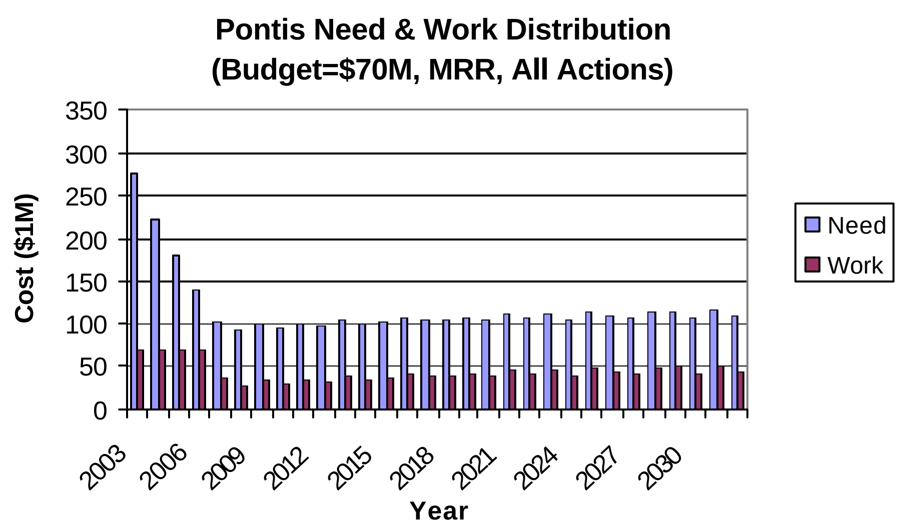

Figure E. 7
PONTIS need & work distribution (Budget = $70M, All Actions)

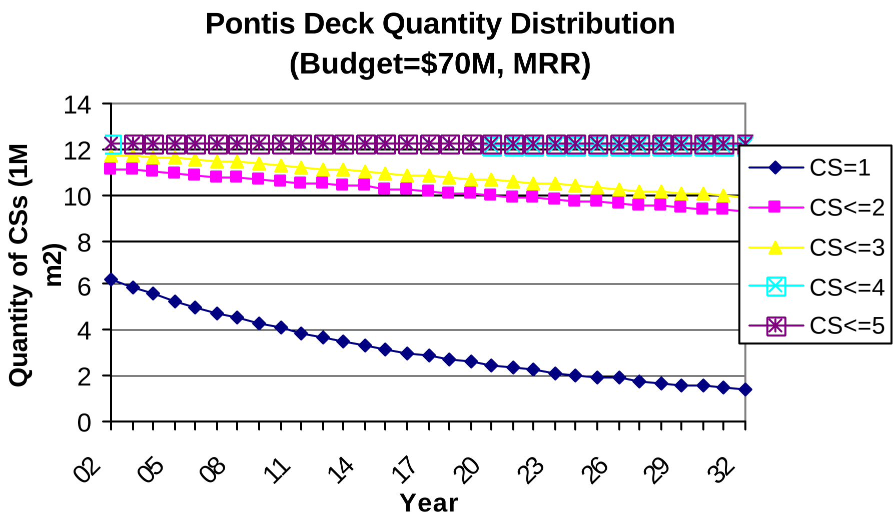

Figure E. 8
PONTIS deck quantity distribution (Budget = $70M, MRR)

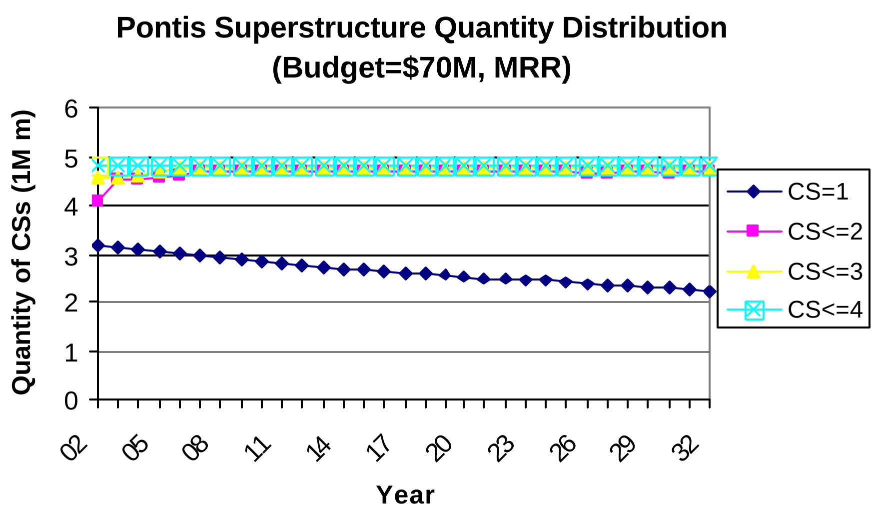

Figure E. 9
PONTIS superstructure quantity distribution (Budget = $70M, MRR)

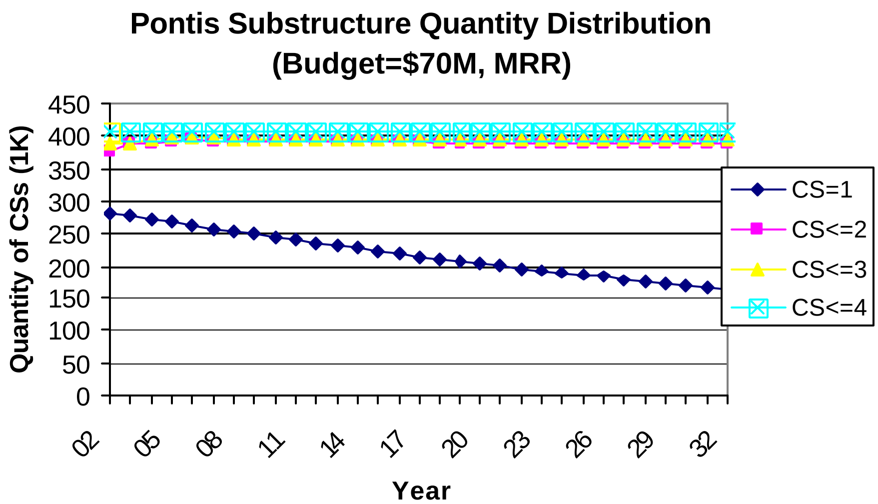

Figure E. 10
PONTIS substructure quantity distribution (Budget = $70M, MRR)

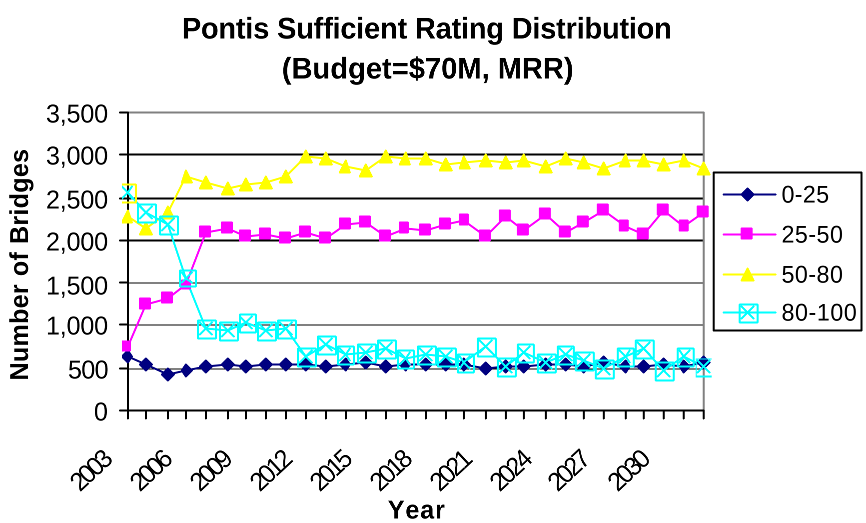

Figure E. 11
PONTIS sufficiency rating distribution (Budget = $70M, MRR)

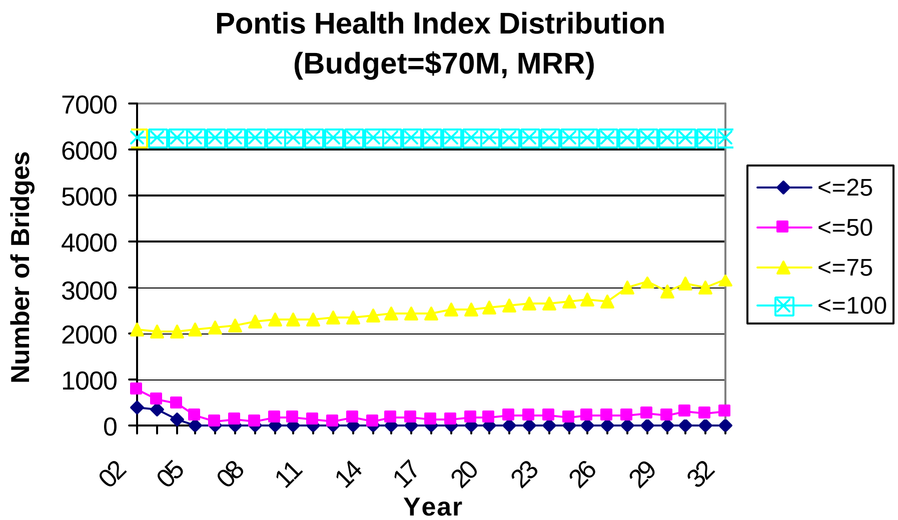

Figure E. 12
PONTIS health index distribution (Budget = $70M, MRR)

Results from Scenario S-70-3:

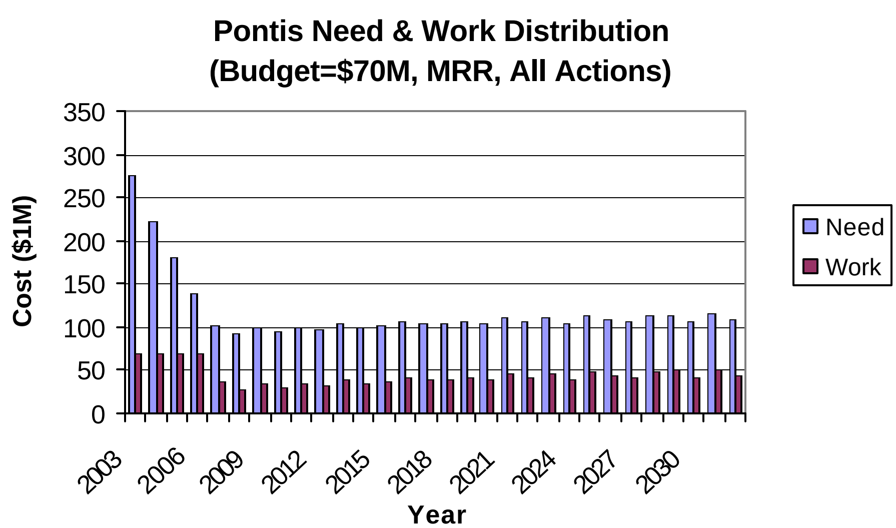

Figure E. 13
PONTIS need and work distribution (Budget = $70M, MRR)

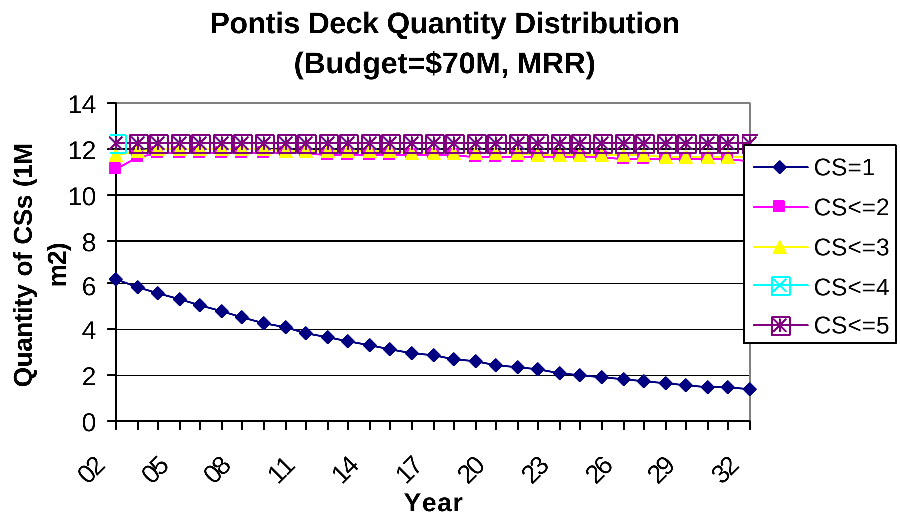

Figure E. 14
PONTIS deck quantity distribution (Budget = $70M, MRR)

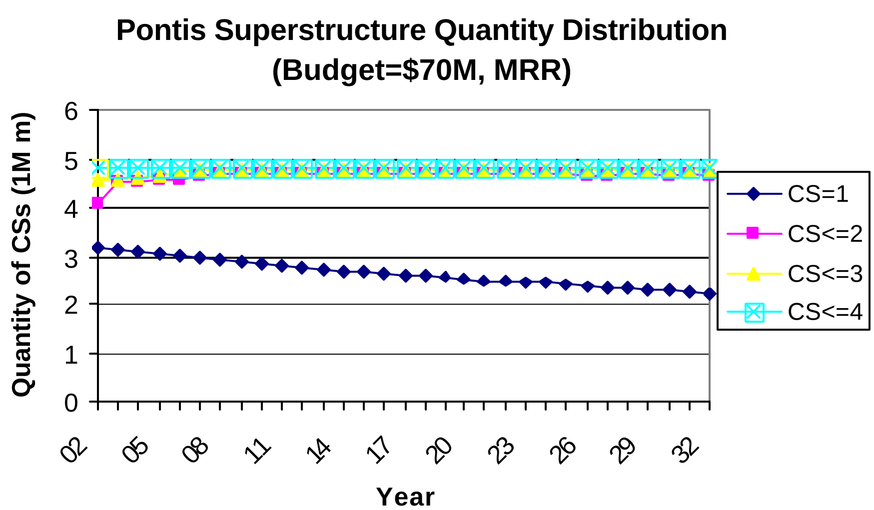

Figure E. 15
PONTIS superstructure quantity distribution (Budget = $70M, MRR)

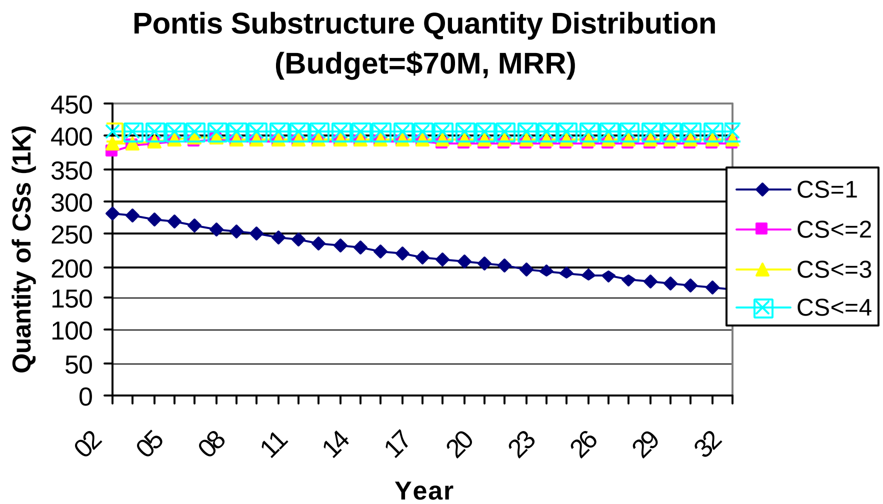

Figure E. 16
PONTIS substructure quantity distribution (Budget = $70M, MRR)

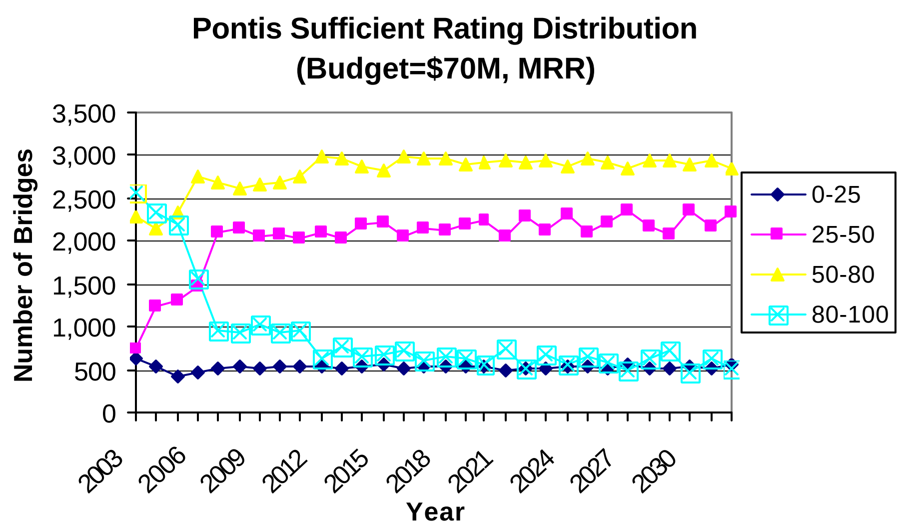

Figure E. 17
PONTIS sufficiency rating distribution (Budget = $70M, MRR)

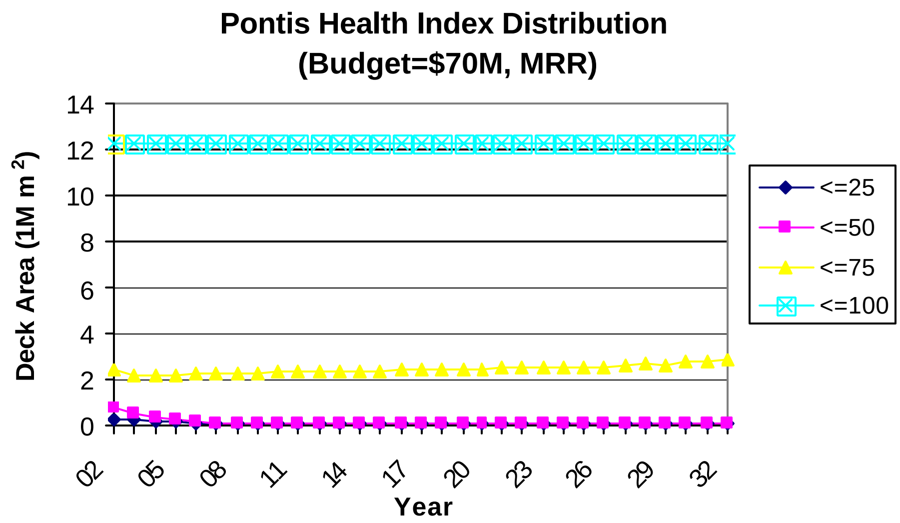

Figure E. 18
PONTIS health index distribution (Budget = $70M, MRR)

<u>*Results from Scenario S-70-4:*</u>

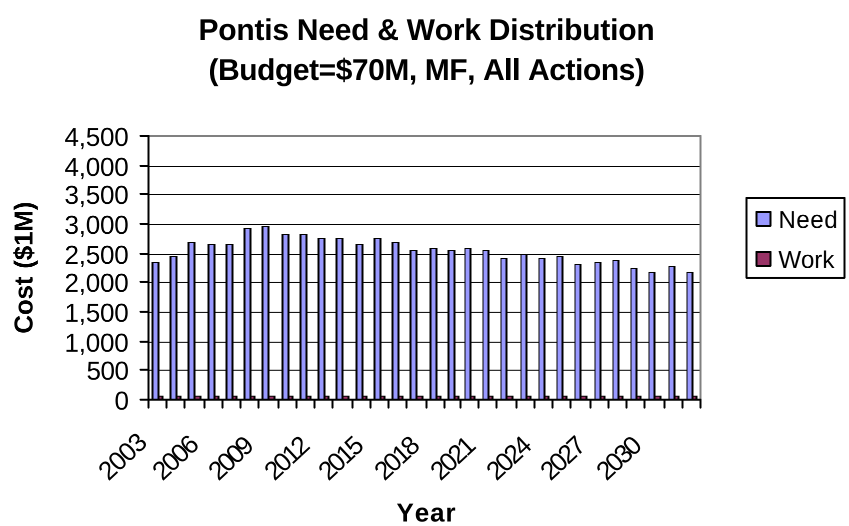

Figure E. 19
PONTIS need & work distribution (Budget = $70M, MF, all actions)

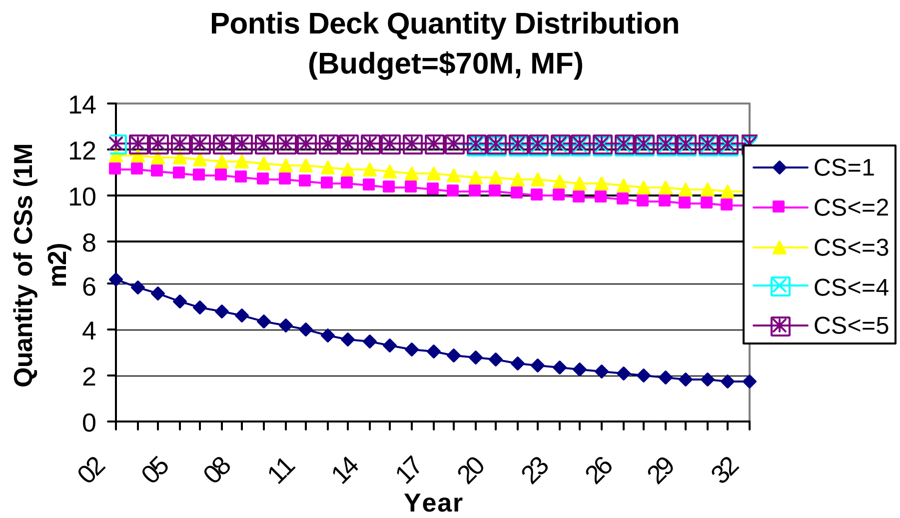

Figure E. 20
PONTIS deck quantity distribution (Budget = $70M, MF)

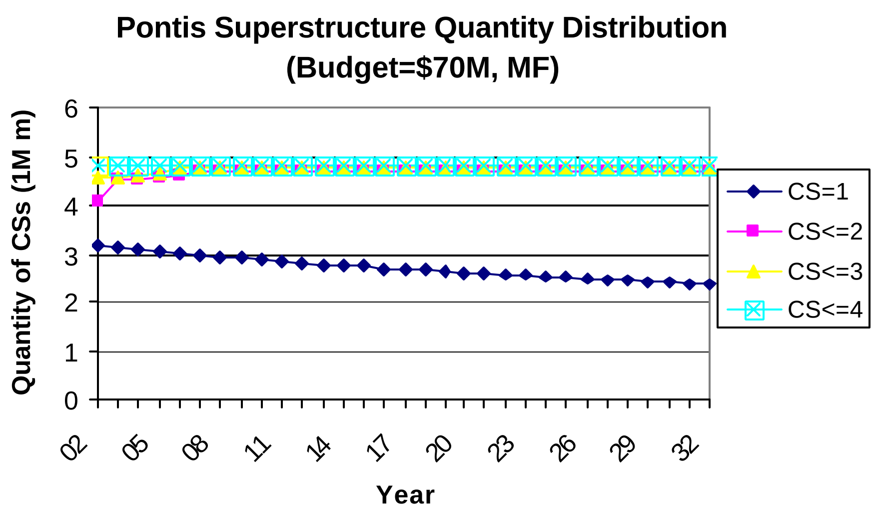

Figure E. 21
PONTIS superstructure quantity distribution (Budget = $70M, MF)

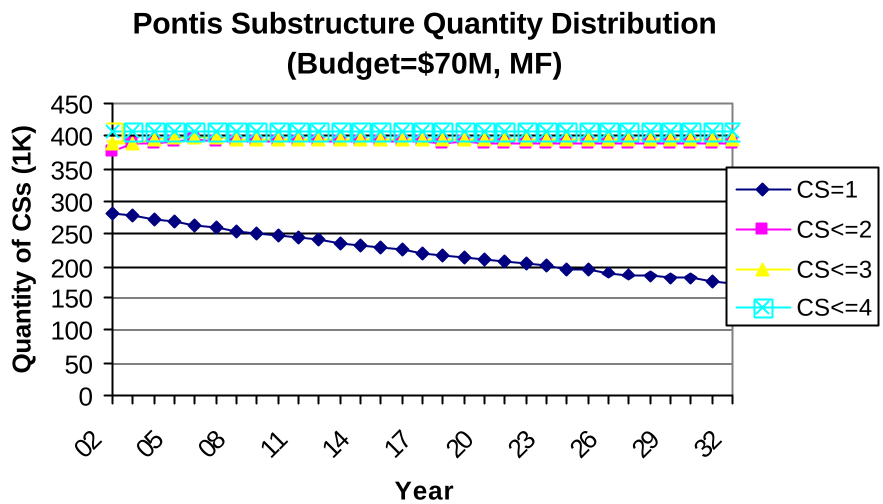

Figure E. 22
PONTIS substructure quantity distribution (Budget = $70M, MF)

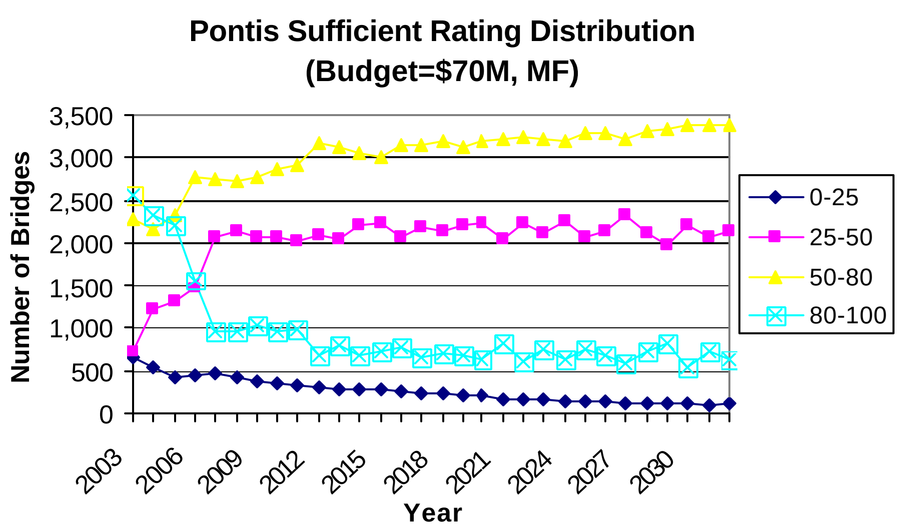

Figure E. 23
PONTIS sufficiency rating distribution (Budget = $70M, MF)

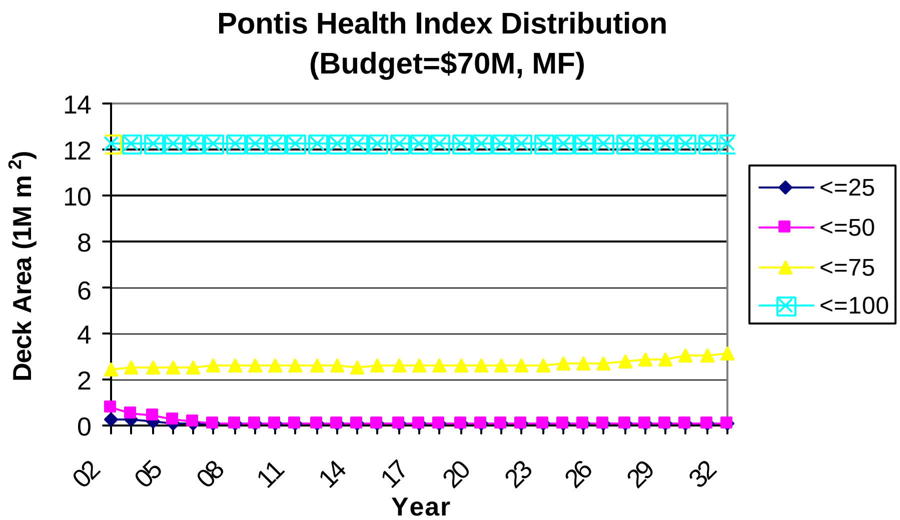

Figure E. 24
PONTIS health index distribution (Budget = $70M, MF)

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APPENDIX F. RESULTS WITH AN ANNUAL BUDGET OF $140M

As listed in Table 32 of the report, there are two scenarios, S-140-1 and S-140-2 under this budget level. This appendix contains the results from these scenarios in the following order:

1. Work vs. Need
2. PONTIS condition ratings (accumulated curves)
    a. Deck
    b. Superstructure
    c. Substructure
3. Sufficient ratings
4. Health index (accumulated)
    a. By number of bridges
    b. By deck areas

Results from S-140-1:

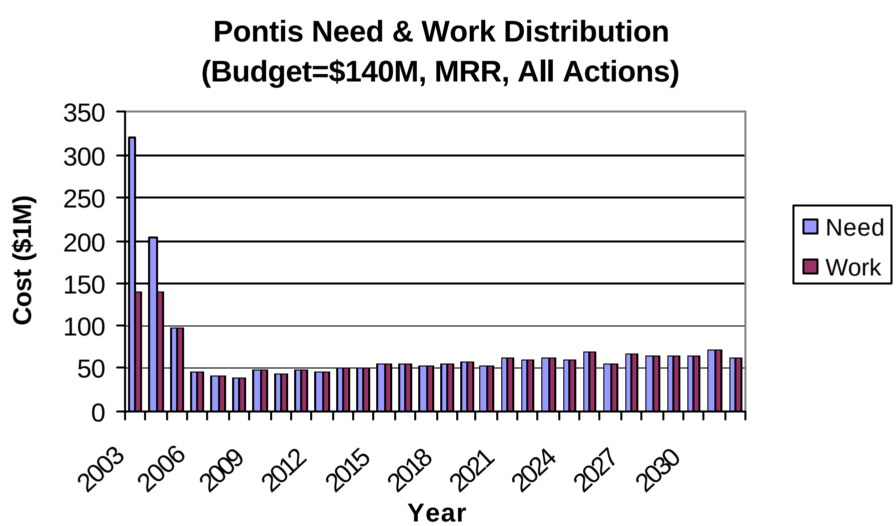

Figure F. 1
PONTIS need & work distribution (Budget = $140M, MRR, all actions)

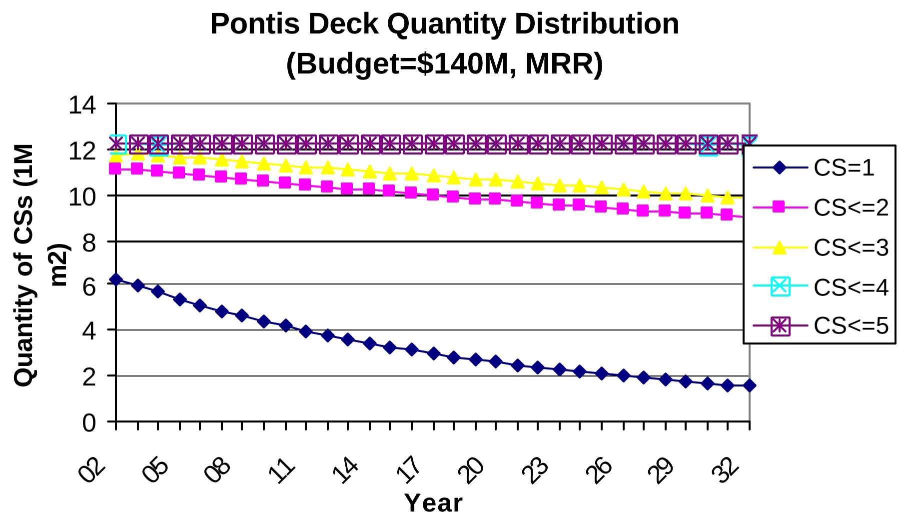

Figure F. 2
PONTIS deck quantity distribution (Budget = $140M, MRR)

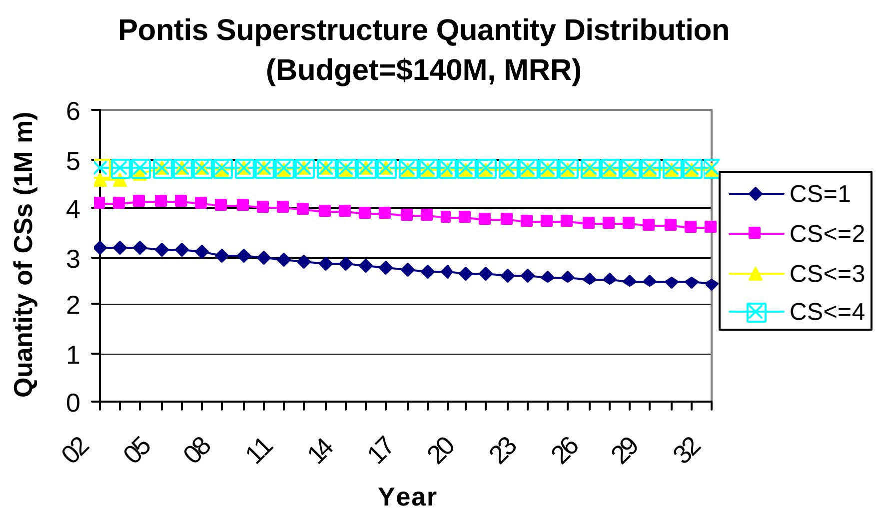

Figure F. 3
PONTIS superstructure quantity distribution (Budget = $140M, MRR)

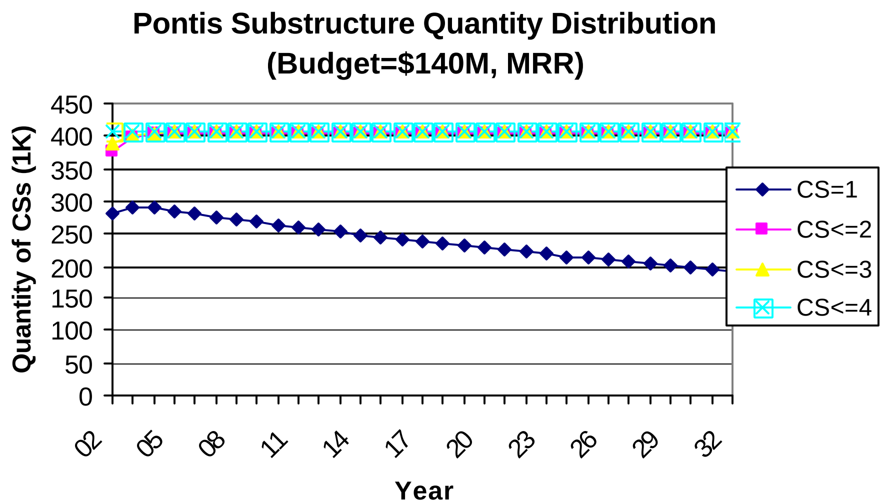

Figure F. 4
PONTIS substructure quantity distribution (Budget = $140M, MRR)

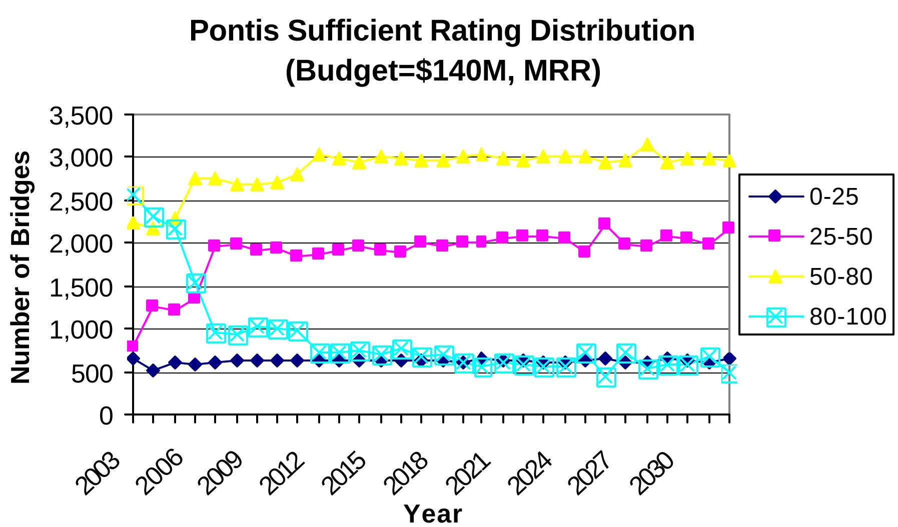

Figure F. 5
PONTIS sufficiency rating distribution (Budget = $140M, MRR)

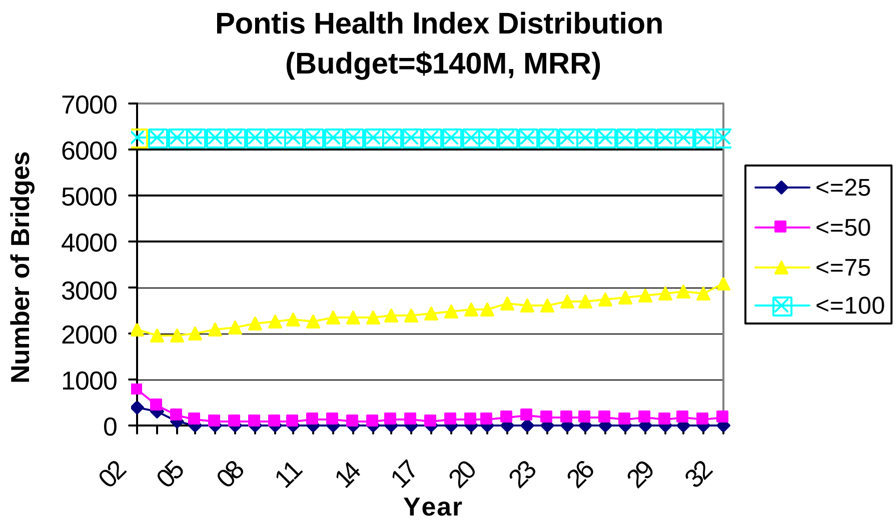

Figure F. 6
PONTIS health index distribution (Budget = $140M, MRR)

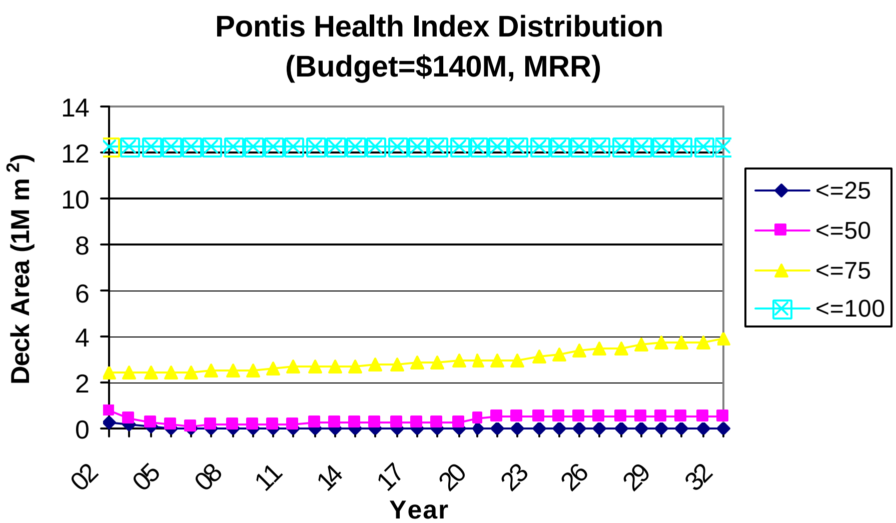

Figure F. 7
PONTIS health index distribution (Budget = $140M, MRR)

Results from S-140-1:

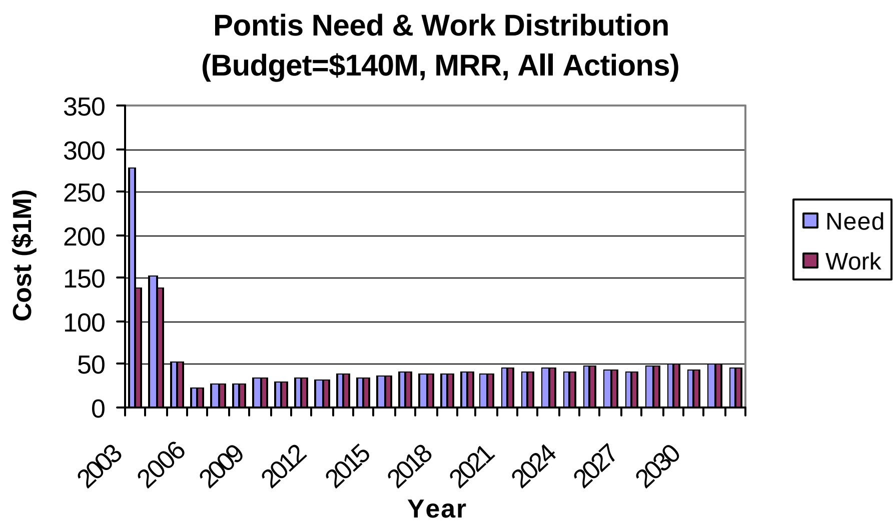

Figure F. 8
PONTIS need & work distribution (Budget = $140M, all actions)

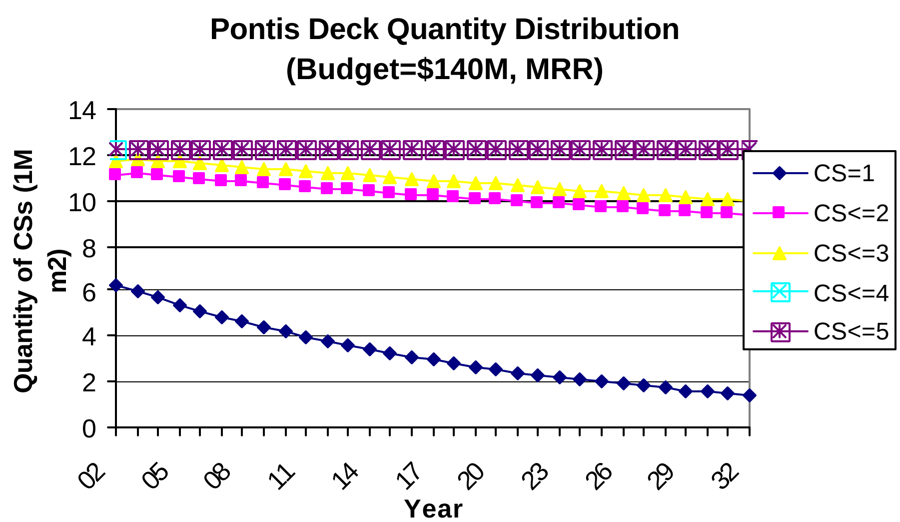

Figure F. 9
PONTIS deck quantity distribution (Budget = $40M, MRR)

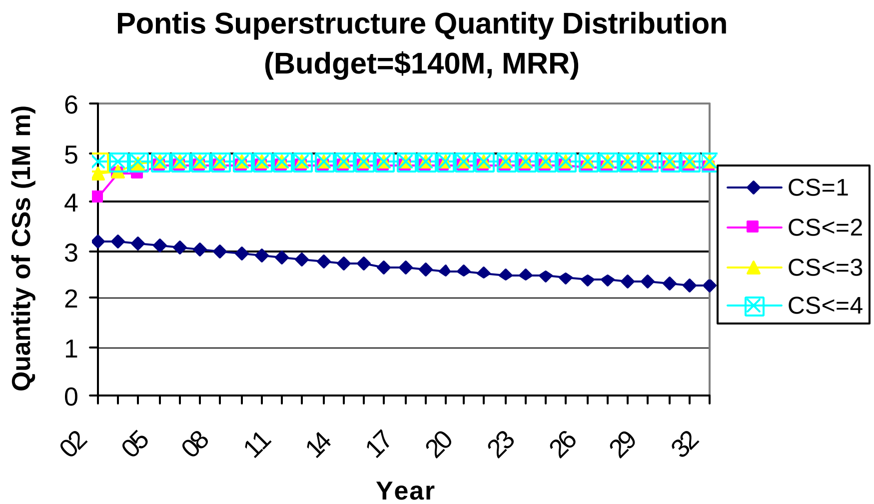

Figure F. 10
PONTIS superstructure quantity distribution (Budget = $140M, MRR)

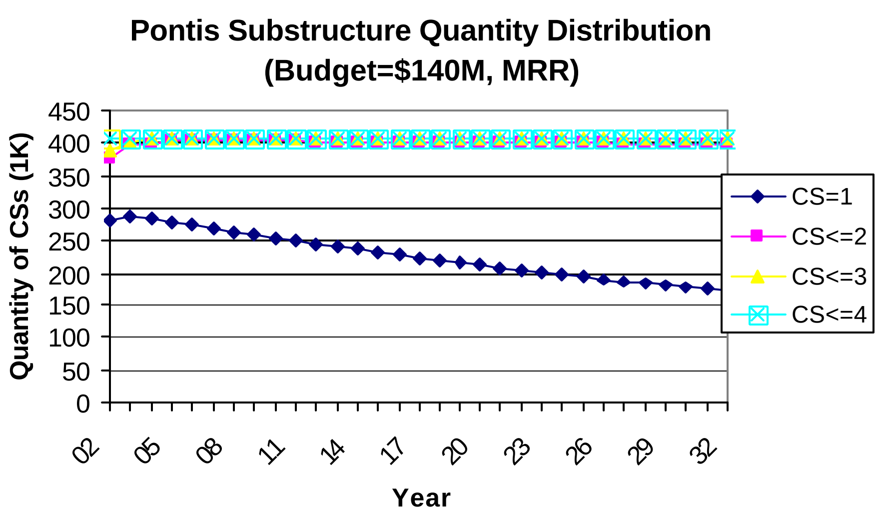

Figure F. 11
PONTIS substructure quantity distribution (Budget = $140M, MRR)

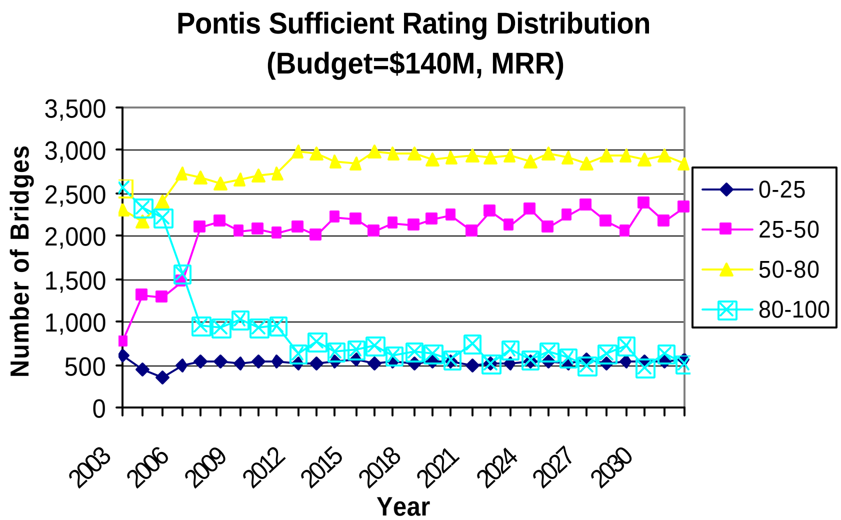

Figure F. 12
PONTIS sufficiency rating distribution (Budget = $140M, MRR)

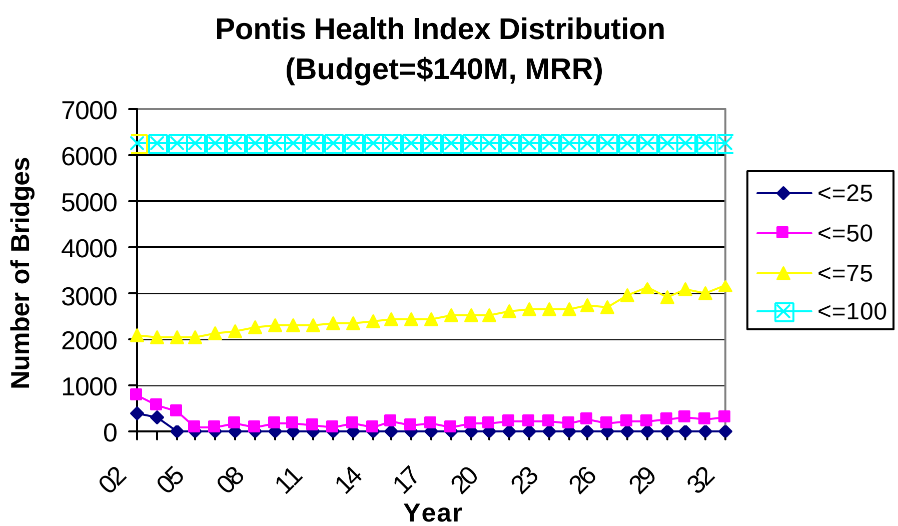

Figure F. 13
PONTIS health index distribution (Budget = $140M, MRR)

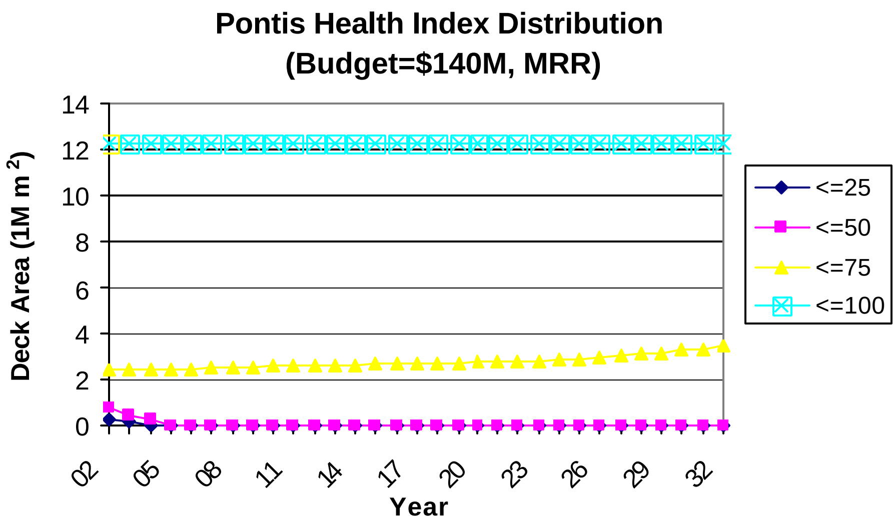

Figure F. 14
PONTIS health index distribution (Budget = $140M, MRR)