Rigid Overlays:
Expected Service Life

Prepared for

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by

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Introduction

1.1 History

The Michigan Department of Transportation (MDOT) has been designing and applying overlays to bridge decks dating back to the early 1970s. The majority of the overlays during this time were considered to be shallow as compared to deep. The difference between the overlays is how much material is removed and replaced within the previous deck. A shallow overlay is typically 1 ¾ inch thick removing only ¾ of an inch off the top of the previous deck. A deep overlay is typically 4 inches thick and the previous deck is removed down to ¾ of an inch below the top of steel rebar. Steel rebar is typically found within 2 to 3 inches below the top of the deck surface depending on the concrete design. Originally the mix design of a concrete overlay contained the addition of latex, resulting in a latex modified concrete overlay. In the mid 1990s silica fume was introduced to the concrete mix design, this design was generally only used with deep overlays. The application of an overlay is implemented with respect to the most current bridge deck preservation matrix *(Appendix Fig 5-14).* According to the most current preservation matrix, both shallow and deep concrete overlays should be applied to a bridge deck with a surface rating of 4 or 5 and deficiencies in the range of 10% to 25%. A deep concrete overlay should be applied when the deck bottom surface rating is equal to a 5 or 6 and deficiencies are less than or equal to 10%. A shallow overlay should be applied with a deck bottom surface rating of 4 and a deficiency of 10% to 25%. Therefore, according to the bridge deck preservation matrix, a deep and shallow overlay application is determined by the condition of the bottom surface of the deck. Furthermore the expected service life of a deep overlay is stated to be 25 to 30 years, while a shallow overlay is only expected to service for 10 to 15 years.

1.2 Objectives

The objectives of this study are as follows:

- Estimate service life of deep overlays.
- Estimate service life of shallow overlays.
- Compare the service lives of the two overlays.

The ultimate objective of this study is to accurately predict the service life of deep and shallow overlays separately. Currently a deep overlay has an expected service life of 25 to 30 years, while a shallow overlay is only expected to last 10 to 15 years. Expected service life is the time until “poor condition”. Poor condition of a deck surface is defined as a rating of 4 or below on the Bridge Safety Inspection Report (BSIR), and indicates the need for rehabilitation. If a known approximate service life was available for these overlays then future overlays and preventive maintenance can be planned and budgeted accordingly.

1.3 Markov Model

Markov models use transition matrices that describe the probability that a bridge element in a known condition state at a known time will change to some other condition state in the next time period. This process assumes that the probability of changing from one state to another is a function only of the condition state and time period in which the deck is currently located. Therefore, the past performance of a bridge deck has no impact on the predicted rate of change in future performance [1]. This report reviews Markov transition probabilities for deck surface condition ratings for concrete bridge decks containing deep and shallow overlays. The transition probabilities are then converted to a deterioration rate using the following equation:

$$n = \frac{\log(0.5)}{\log(T)} \qquad [2]$$

where; T = Transition Probability
n = average # of years to reach next condition state.

Deterioration rates can help predict the time for a bridge deck to reach a specific condition state. With multiple year transition probabilities and deterioration rates calculated, averages from each one step transition can be averaged resulting in the most accurate results as possible.

Results

2.1 Data Set

A data set of 506 bridges was selected for use within this study. Out of this sample, 333 were bridge decks containing a shallow overlay and 173 were bridge decks containing a deep overlay. The data set was composed from the Q88 database which contains structural ID, type of work done, and a date that the work was completed. The type of work done prior to 1990s is only noted as an overlay, rather than what type of overlay was applied, therefore reviewing the work plans would be the only way to determine a shallow from deep overlay for this time period.

From 1991 to 2000 latex modified overlays were entered as their own entity under work type. This population was further examined by reviewing work plans. After reviewing a random sample of 20 bridges, all were found to have a shallow overlay applied. Therefore it is assumed that most if not all of the overlays labeled as latex modified are considered as a shallow overlay. 175 bridges were added to the shallow overlay data set based on the condition that the work type was a latex modified overlay between 1991 and 2000.

Another coded work type was concrete overlay and the dates of these overlays range from 1998 to 2005. A random sample of 25 was taken and the work plans were reviewed to determine a shallow or deep overlay. Of the 25 samples, 23 were found to be shallow and only 2 were found to be deep. This resulted in 92% bridge decks containing shallow overlays and only 8% containing deep overlays. 158 bridges that were labeled having a concrete overlay were added to the shallow overlay data set, neglecting that nearly 10% were deep overlays as a simplification.

Silica fume overlay was also coded as its own entity in the Q88 database and the dates range from 1999 to 2005. A random sample of 52 was taken from this data set and evaluated further by examining work plans. Of the sample of 52, 45 were found to be deep overlay while the other 7 were found to be shallow, resulting in 86% and 14% respectively. 173 bridges were added to the deep overlay data set, neglecting that nearly 15% were shallow overlays as a simplification.

The age of overlays used in this data set can be found within the following figures. *Figure 2-1* represents the population of shallow overlays with respect to their age. Notice that there are few overlays over the age of 20 years; this is because the Q88 database did not separate overlays prior to 20 years ago making it difficult and very time consuming to evaluate the work plans on each bridge. *Figure 2-2* represents the population of deep overlays with respect to their age. In this figure the majority of overlays fall between 0 and 10 years old, again this is because the coding for silica fume modified only began 10 years ago, limiting the data set.

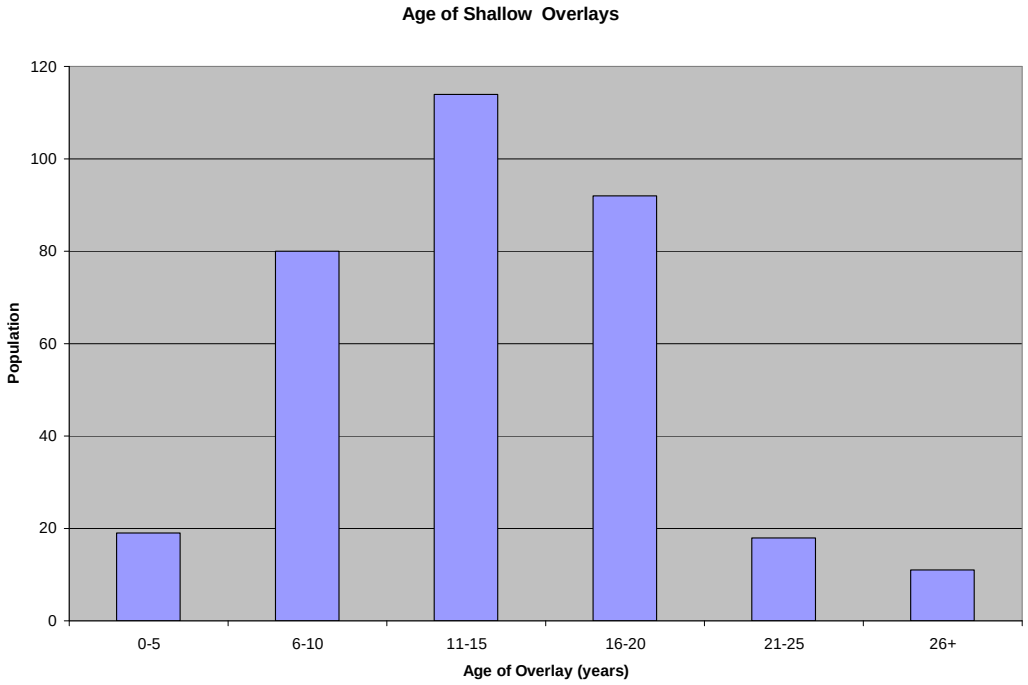

Figure 2-1: Shallow Overlay Data Set

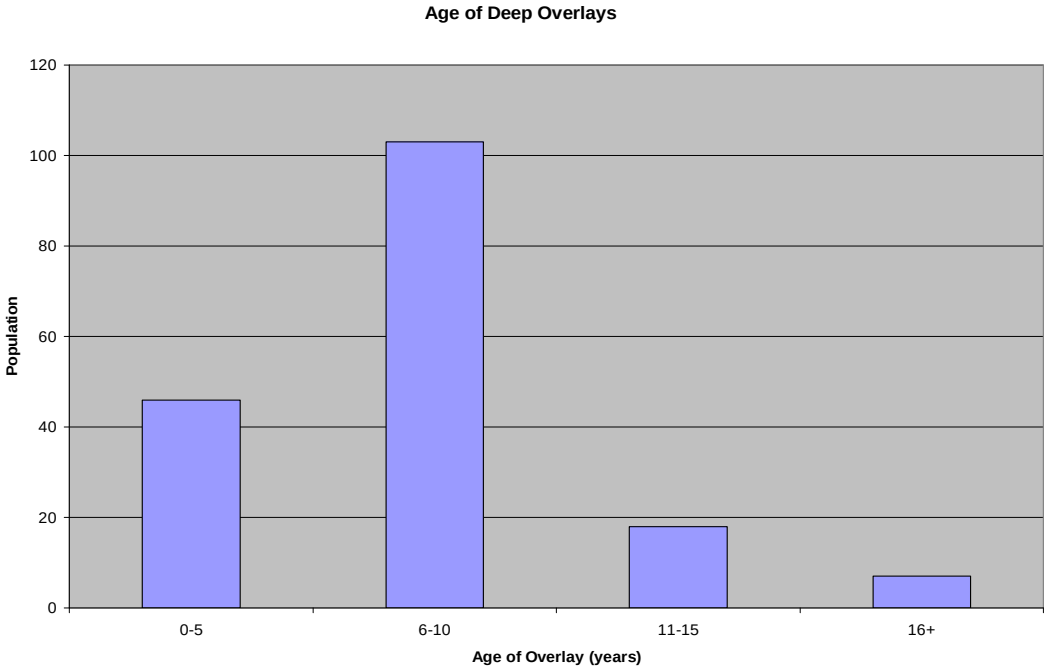

Figure 2-2: Deep Overlay Data Set

2.2 Transition Probabilities and Deterioration Curves

Transition probabilities were calculated using bridge deck surface ratings from 2004 to 2010. These ratings were analyzed from year to year intervals, resulting in a transition probability for each year. For instance; in 2004 121 bridge decks containing a shallow overlay held a rating of a 7, in 2005 117 remained a rating of a 7 while the other 4 bridge decks lowered to a rating of a 6. The transition probability is 97% that a bridge deck will remain at a 7 and a 3% chance that a bridge deck will lower to a 6. This was done for each deck surface rating, creating a transition probability matrix. This process was then repeated for 2005-2006, 06-07, 07-08, 08-09, and 09-10 resulting in six different probability matrices *(Appendix Tables 5-1 thru 5-12)*. The probabilities were then averaged based on the six different matrices, resulting in an average transition probability matrix. Deterioration rates were calculated using the equation previously mentioned *(Section 1.3)*. The deterioration rates were then plotted along the x-axis with deck surface ratings assigned to the y-axis *(Appendix Fig 5-1 thru 5-12)*.

2.2.1 Shallow Overlay

Table 2-1 displays the average transition probability from 2004-2010 for bridge decks containing a shallow overlay. The numbers located along the left side and highlighted in bright green represent the previous year deck surface rating. The numbers located along the top and highlighted in bright green represent the following year deck surface ratings and highlighted in blue are the average transition probabilities. For instance; there is a 49% chance that a 9 will remain a 9 the following year, 31% chance to decrease to an 8, and a 19% chance to decrease to a 7. Deterioration rates are in bold and highlighted light green.

Table 2-1: Transition Probability Matrix for Shallow Overlay

Shallow Overlay										
Average from 2004-2010							Item 58A Deck Surface Ratings			
Transition Probability Matrix										
	0	1	2	3	4	5	6	7	8	9
9	0	0	0	0	0	0	0.0089	0.1875	0.3125	0.4911
8	0	0	0	0	0	0	0.0168	0.2350	0.7482	**0.97**
7	0	0	0	0	0.0011	0.0159	0.0852	0.8977	2.3895	
6	0	0	0	0	0.0138	0.0552	0.9309	6.4246	**3.36**	
5	0	0	0	0	0.0533	0.9467	9.6861	**9.79**		
4	0	0	0	0.0345	0.9655	12.6468	**19.47**			
3	0	0	0	1.0000	19.7527	**32.12**				
2	0	0	0	#DIV/0!	**51.87**					
1	0	0								

Figure 2-3 displays the deck surface ratings plotted against deterioration rates calculated in Table 2-1. According to Figure 2-3; on average a bridge deck containing a shallow overlay will take 19 years to attain a rating of 5 and 32 years to reach a rating of 4, a 4 being equivalent to poor condition.

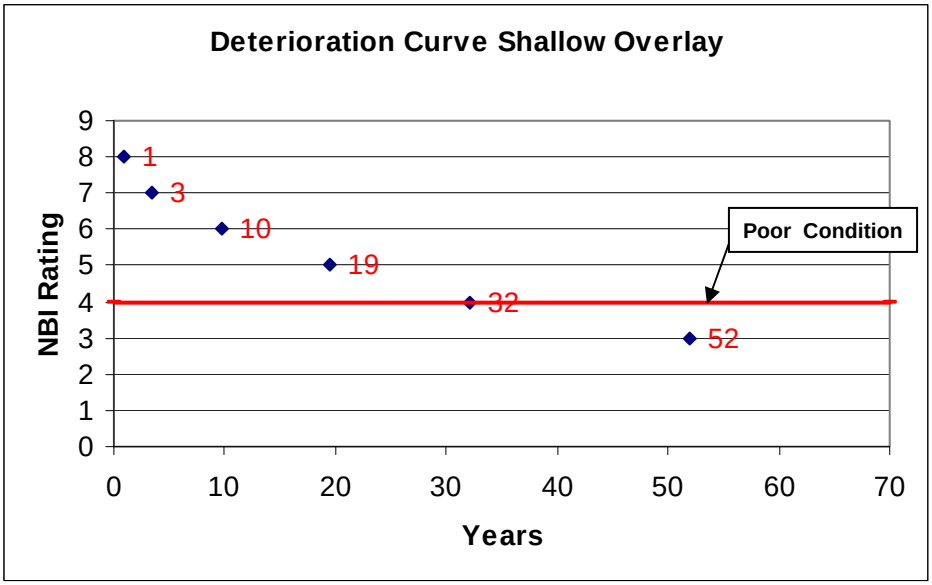

Figure 2-3: Shallow Overlay Bridge Deck Deterioration Curve

2.2.2 Deep Overlay

Table 2-2 displays the average transition probability from 2004-2010 for bridge decks containing a deep overlay. Again, transition probabilities are highlighted in blue and the deterioration rates are in bold and highlighted light green.

Table 2-2: Transition Probability Matrix for Deep Overlay

Deep Overlay										
Average from 2004-2010							Item 58A Deck Surface Ratings			
Transition Probability Matrix							Percent			
	0	1	2	3	4	5	6	7	8	9
9	0	0	0	0	0	0	0.0108	0.0968	0.3871	0.5054
8	0	0	0	0	0	0.0067	0.0168	0.1879	0.7886	**1.02**
7	0	0	0	0	0	0	0.1098	0.8902	2.9184	
6	0	0	0	0	0.0087	0.0522	0.9391	5.9567	**3.93**	
5	0	0	0	0	0.1957	0.8043	11.0372	**9.89**		
4	0	0	0	0.0370	0.9630	3.1836	**20.93**			
3	0	0	0	1.0000	18.3662	**24.11**				
2	0	0	0	#DIV/0!	**42.48**					
1	0	0								

Figure 2-4 displays the deck surface ratings plotted against deterioration rates calculated in Table 2-2. According to Figure 2-4; on average a bridge deck containing a deep overlay will take 21 years to attain a rating of 5 and 24 years to reach a rating of 4. This value of 24 years to reach a rating of 4 seems to be inaccurate as it only takes 3 years to reduce from a rating of a 5 to a 4. A line of best fit has been drawn excluding the outlying data point. Following the line of best fit it will take approximately 32 years for a deep overlay to become poor.

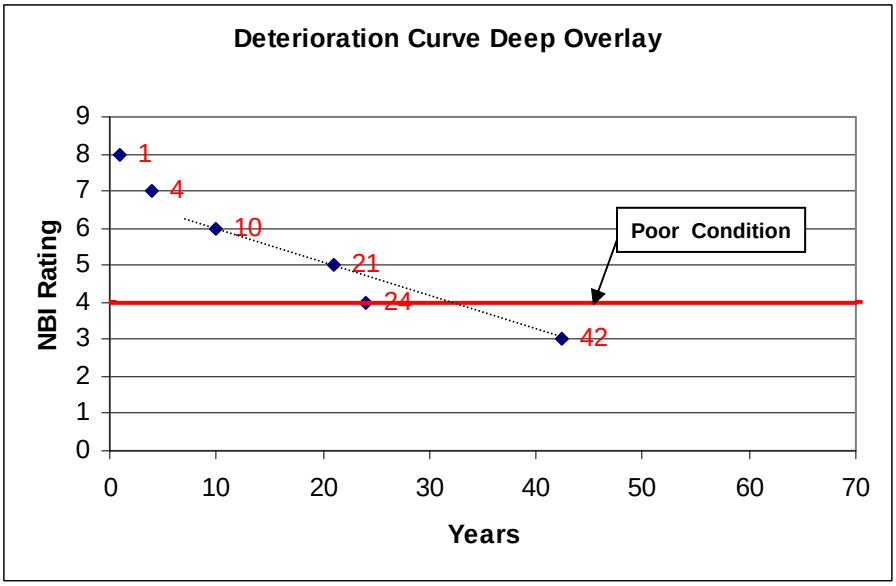

Figure 2-4: Deep Overlay Bridge Deck Deterioration Curve

Discussion

3.1 Expected Service Life of Overlays

3.1.1 Shallow Overlay

A sample size of 333 bridge decks was used in calculating the transition probabilities for shallow overlays. A more complete deterioration curve can be drawn due to a higher sample size and a larger variation in age of the overlays. *Figure 2-3* shows 19 years for a shallow overlay to reach a rating of 5, and 32 years to reach a rating of 4. The current bridge deck preservation matrix of a shallow overlay anticipates an expected life of 10 to 15 years. The results from this study expect a shallow overlay to last 2 to 3 times of that stated in the bridge deck preservation matrix.

3.1.2 Deep Overlay

The data available for deep overlay analysis was very limited with a sample of only 173 bridge decks and about a hundred of them within 5 years of age. This is more than likely the cause of the outlier found, 24 years with a condition rating of 4, within the deterioration curve *(Figure 2-4)*. To avoid this outlier altering the data a line of best fit was drawn excluding the point (24, 4). With the presence of a line of best fit the approximate age to reach poor condition is 32 years. Also note that the deterioration curve displays 21 years to reach a rating of 5. The most current bridge deck preservation matrix anticipates poor condition of a deep concrete overlay to occur in 25 to 30 years *(Appendix Fig 5-13)*. The results from this study seem to be accurate as compared to the bridge deck preservation matrix.

3.1.3 Comparison

The two deterioration curves found for shallow and deep overlays are nearly identical to each other. The approximate age of a deep overlay to attain a rating of a 5 is 21 years as compared to 19 years for a shallow overlay. The difference in deterioration between the overlays is only 2 years at a deck surface rating of 5. The approximate age for both deep and shallow overlays to attain a rating of 4 is 32 years. According to the deterioration curves both deep and shallow overlays have nearly the exact same deterioration rates.

3.2 Errors and Uncertainties

The data set used within this study was limited due to the lack of coding separation between overlays. The shallow overlay data set contained 175 bridges labeled latex modified overlay and most if not all should contain a shallow overlay. Bridges labeled as having a concrete overlay were also added to this set with approximately 92% containing a shallow overlay and only 8% containing a deep overlay. 158 bridges were added from this sample, resulting in the possibility of 12 contain a deep overlay. With a total sample size of 333 and the probability that 12 are inaccurate, an error of 3.6% is found. The sample size for deep overlays consisted of 173 bridges containing 14% shallow overlays. This results in a 14% error and the probability that 24 of the bridge decks actually contain a shallow overlay. Also, 60% of the data population for deep overlay contained bridge decks with an age of overlay between 6 and 10 years. A broader range of overlay ages is more ideal but simplifications were implemented. These simplifications were made due to the fact that the only other way to determine the type of overlay is by examining the corresponding work plans for each individual bridge.

Conclusion

The study has yielded the following conclusions:

- The service life of a deep overlay is estimated to be 32 years.
- The service life of a shallow overlay is estimated to be 32 years.
- There appears to be minimal difference in the deterioration rates between deep and shallow overlays.

Appendix

5.1 Deep Overlay Transition Probabilities & Deterioration Curves

Table 5-1: 2004-2005 Deep Overlay Transition Probability Matrix

Bridge Condition Change Matrix 2004-2005

Went up	Sample Size	0	1	2	3	4	5	6	7	8	9
0	7										
9	19								5	1	1
8	17						1		4	14	
7	24					1		2	15		
6	22					8	4	19			
5	19				1	18	14				
4	12			0	12						
3			0								
2											
1											
0	2										
	53										
Unrated	120										

Transition Probability Matrix Percent

		0	1	2	3	4	5	6	7	8	9
9		0	0	0	0	0	0	0	0.7142857	0.1428571	0.1428571
8		0	0	0	0	0	0.0526316	0	0.2105263	0.7368421	0.3562072
7		0	0	0	0	0	0	0.1176471	0.8823529	2.2697735	
6		0	0	0	0	0.0416667	0.1666667	0.7916667	5.5379496	2.6259807	
5		0	0	0	0	0.3636364	0.6363636	2.967051	8.1639303		
4		0	0	0	0.0526316	0.9473684	1.5335619	11.130981			
3		0	0	0	1	12.8201	12.664543				
2	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	25.484643					
1	#DIV/0!	#DIV/0!									

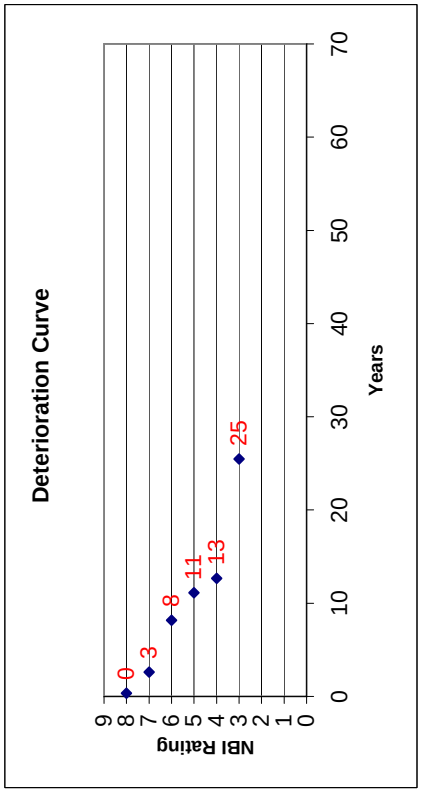

Figure 5-1: 2004-2005 Deep Overlay Deterioration Curve

Table 5-2: 2005-2006 Deep Overlay Transition Probability Matrix

Bridge Condition Change Matrix 2005-2006

Went up	Sample Size		0	1	2	3	4	5	6	7	8	9
0	19	9							1		2	16
1	40	8						1	1	8	30	
1	29	7							7	22		
9	14	6						1	13			
7	12	5					1	11				
11	16	4				1	15					
9	4	3				4						
		2			0							
		1		0								
		0										
38	134											

Transition Probability Matrix Percent

Unrated		0	1	2	3	4	5	6	7	8	9
9		0	0	0	0	0	0	0.0526316	0	0.1052632	0.8421053
8		0	0	0	0	0	0.025	0.025	0.2	0.75	4.033437
7		0	0	0	0	0	0	0.2413793	0.7586207	2.4094208	
6		0	0	0	0	0	0.0714286	0.9285714	2.5090994	6.4428578	
5		0	0	0	0	0.0833333	0.9166667	9.3532067	8.9519572		
4		0	0	0	0.0625	0.9375	7.9661672	18.305164			
3		0	0	0	1	10.740054	26.271331				
2		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	37.011385					
1		#DIV/0!	#DIV/0!								

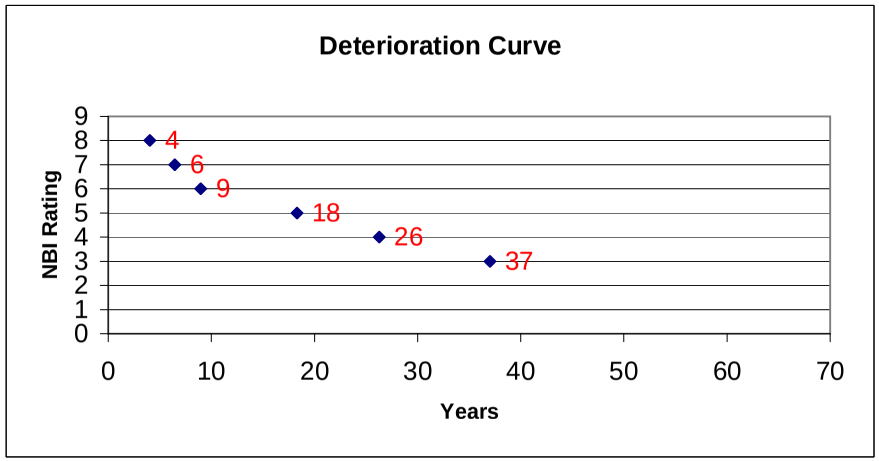

Figure 5-2: 2005-2006 Deep Overlay Deterioration Curve

Table 5-3: 2006-2007 Deep Overlay Transition Probability Matrix

Bridge Condition Change Matrix 2006-2007

Went up	Sample Size		0	1	2	3	4	5	6	7	8	9
0	25	9								2	17	6
	49	8							1	11	37	
2	37	7							2	35		
8	15	6							15			
6	7	5						7				
8	8	4					8					
3	2	3				2						
		2			0							
		1		0								
		0										
27	143											

Transition Probability Matrix Percent

Unrated			0	1	2	3	4	5	6	7	8	9
		9	0	0	0	0	0	0	0	0.08	0.68	0.24
		8	0	0	0	0	0	0	0.0204082	0.2244898	0.755102	0.4856977
		7	0	0	0	0	0	0	0.0540541	0.9459459	2.4675731	
		6	0	0	0	0	0	0	1	12.47344	2.9532709	
		5	0	0	0	0	0	1	#DIV/0!	15.42671		
		4	0	0	0	0	1	#DIV/0!	#DIV/0!			
		3	0	0	0	1	#DIV/0!	#DIV/0!				
		2	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!					
		1	#DIV/0!	#DIV/0!								

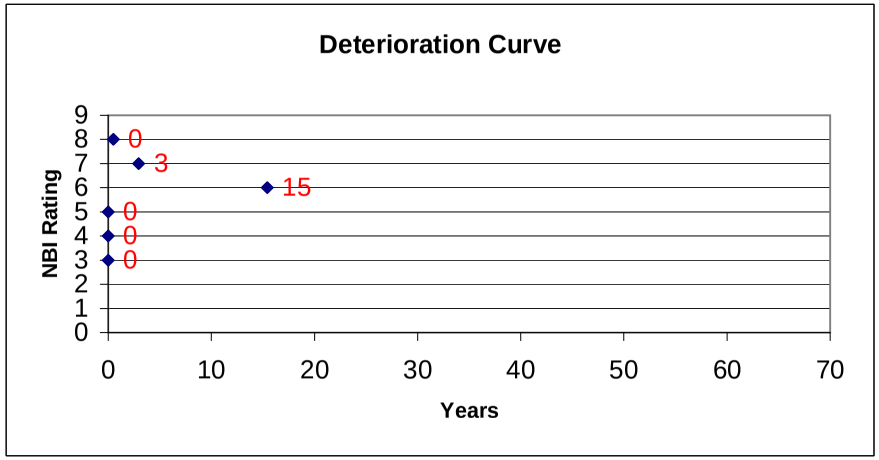

Figure 5-3: 2006-2007 Deep Overlay Deterioration Curve

Table 5-4: 2007-2008 Deep Overlay Transition Probability Matrix

Bridge Condition Change Matrix 2007-2008

Went up	Sample Size		0	1	2	3	4	5	6	7	8	9
0	17	9								1	8	8
	64	8								7	57	
	55	7							4	51		
2	17	6						1	16			
6	1	5						1				
1	7	4					7					
	2	3				2						
		2			0							
		1		0								
		0										
9	163											

Transition Probability Matrix Percent

Unrated			0	1	2	3	4	5	6	7	8	9
		9	0	0	0	0	0	0	0	0.0588235	0.4705882	0.4705882
		8	0	0	0	0	0	0	0	0.109375	0.890625	0.9195717
		7	0	0	0	0	0	0	0.0727273	0.9272727	5.9840828	
		6	0	0	0	0	0	0.0588235	0.9411765	9.1798391	6.9036545	
		5	0	0	0	0	0	1	11.433427	16.083494		
		4	0	0	0	0	1	#DIV/0!	27.51692			
		3	0	0	0	1	#DIV/0!	#DIV/0!				
		2	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!					
		1	#DIV/0!	#DIV/0!								

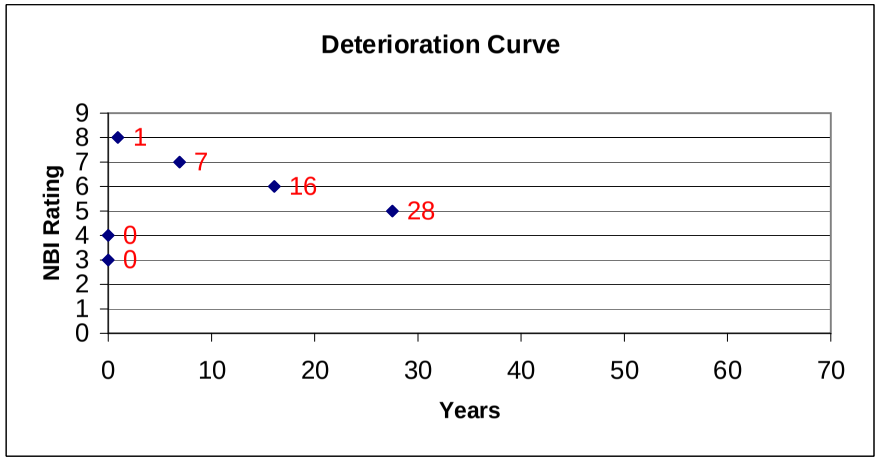

Figure 5-4: 2007-2008 Deep Overlay Deterioration Curve

Table 5-5: 2008-2009 Deep Overlay Transition Probability Matrix

Bridge Condition Change Matrix 2008-2009

Went up	Sample Size		0	1	2	3	4	5	6	7	8	9
0	12	9									3	9
	68	8							1	12	55	
	60	7							7	53		
	21	6							21			
	2	5						2				
4	3	4					3					
	2	3				2						
		2			0							
		1		0								
		0										
4	168											

Transition Probability Matrix Percent

Unrated			0	1	2	3	4	5	6	7	8	9
		9	0	0	0	0	0	0	0	0	0.25	0.75
		8	0	0	0	0	0	0	0.0147059	0.1764706	0.8088235	2.4094208
		7	0	0	0	0	0	0	0.1166667	0.8833333	3.2668729	
		6	0	0	0	0	0	0	1	5.5875242	5.6762937	
		5	0	0	0	0	0	1	#DIV/0!	11.263818		
		4	0	0	0	0	1	#DIV/0!	#DIV/0!			
		3	0	0	0	1	#DIV/0!	#DIV/0!				
		2	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!					
		1	#DIV/0!	#DIV/0!								

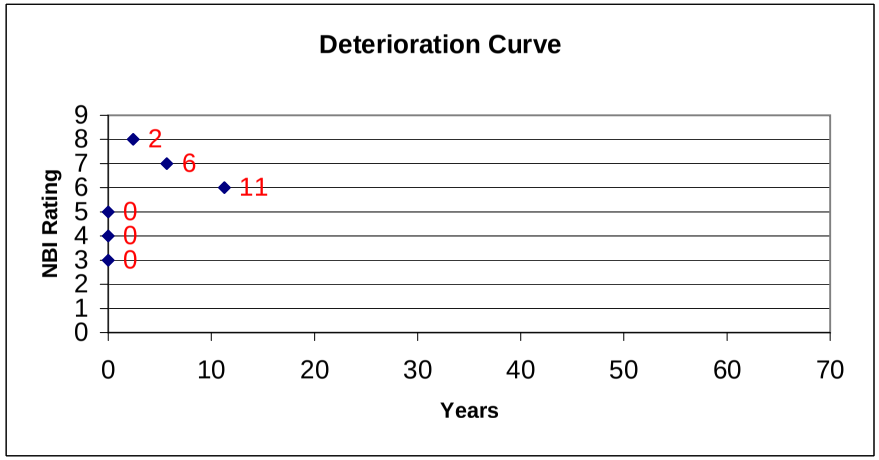

Figure 5-5: 2008-2009 Deep Overlay Deterioration Curve

Table 5-6: 2009-2010 Deep Overlay Transition Probability Matrix

Bridge Condition Change Matrix 2009-2010

Went up	Sample Size		0	1	2	3	4	5	6	7	8	9
0	13	9								1	5	7
	58	8							2	14	42	
	66	7							7	59		
5	24	6							24			
	2	5						2				
2	1	4					1					
2		3				0						
		2			0							
		1		0								
		0										
9	164											

Transition Probability Matrix Percent

Unrated		0	1	2	3	4	5	6	7	8	9
	9	0	0	0	0	0	0	0	0.0769231	0.3846154	0.5384615
	8	0	0	0	0	0	0	0.0344828	0.2413793	0.7241379	1.1197145
	7	0	0	0	0	0	0	0.1060606	0.8939394	2.1474731	
	6	0	0	0	0	0	0	1	6.1823393	3.2671876	
	5	0	0	0	0	0	1	#DIV/0!	9.4495269		
	4	0	0	0	0	1	#DIV/0!	#DIV/0!			
	3	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!				
	2	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!					
	1	#DIV/0!	#DIV/0!								

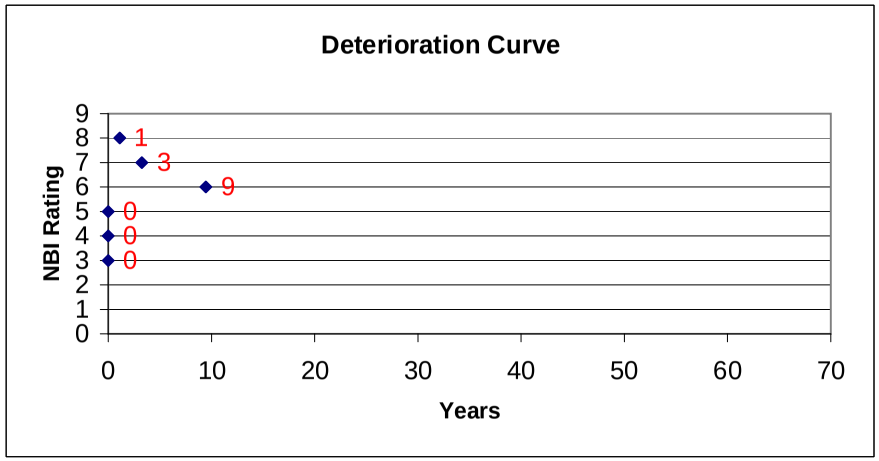

Figure 5-6: 2009-2010 Deep Overlay Deterioration Curve

5.2 Shallow Overlay Transition Probabilities & Deterioration Curves

Table 5-7: 2004-2005 Shallow Overlay Transition Probability Matrix

Bridge Condition Change Matrix 2004-2005

Went up	Sample Size		0	1	2	3	4	5	6	7	8	9
0	24	9								7	12	5
1	80	8							1	23	56	
1	121	7							4	117		
7	50	6					3	2	45			
3	16	5					1	15				
8	11	4				1	10					
6	5	3				5						
		2			0							
		1		0								
		0										
26	307											

Transition Probability Matrix Percent

Unrated			0	1	2	3	4	5	6	7	8	9
		9	0	0	0	0	0	0	0	0.2916667	0.5	0.2083333
		8	0	0	0	0	0	0	0.0125	0.2875	0.7	0.4418846
		7	0	0	0	0	0	0	0.0330579	0.9669421	1.9433582	
		6	0	0	0	0	0.06	0.04	0.9	20.619187	2.3852428	
		5	0	0	0	0	0.0625	0.9375	6.5788135	23.00443		
		4	0	0	0	0.0909091	0.9090909	10.740054	29.583243			
		3	0	0	0	1	7.2725409	40.323297				
		2	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	47.595838					
		1	#DIV/0!	#DIV/0!								

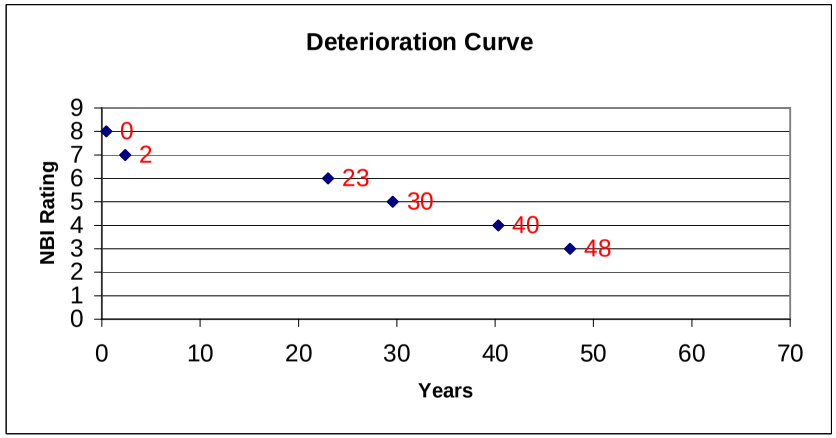

Figure 5-7: 2004-2005 Shallow Overlay Deterioration Curve

Table 5-8: 2005-2006 Shallow Overlay Transition Probability Matrix

Bridge Condition Change Matrix 2005-2006

Went up	Sample Size		0	1	2	3	4	5	6	7	8	9
0	17	9								2		15
	75	8								19	56	
2	148	7					1	5	13	129		
2	51	6					1	6	44			
7	11	5					1	10				
10	4	4					4					
6		3				0						
		2			0							
		1		0								
		0										
27	306											

Transition Probability Matrix Percent

Unrated		0	1	2	3	4	5	6	7	8	9
9		0	0	0	0	0	0	0	0.1176471	0	0.8823529
8		0	0	0	0	0	0	0	0.2533333	0.7466667	5.5379496
7		0	0	0	0	0.0067568	0.0337838	0.0878378	0.8716216	2.3726832	
6		0	0	0	0	0.0196078	0.1176471	0.8627451	5.0447441	7.9106328	
5		0	0	0	0	0.0909091	0.9090909	4.694974	12.955377		
4		0	0	0	0	1	7.2725409	17.650351			
3		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	24.922892				
2		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!					
1		#DIV/0!	#DIV/0!								

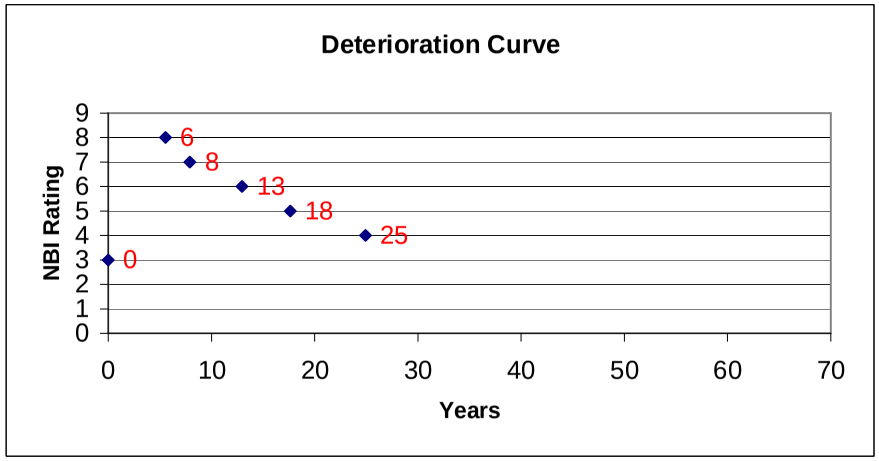

Figure 5-8: 2005-2006 Shallow Overlay Deterioration Curve

Table 5-9: 2006-2007 Shallow Overlay Transition Probability Matrix

Bridge Condition Change Matrix 2006-2007

Went up	Sample Size		0	1	2	3	4	5	6	7	8	9
0	23	9								3	12	8
	67	8							1	13	53	
3	151	7						1	6	144		
3	57	6					1	1	55			
9	12	5						12				
3	4	4					4					
		3				0						
		2			0							
		1		0								
		0										
18	314											

Transition Probability Matrix Percent

Unrated			0	1	2	3	4	5	6	7	8	9
		9	0	0	0	0	0	0	0	0.1304348	0.5217391	0.3478261
		8	0	0	0	0	0	0	0.0149254	0.1940299	0.7910448	0.6563566
		7	0	0	0	0	0	0.0066225	0.0397351	0.9536424	2.9571036	
		6	0	0	0	0	0.0175439	0.0175439	0.9649123	14.60286	3.6134603	
		5	0	0	0	0	0	1	19.406058	18.21632		
		4	0	0	0	0	1	#DIV/0!	37.622378			
		3	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!				
		2	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!					
		1	#DIV/0!	#DIV/0!								

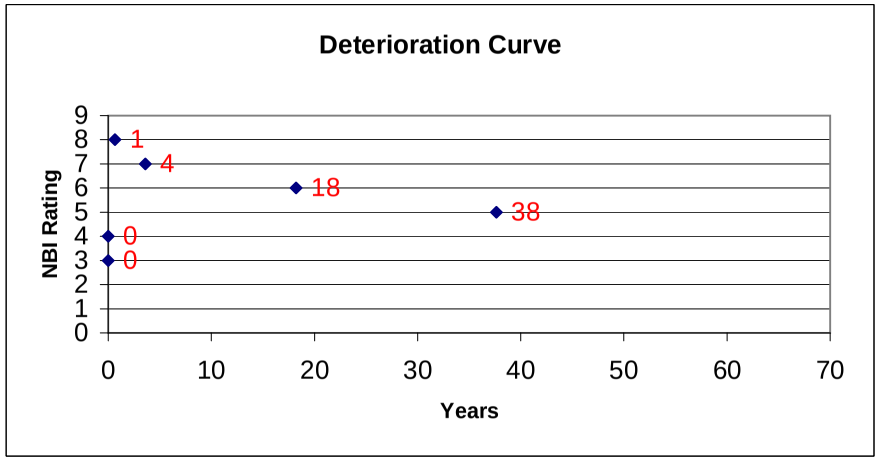

Figure 5-9: 2006-2007 Shallow Overlay Deterioration Curve

Table 5-10: 2007-2008 Shallow Overlay Transition Probability Matrix

Bridge Condition Change Matrix 2007-2008

Went up	Sample Size		0	1	2	3	4	5	6	7	8	9
0	10	9								1	3	6
	71	8							1	7	63	
8	160	7						1	24	135		
9	55	6						5	50			
2	13	5					2	11				
1	4	4					4					
		3				0						
		2			0							
		1		0								
		0										
20	313											

Transition Probability Matrix Percent

Unrated			0	1	2	3	4	5	6	7	8	9
		9	0	0	0	0	0	0	0	0.1	0.3	0.6
		8	0	0	0	0	0	0	0.0140845	0.0985915	0.8873239	1.3569154
		7	0	0	0	0	0	0.00625	0.15	0.84375	5.7982041	
		6	0	0	0	0	0	0.0909091	0.9090909	4.0797593	7.1551195	
		5	0	0	0	0	0.1538462	0.8461538	7.2725409	11.234879		
		4	0	0	0	0	1	4.1492381	18.50742			
		3	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	22.656658				
		2	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!					
		1	#DIV/0!	#DIV/0!								

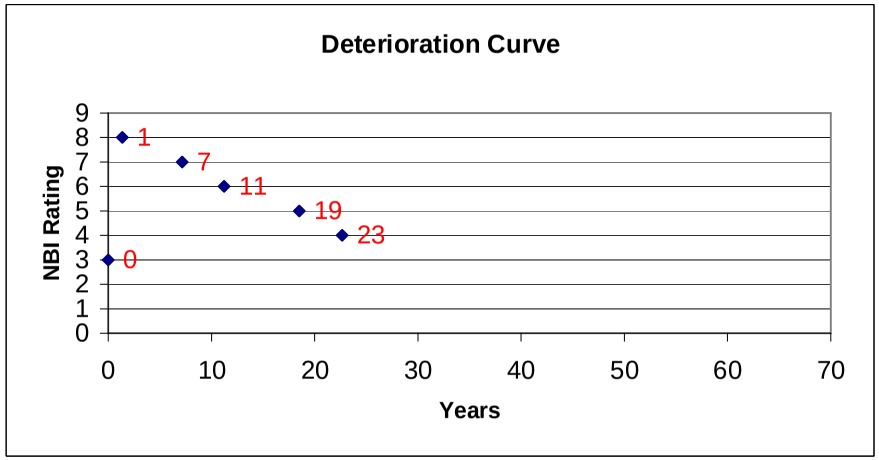

Figure 5-10: 2007-2008 Shallow Overlay Deterioration Curve

Table 5-11: 2008-2009 Shallow Overlay Transition Probability Matrix

Bridge Condition Change Matrix 2008-2009

Went up	Sample Size		0	1	2	3	4	5	6	7	8	9
0	17	9								2	2	13
1	70	8							1	20	49	
	146	7							14	132		
6	70	6							70			
2	15	5						15				
3	3	4					3					
		3				0						
		2			0							
		1		0								
		0										
12	321											

Transition Probability Matrix Percent

Unrated		0	1	2	3	4	5	6	7	8	9
	9	0	0	0	0	0	0	0	0.1176471	0.1176471	0.7647059
	8	0	0	0	0	0	0	0.0142857	0.2857143	0.7	2.5838249
	7	0	0	0	0	0	0	0.0958904	0.9041096	1.9433582	
	6	0	0	0	0	0	0	1	6.8761396	4.5271832	
	5	0	0	0	0	0	1	#DIV/0!	11.403323		
	4	0	0	0	0	1	#DIV/0!	#DIV/0!			
	3	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!				
	2	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!					
	1	#DIV/0!	#DIV/0!								

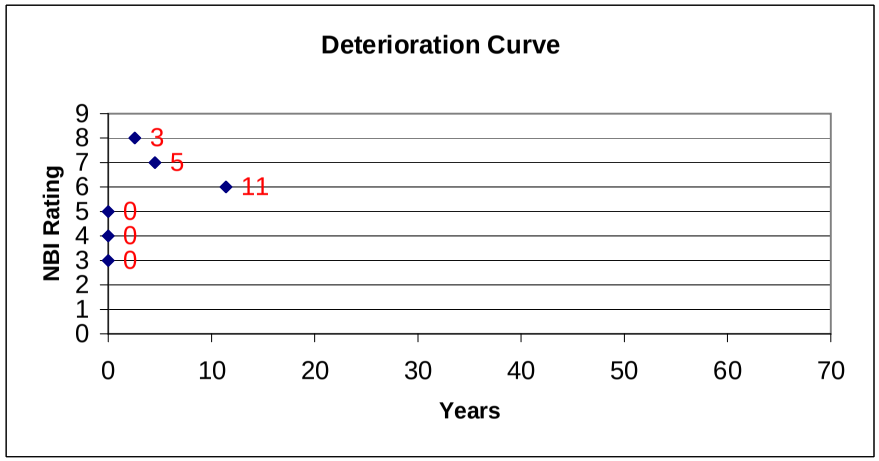

Figure 5-11: 2008-2009 Shallow Overlay Deterioration Curve

Table 5-12: 2009-2010 Shallow Overlay Transition Probability Matrix

Bridge Condition Change Matrix 2009-2010

Went up	Sample Size		0	1	2	3	4	5	6	7	8	9
0	21	9							1	6	6	8
	54	8							3	16	35	
1	154	7						7	14	133		
6	79	6						6	73			
7	8	5						8				
	3	4					3					
		3				0						
		2			0							
		1		0								
		0										
14	319											

Transition Probability Matrix Percent

Unrated			0	1	2	3	4	5	6	7	8	9
		9	0	0	0	0	0	0	0.047619	0.2857143	0.2857143	0.3809524
		8	0	0	0	0	0	0	0.0555556	0.2962963	0.6481481	0.718227
		7	0	0	0	0	0	0.0454545	0.0909091	0.8636364	1.598454	
		6	0	0	0	0	0	0.0759494	0.9240506	4.7280406	2.316681	
		5	0	0	0	0	0	1	8.7753022	7.0447217		
		4	0	0	0	0	1	#DIV/0!	15.820024			
		3	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!				
		2	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!					
		1	#DIV/0!	#DIV/0!								

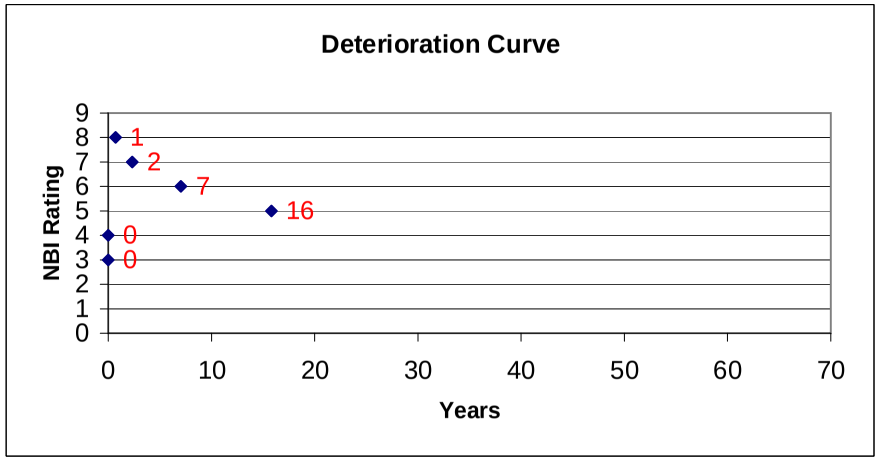

Figure 5-12: 2009-2010 Shallow Overlay Deterioration Curve

BRIDGE DECK PRESERVATION MATRIX

DECK CONDITION STATE				REPAIR OPTIONS	POTENTIAL RESULT TO DECK BSIR		NEXT ANTICIPATED EVALUATION
Top Surface		Bottom Surface			Top Surface BSIR #58a	Bottom Surface BSIR #58b	
BSIR #58a	Deficiencies % (a)	BSIR #58b	Deficiencies % (b)				
≥ 5	N/A	N/A	N/A	Hold (c) Seal Cracks/Healer Sealer (d)	No Change	No Change	1 to 8 years
	≤ 5%	> 5	≤ 2%	Epoxy Overlay	8, 9	No Change	10 to 15 years
	≤ 10%	≥ 4	≤ 25%	Deck Patch (e)	Up by 1 pt.	No Change	3 to 10 years
4 or 5	10% to 25%	5 or 6	≤ 10%	Deep Concrete Overlay (h)	8, 9	No Change	25 to 30 years
		4	10% to 25%	Shallow Concrete Overlay (h, i)	8, 9	No Change	10 to 15 years
				HMA Overlay with water-proofing membrane (f, h, i)	8, 9	No Change	8 to 10 years
		2 or 3	> 25%	HMA Cap (g, h, i)	8, 9	No Change	2 to 4 years
≤ 3	>25%	> 5	< 2%	Deep Concrete Overlay (h)	8, 9	No Change	20 to 25 years
		4 or 5	2% to 25%	Shallow Concrete Overlay (h, i)	8, 9	No Change	10 years
				HMA Overlay with water-proofing membrane (f, h, i)	8, 9	No Change	5 to 7 years
		2 or 3	>25%	HMA Cap (g, h, i)	8, 9	No Change	1 to 3 years
				Replace Deck	9	9	40+ years

(a) Percent of deck surface area that is spalled, delaminated, or patched with temporary patch material.
(b) Percent of deck underside area that is spalled, delaminated or map cracked.
(c) The "Hold" option implies that there is on-going maintenance of filling potholes with cold patch and scaling of incipient spalls.
(d) Seal cracks when cracks are easily visible and minimal map cracking. Apply healer sealer when crack density is too great to seal individually by hand. Sustains the current condition longer.
(e) Crack sealing can also be used to seal the perimeter of deck patches.
(f) Hot Mix Asphalt overlay with waterproofing membrane. Deck patching required prior to placement of waterproofing membrane.
(g) Hot Mix Asphalt cap without waterproofing membrane for ride quality improvement. Deck should be scheduled for replacement in the 5 year plan.
(h) If bridge crosses over traveled lanes and the deck contains slag aggregate, do deck replacement.
(i) When deck bottom surface is rated poor (or worse) and may have loose or delaminated concrete over traveled lanes, an in-depth inspection should be scheduled. Any loose or delaminated concrete should be scaled off and false decking should be placed over traveled lanes where there is potential for additional concrete to become loose.

Bridge Deck Preservation Matrix **March 12, 2008 Rev.**

Figure 5-13: Bridge Deck Preservation Matrix

References

[1] Devaraj, Dinesh, and Fu, Gongkang. *Methodology of Homogeneous and Non-Homogeneous Markov Chains for Modeling Bridge Element Deterioration.* Detroit, MI: Wayne State University Press, 1998. Print

[2] Juntunen, Dave. *BMS: Domestic Scan on Bridge Management.* Lansing, MI: Michigan Department of Transportation, 19 Nov 2009. Powerpoint.