DEVELOPING DETERIORATION MODELS FOR LIFE CYCLE COST ANALYSIS OF BRIDGES

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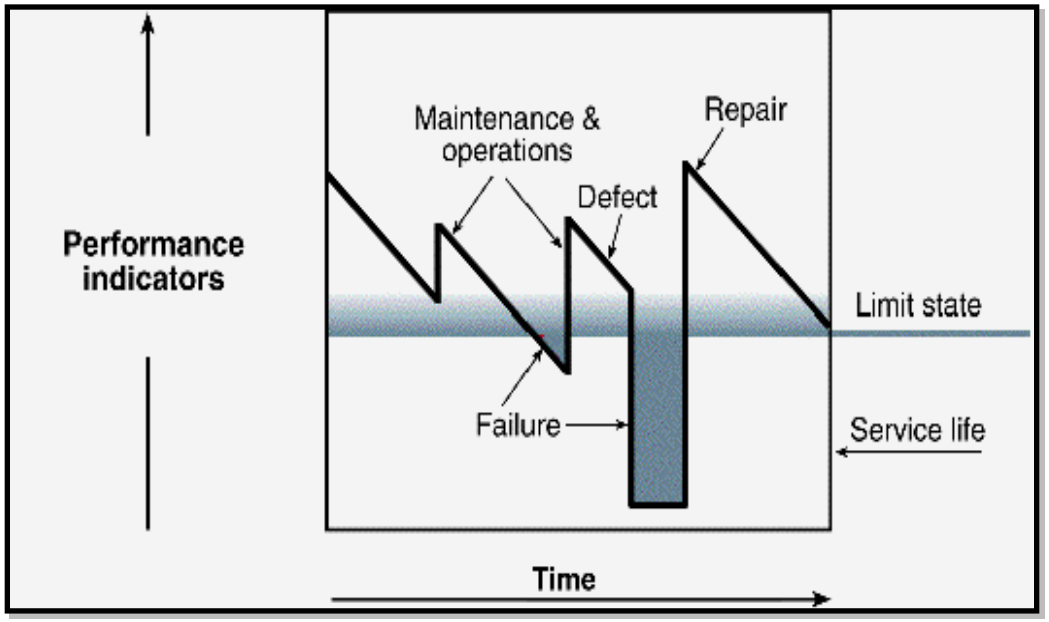
Contents

1- Problem Statement

- National average deterioration rates are neither adequate nor accurate representation of the actual performance of local bridges.
- Reliable LCCA of preservation decisions requires accurate prediction of bridge condition.



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2- Objective

- Develop deterioration models for bridge decks considering the following parameters:

✓ Average daily traffic (ADT)
✓ Average daily truck traffic (ADTT)
✓ Wearing surface type
✓ Highway district
✓ Deck protection

- Perform LCCA for different deck overlay decisions using the developed deterioration models and latest cost data.

3- Data Analysis

	Data Item	Item #
Inventory	Average Daily Traffic (ADT)	29
	% of Truck Traffic	109
	Deck Structure Type	107
	Material Type	43A
	Structure Type (Main)	43B
	Type of Wearing Surface	108A
	Deck Protection	108C
	Highway Agency District (Climatic Region)	2
	Functional Classification	26
	Year Built	27
	Year Reconstructed	106
	Structure Authority (Structure Number)	8
	Type of Service on Bridge	42A
Rating	Inspection Date	90
	Deck Condition Rating	58
	Superstructure Condition Rating	59
	Substructure Condition Rating	60

State	Description
N	NOT APPLICABLE
9	EXCELLENT CONDITION
8	VERY GOOD CONDITION - no problems noted.
7	GOOD CONDITION - some minor problems.
6	SATISFACTORY CONDITION
5	FAIR CONDITION
4	POOR CONDITION
3	SERIOUS CONDITION
2	CRITICAL CONDITION
1	"IMMINENT" FAILURE CONDITION
0	FAILED CONDITION

3- Data Analysis

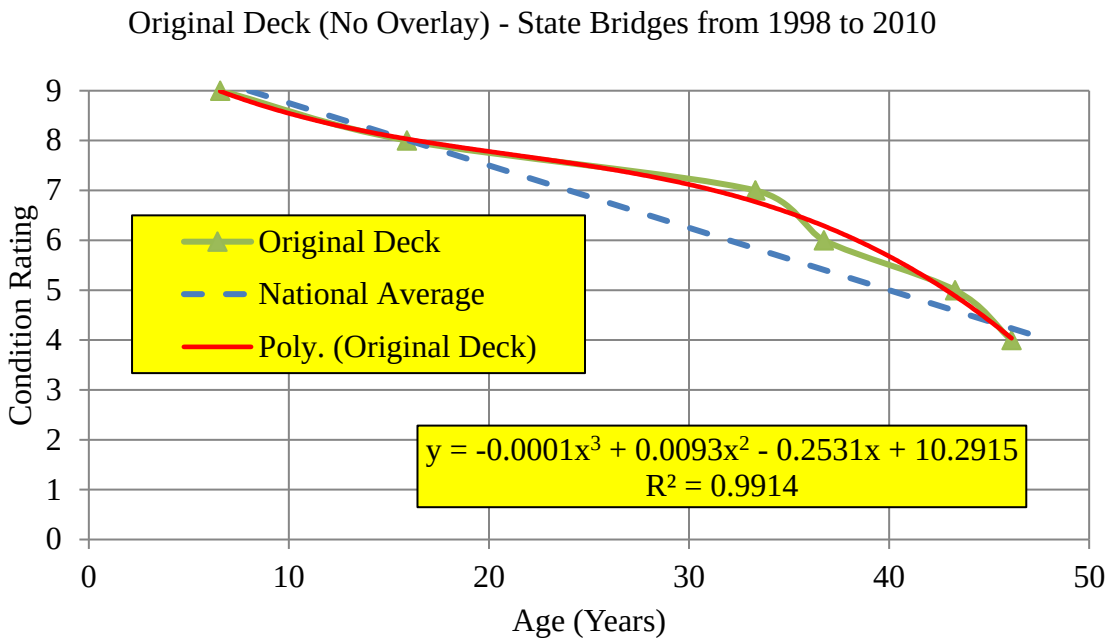
- The following records were eliminated:
  - Not applicable or blank condition data (culverts)
  - Duplicate records
  - Records with the same year built and year reconstructed
  - Records with unrecorded major maintenance actions (Outliers)

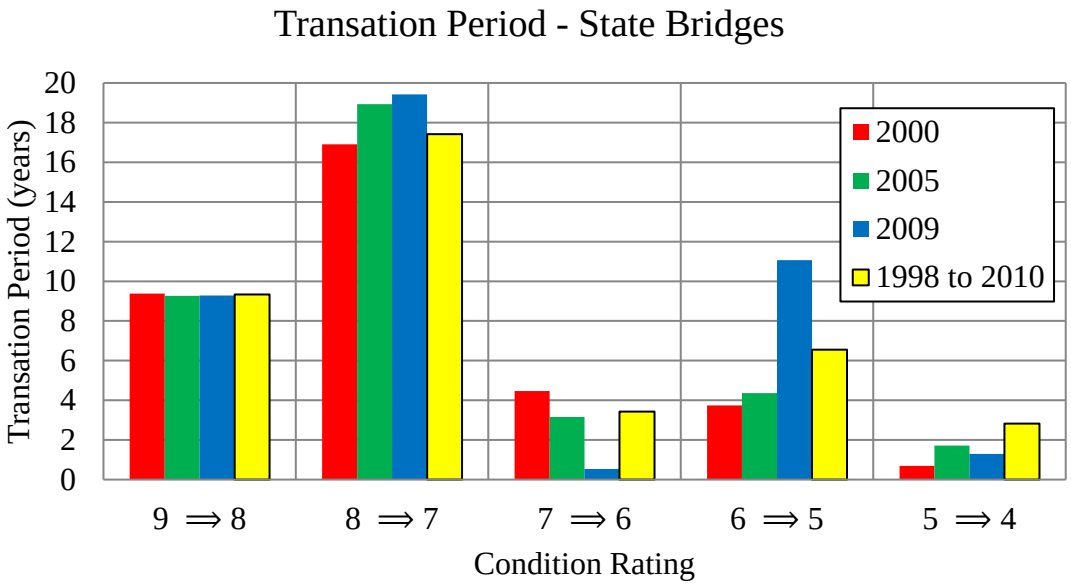
year 2010

Condition Rating	Deck	Superstructure	Substructure
0	53	51	49
1	2	4	7
2	6	22	28
3	68	153	329
4	503	702	947
5	3679	1731	1799
6	1642	1784	1683
7	1987	2593	2684
8	3026	3263	3003
9	1435	2140	1913
N	3415	3373	3374
Blank	0	0	0
Total	15816	15816	15816

4- Deterministic Deterioration Models - Original Deck

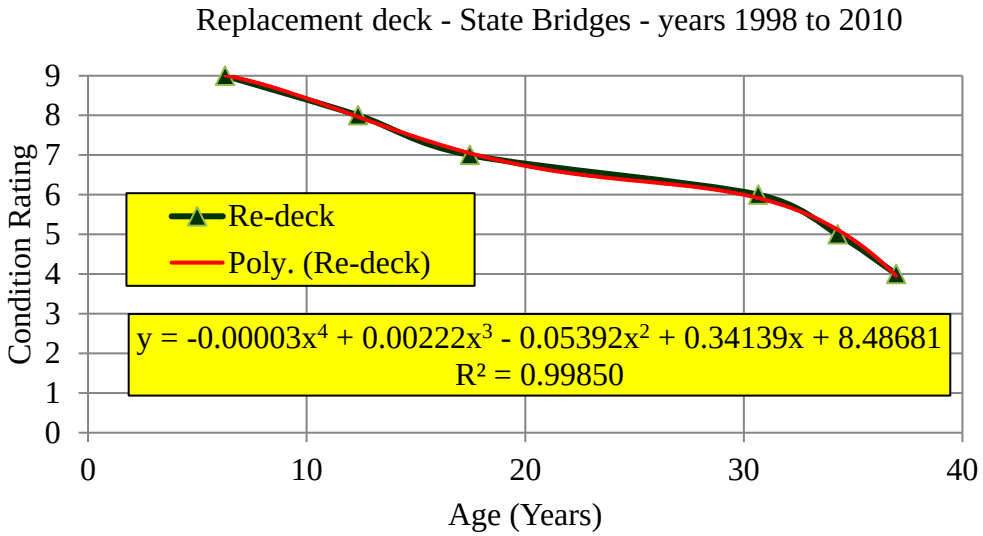
✓ Original Deck

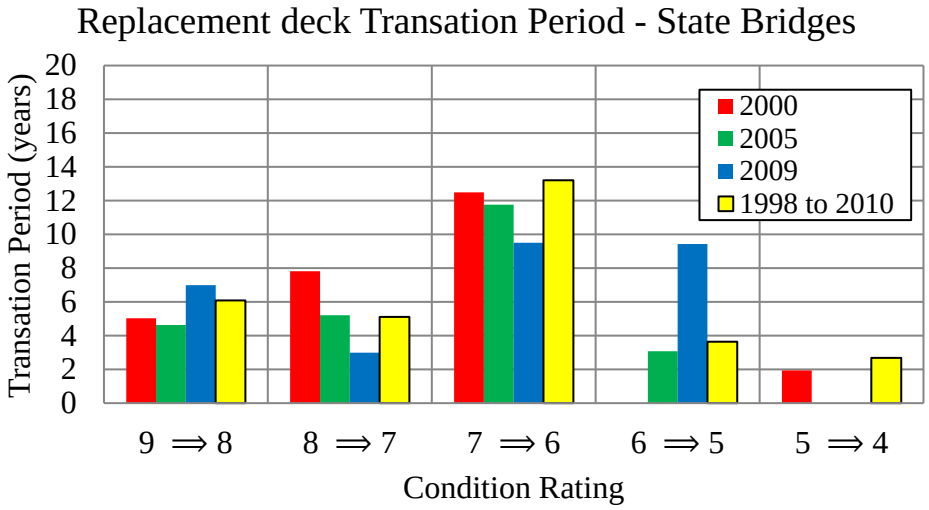


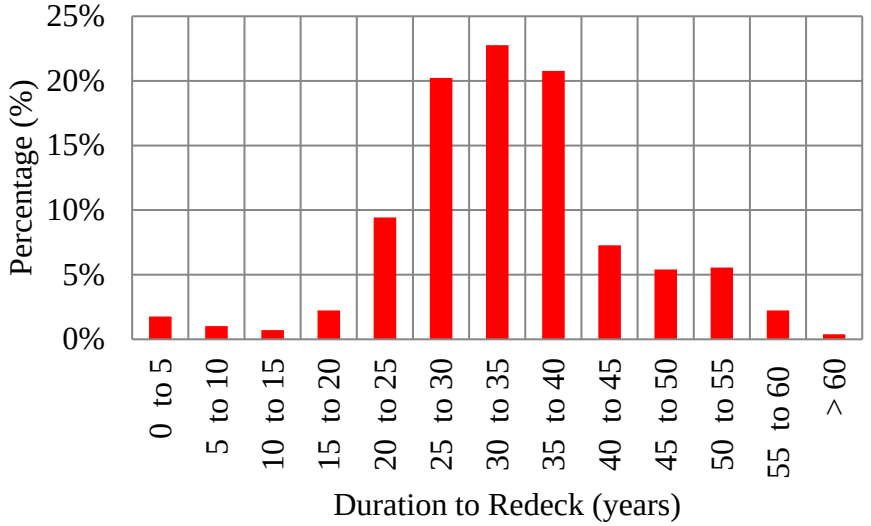


4- Deterministic Deterioration Models - Replacement Deck

✓ Replacement Deck



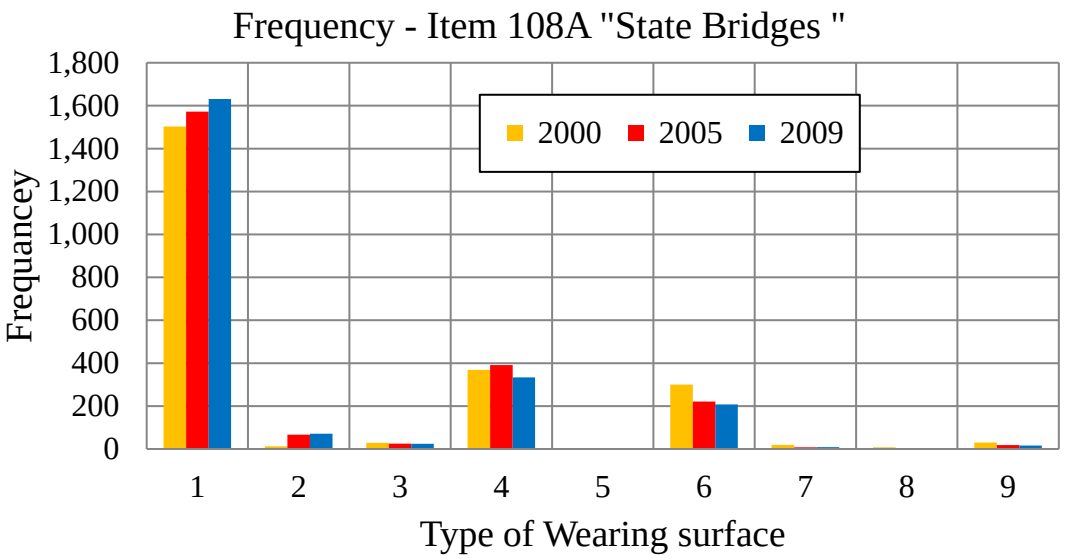


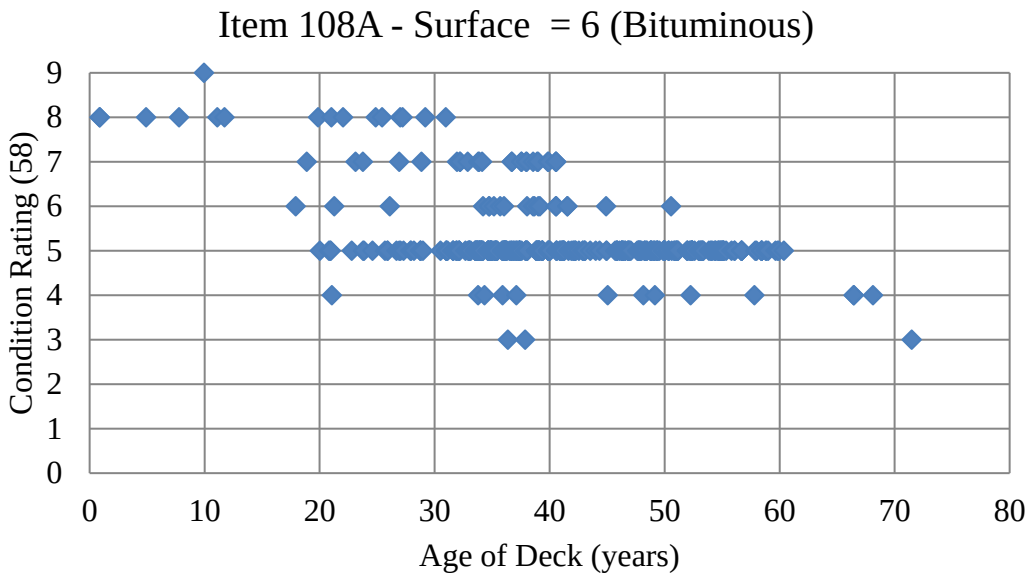


4- Deterministic Deterioration Models - Wearing Surface

✓ Type of wearing surface

None	0
Concrete	**1**
Silica fume	2
Latex concrete	3
Low slump con.	**4**
Epoxy overlay	5
Bituminous	**6**
Timber	7
Gravel	8
Other	9
Not applicable	N

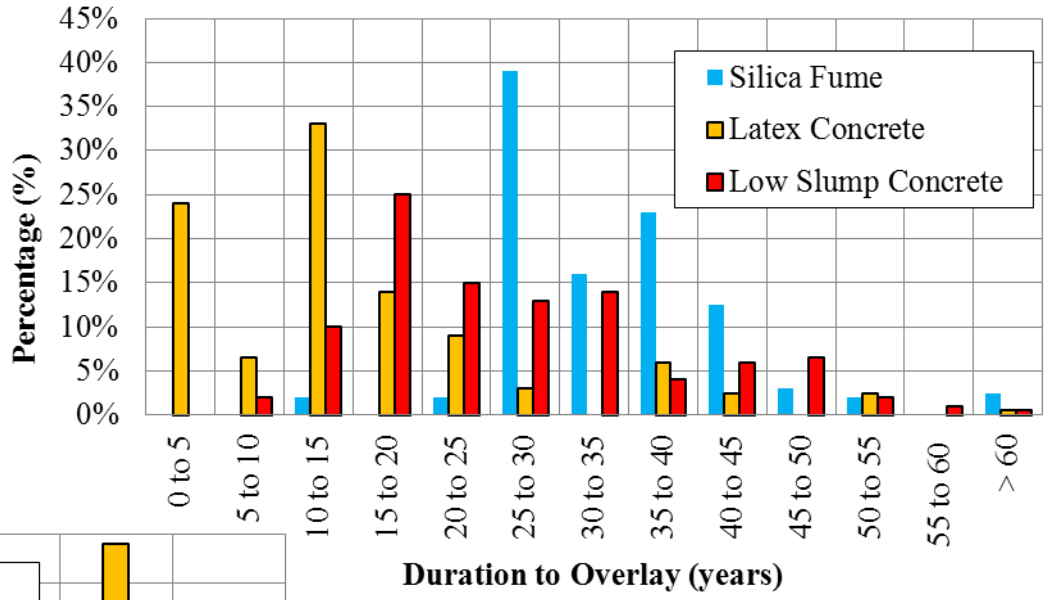


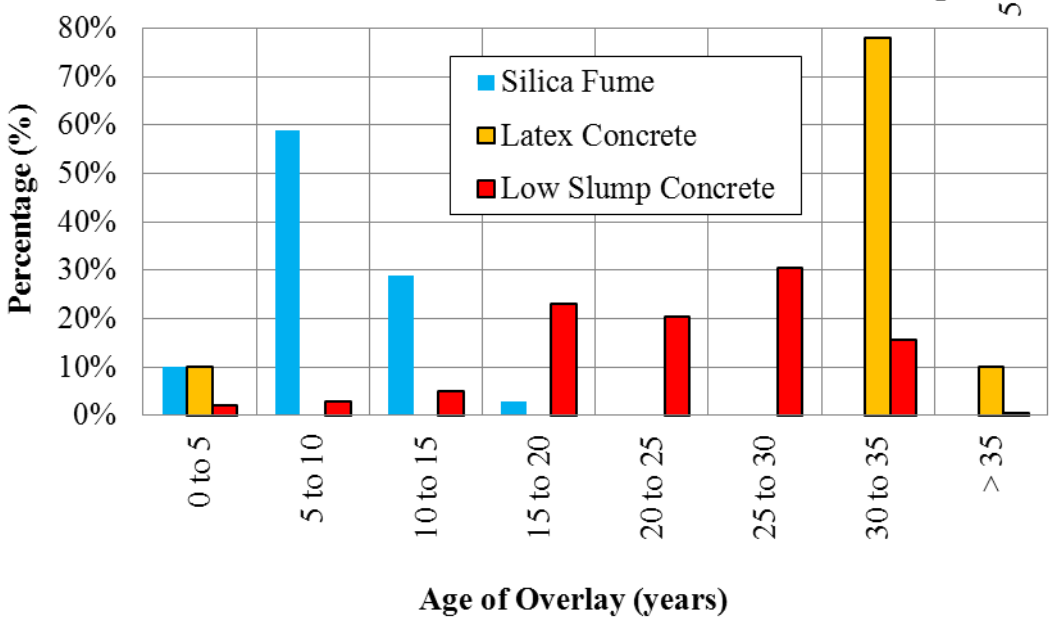


4- Deterministic Deterioration Models – Wearing Surface

Deck Overlays

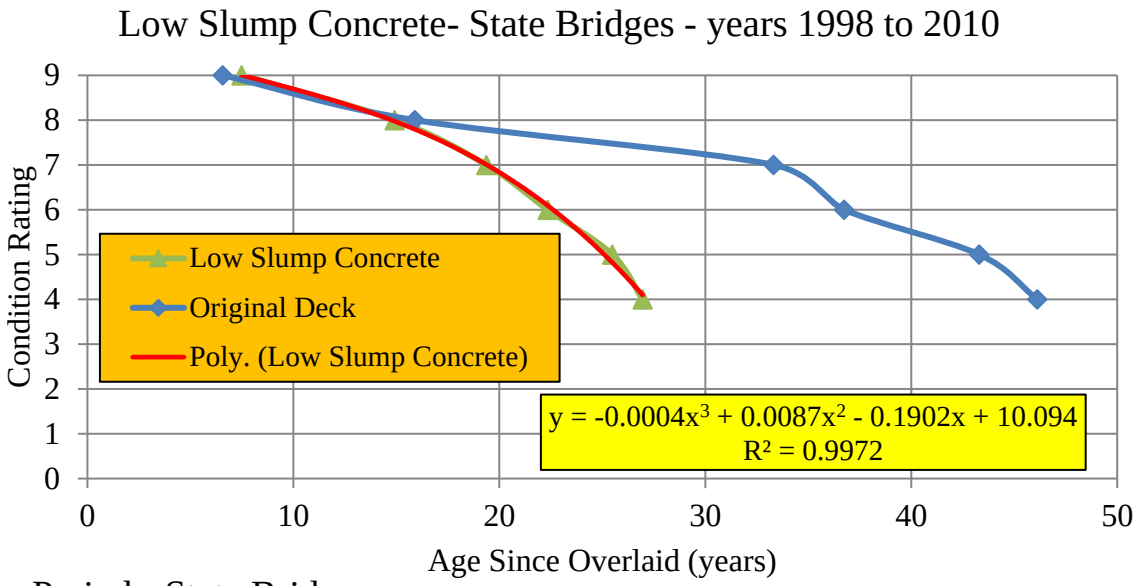
- ✓Silica Fume (70 data)
- ✓Latex Concrete (27 data)
- ✓Low Slump Concrete (338 data)

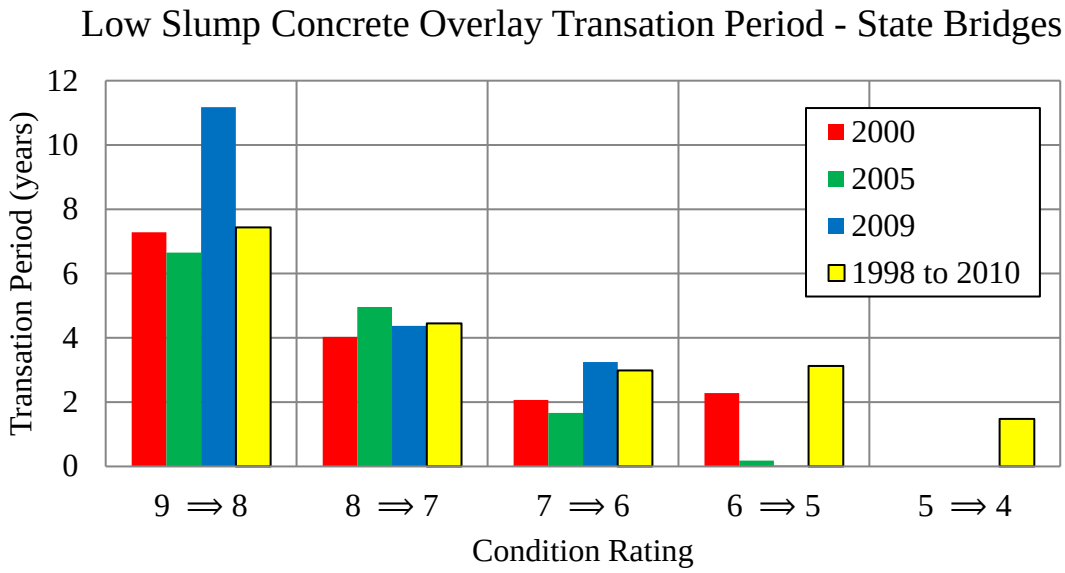




4- Deterministic Deterioration Model – Wearing Surface

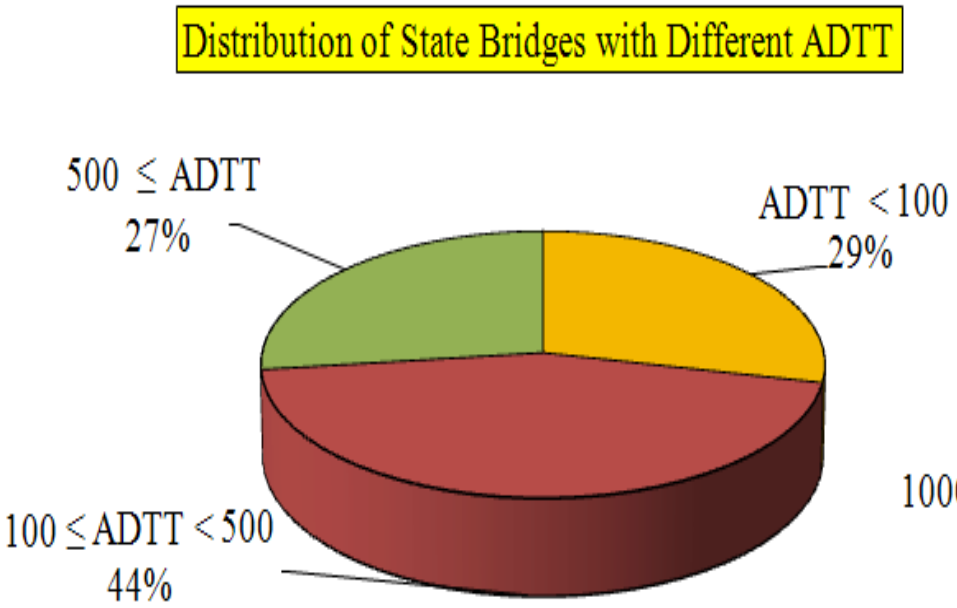
✓Low Slump Concrete

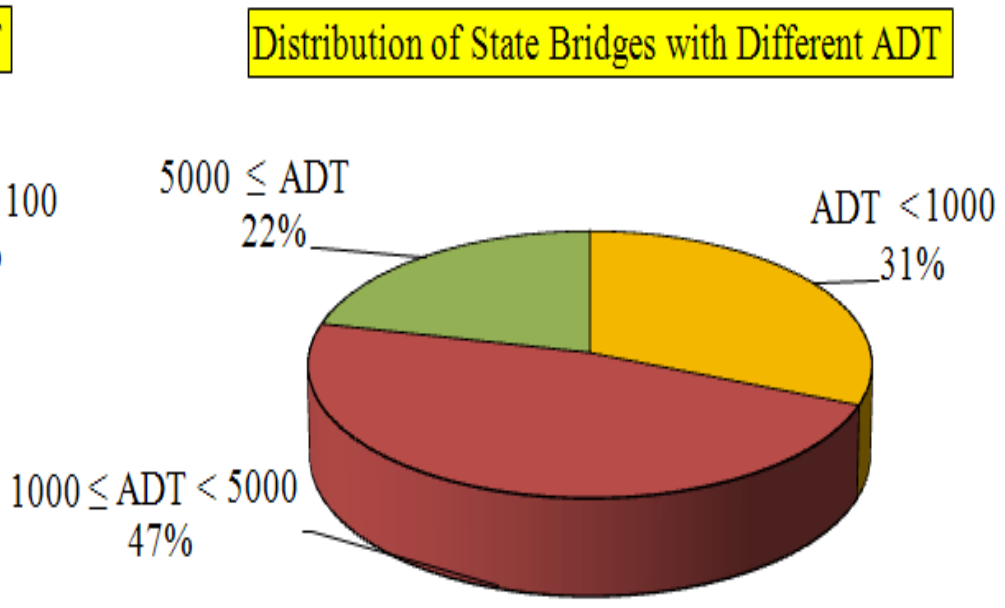




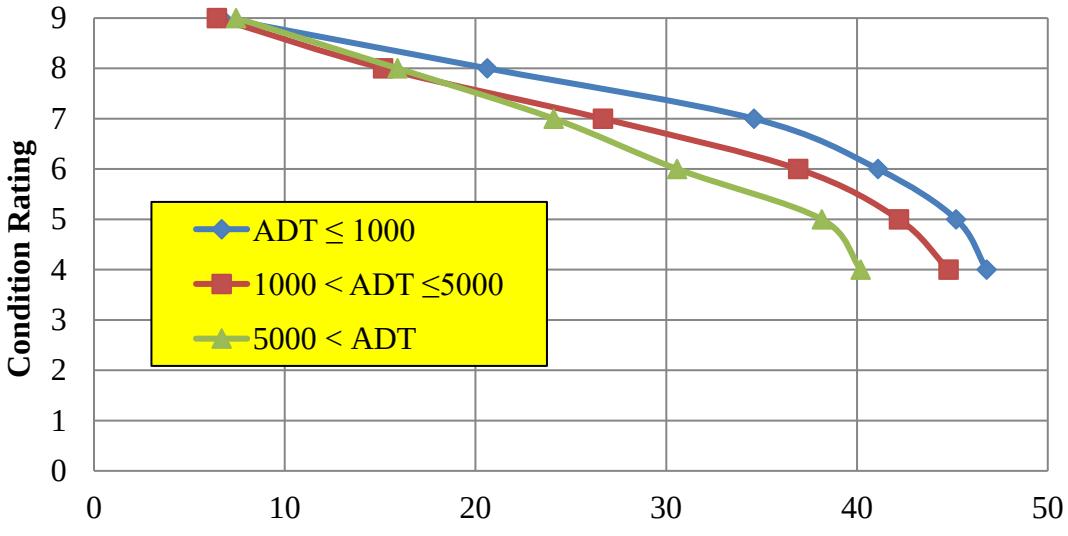
4- Deterministic Deterioration Models - Deck

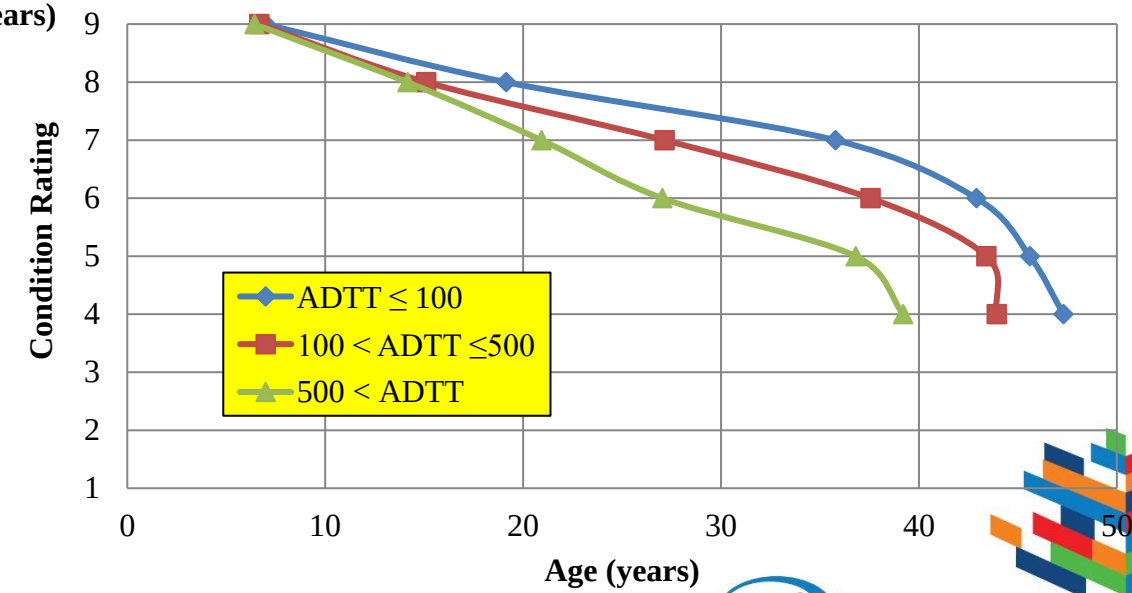
✓Average Daily Traffic (ADT) & Average Daily Truck Traffic (ADTT)





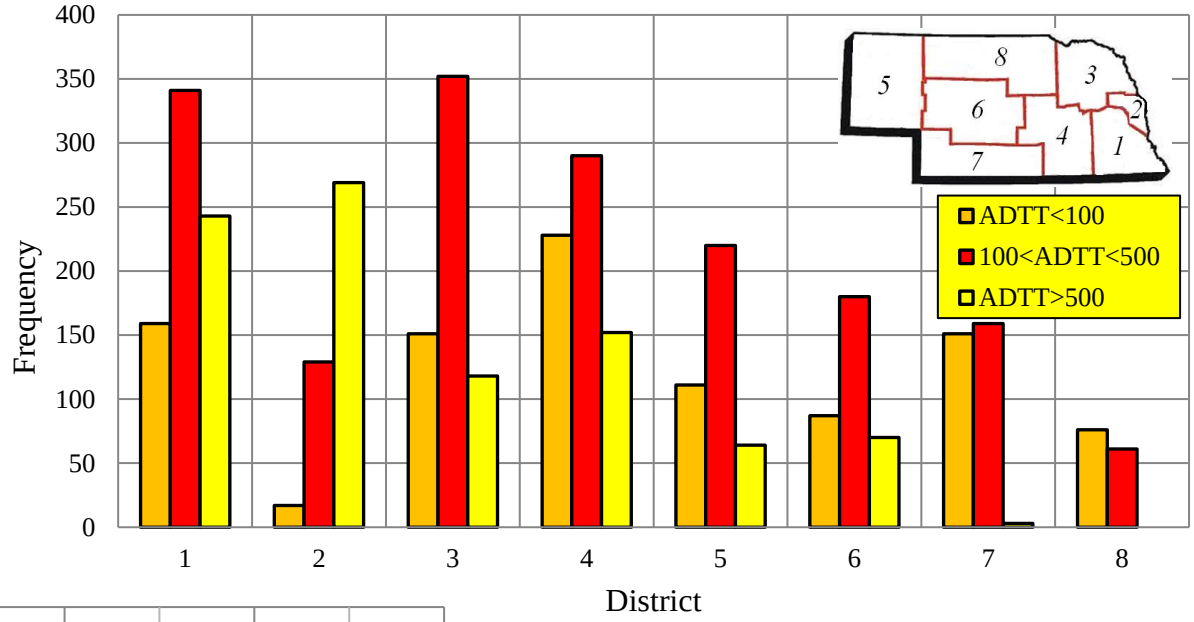
4- Deterministic Deterioration Models - Deck

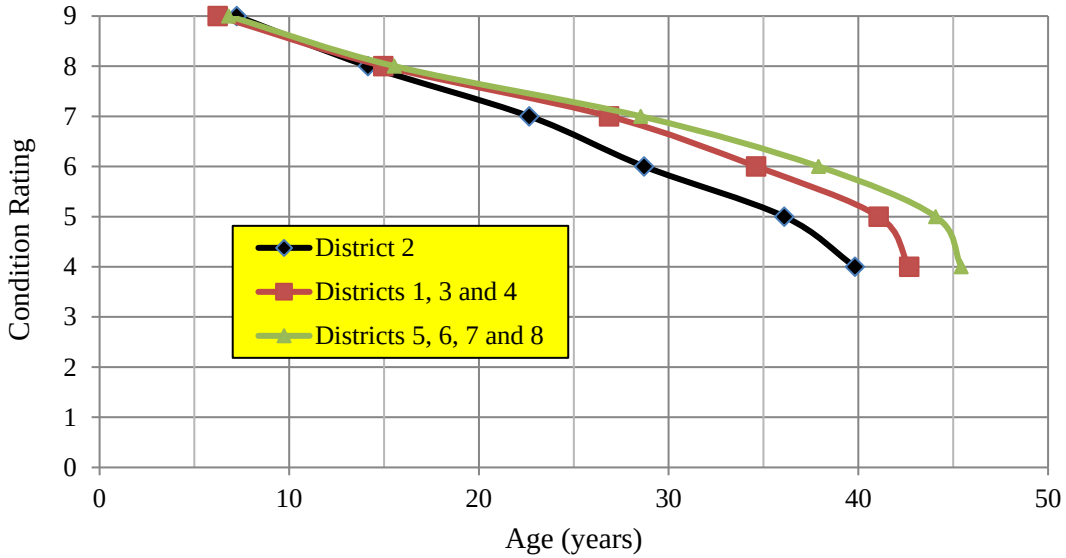




4- Deterministic Deterioration Models - Deck

✓Highway Agency District





5- Stochastic Deterioration Models

- Markov-chain models predict the transition probability from one condition state to another given the transition period

  $p_{i,j}$: *probability of a bridge element transiting from one condition state, say i, to a lower condition state, j,*

$$P(t) = P(0) * P^t$$

$$\mathbf{P}=\begin{bmatrix} p_{1,1} & p_{1,2} & \cdots & p_{1,n} \\ p_{2,1} & p_{2,2} & \cdots & p_{2,n} \\ \cdot & \cdot & \cdots & \cdot \\ \cdot & \cdot & \cdots & \cdot \\ p_{n,1} & p_{n,2} & \cdots & p_{n,n} \end{bmatrix}$$

P(0): the present condition of a bridge component

*P(t) :*the future condition vector at any number of transition periods *(t)*

- Transition probabilities were determined using the percentage prediction method.

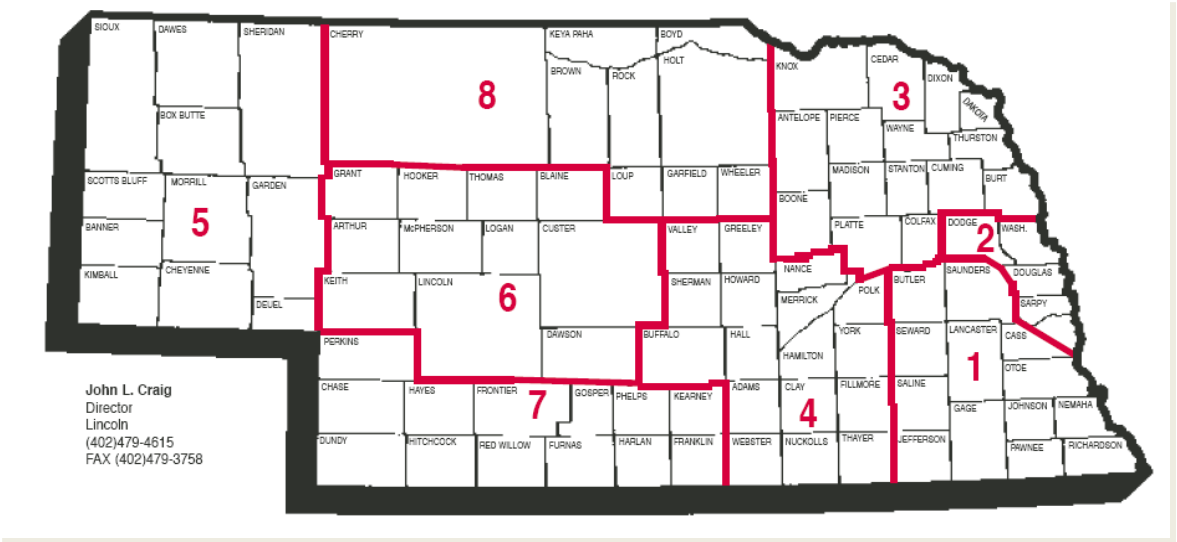
$$p_{i,,j} = n_{i,j} / n_i$$

$n_{i,j}$ = *number of transitions from state i to state j within a given time period,*

n_i = *total number of bridges in state i before the transition.*

5- Stochastic Deterioration Models - Deck

Environment / Category / District	Low Environment (ADT < 1000 & ADTT < 100)	Moderate Environment (1000 < ADT < 5000 & 100 < ADTT < 500)	Sever Environment (ADT > 5000 & ADTT > 500)	Total
Omaha and metro-politan area (district 2)	5%	15%	**80%**	100%
Eastern Nebraska (districts 1,3 & 4)	18%	**49%**	33%	100%
Western Nebraska (districts 5, 6, 7 & 8)	**48%**	38%	14%	100%



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5- Stochastic Deterioration Models - Deck

➢Low Environment

Condition	9	8	7	6	5	4	3	2	1
9	0.66	0.33	0	0	0	0	0	0	0
8	0	0.94	0.03	0.03	0	0	0	0	0
7	0	0	0.78	0.20	0.02	0	0	0	0
6	0	0	0	0.91	0.08	0.01	0	0	0
5	0	0	0	0	0.95	0.05	0	0	0
4	0	0	0	0	0	1.00	0	0	0
3	0	0	0	0	0	0	1.00	0	0
2	0	0	0	0	0	0	0	1.00	0
1	0	0	0	0	0	0	0	0	1.00

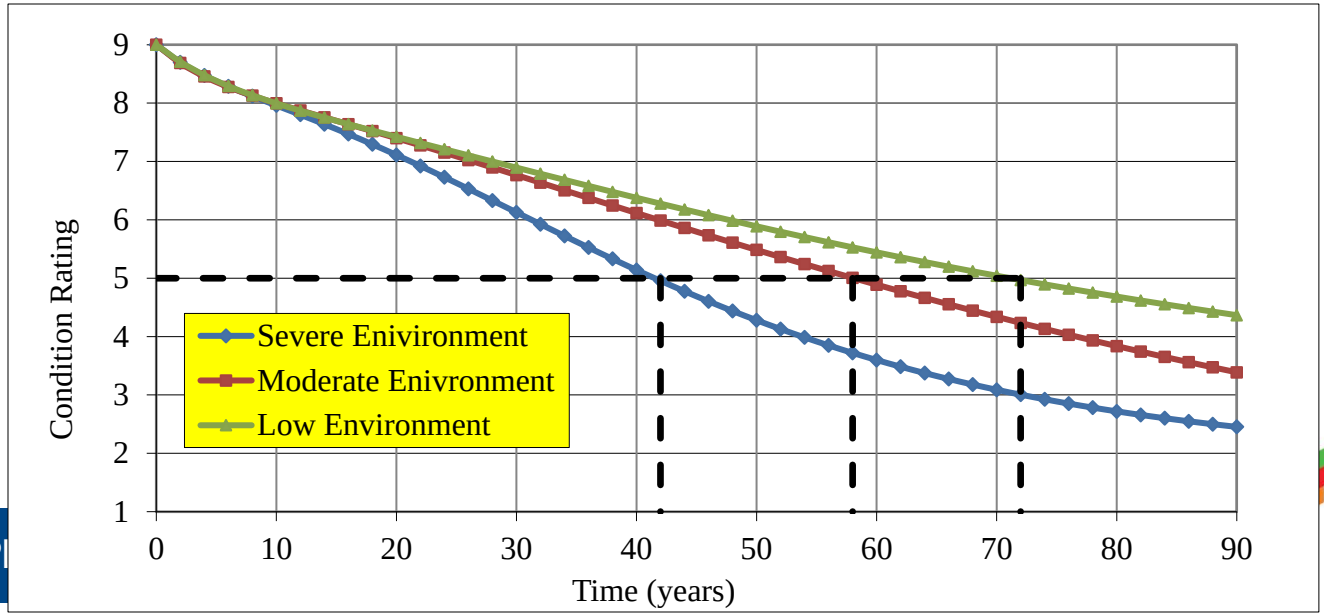
➢Moderate Environment

Condition	9	8	7	6	5	4	3	2	1
9	0.68	0.31	0.01	0.01	0	0	0	0	0
8	0	0.93	0.04	0.03	0	0	0	0	0
7	0	0	0.76	0.17	0.07	0	0	0	0
6	0	0	0	0.79	0.19	0.01	0	0	0
5	0	0	0	0	0.91	0.08	0	0	0
4	0	0	0	0	0	1.00	0	0	0
3	0	0	0	0	0	0	1.00	0	0
2	0	0	0	0	0	0	0	1.00	0
1	0	0	0	0	0	0	0	0	1.00

5- Stochastic Deterioration Models - Deck

➢Severe Environment

Condition	9	8	7	6	5	4	3	2	1
9	0.70	0.29	0.01	0	0	0	0	0	0
8	0	0.89	0.04	0.07	0	0	0	0	0
7	0	0	0.87	0.10	0.03	0.01	0	0	0
6	0	0	0	0.87	0.11	0.02	0	0	0
5	0	0	0	0	0.91	0.07	0.02	0	0
4	0	0	0	0	0	0.97	0.03	0	0
3	0	0	0	0	0	0	1.00	0	0
2	0	0	0	0	0	0	0	1.00	0
1	0	0	0	0	0	0	0	0	1.00



LCCA: Parameters

Analysis Period (N):

- ✓ Long enough to include at least one major activity for each alternative. (NCHRP 483)
- ✓ Longer than pavements (*N* is greater than 40 years) (Setunge et al., 2002)
- ✓ Analysis Period = 60 years

Discount Rate (d):

$$d = (1+e)(1+f)(1+i) - 1$$

e: the "real" opportunity cost of capital

f: the required premium for financial risk associated with investments

i: the anticipated rate of inflation in prices

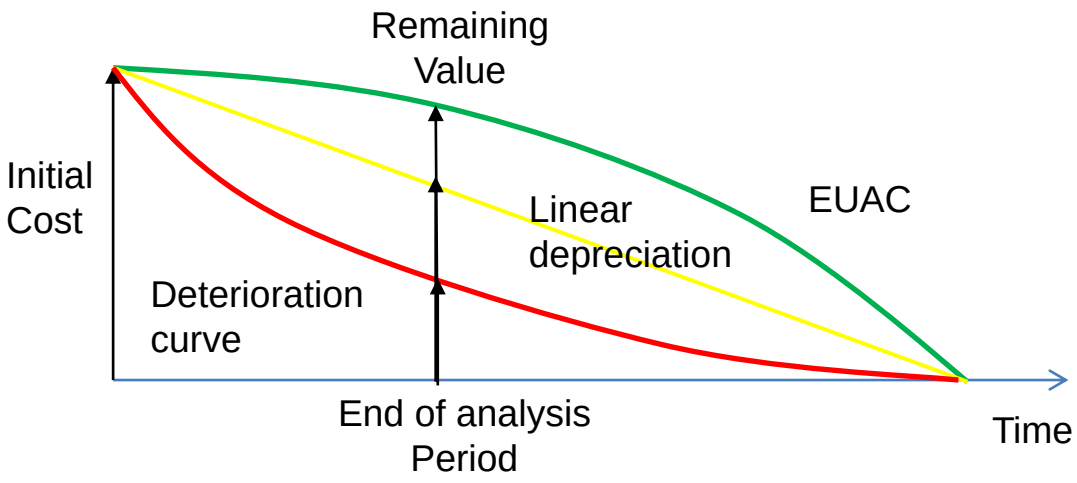
- ✓ NDOT use a current real discount rate of 3% per annum
- ✓ Premium associated with financial risk in investments is eliminated.
- ✓ Use nominal cost with nominal discount rate or constant cost with real discount rate

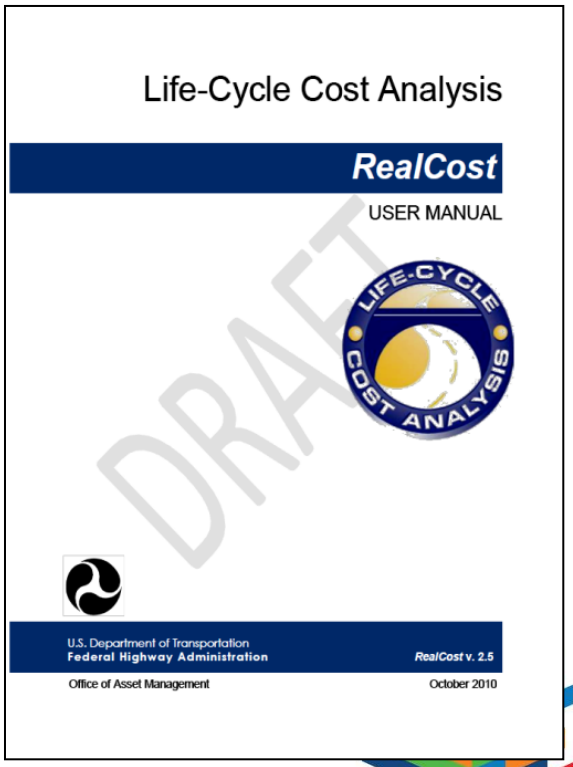
Analysis Type	Nominal (actual)	Real (constant)
Discount/Interest Rate	Nominal Rate (includes inflation i) $d = (1+e)(1+i) - 1$	Real Rate (does not include inflation i) e
Equivalent Present Value	$P = F(1+d)^{-n}$	$P = F(1+e)^{-n}$
Estimated Future Cost	Today's Cost multiplied by $(1+i)^n$	Today's Cost

LCCA: Parameters

Remaining Value (RV):

- Remaining value is not the salvage value
- Linear depreciation is used to calculate the remaining value when the structural life extends beyond the end of the analysis period.





LCCA: NDOT Cost Data

Type	Code	Work Description	Unit Price	Units
Sub	3060	Abutment Repairs	$49	SF
Sub	3090	Replace Existing Abutment Turndowns	$400	urndown
Super	4010	Repair Steel Girders	$23,766	EA
Super	4020	Replace Bearing Devices	$2,858	EA
Super	4050	Repair Bearing		LS
Super	4080	Clean and Reset Bearings	$2,000	EA
Super	4090	Repair End of Conc. Girders	$2,500	EA
Deck	5050	Replace Expansion Joint	$300	LF
Deck	5090	Polymer Overlay	$6	SF
Deck	5100	Remove Concrete Overlay	$3	SF
Deck	5110	Class I deck repairs	$2	SF
Deck	5120	Class II deck repairs	$12	SF
Deck	5130	Class III deck repairs	$60	SF
Deck	5140	Class I, II and III Deck Repairs	$7	SF
Deck	5150	Class I, II and III Deck Repairs, 2 in. Silica Fume Overlay	$30	SF
Deck	5160	Class 5 Mill to Remove Asphalt Overlay	$1	SF
Deck	5170	Bridge Deck Repair (Partial and Full Depth)	$27	SF
Deck	5180	Partial Depth Deck Repair	$13	SF
Deck	5190	Full Depth Deck Repair	$60	SF
Deck	5200	2 in. Asphalt Overlay w/ Membrane	$3	SF
Deck	5240	Concrete Repairs	$82	SF
Deck		5% Class I repair: 0.05*$2 = 0.1$/SF	$0.1	SF
Deck		2% Class III + 10% Class II repair: 0.02*60 + 0.1*12 =2.4$/SF	$2.4	SF
Deck		6% Class III + 29% Class II repair: 0.06*60 + 0.29*12 = 7.1$/SF	$7.1	SF
Deck		10% Class III + 60% Class II repair: 0.10*60 + 0.60*12 = 13.2$/SF	$13.2	SF
Deck		Low slump concrete overlay	$10	SF
W/RRR	6010	Widen to --ft clear width	$180	SF
W/RRR	6020	Widen to --ft clear width and 2 in. Silica Fume Overlay	$70	SF
W/RRR	6030	Widen to --ft clear and Re-deck	$65	SF
W/RRR	6040	Redeck	$50	SF
W/RRR	6050	Rehab Bridge	$70	SF
W/RRR	6060	Widen to --ft clear width and Rehab	$70	SF
W/RRR	6070	Replace with -- ' x --' clear Bridge	$105	SF

LCCA: Example

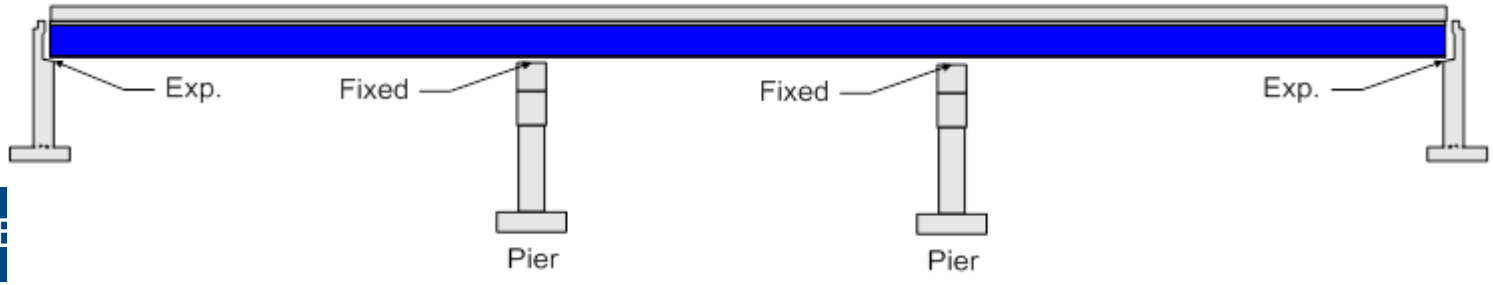
Five alternatives are compared:

Alternative 1) Bare Deck
Alternative 2) Silica Fume Overlay (SFO) on Deck at Condition 5
Alternative 3) Silica Fume Overlay (SFO) on Deck at Condition 6
Alternative 4) Epoxy Polymer Overlay (EPO) on Deck at Condition 7
Alternative 5) Polyester Overlay (PO) on Deck at Condition 7

Project Information

3 lanes, 3 spans
ADT = 14,910
ADTT = 1,490
Length = 257 ft
Width = 47 ft
Area = 12,079 ft^2

Bridge ID	S07706205L
Location	Lincoln west bypass
Year built	1989
Design type	Steel continuous
Construction type	Stringer/Multi girder
Functional classification	Urban
Deck structure type and wearing	Concrete



Alternative 1) Bare Deck

Service Life

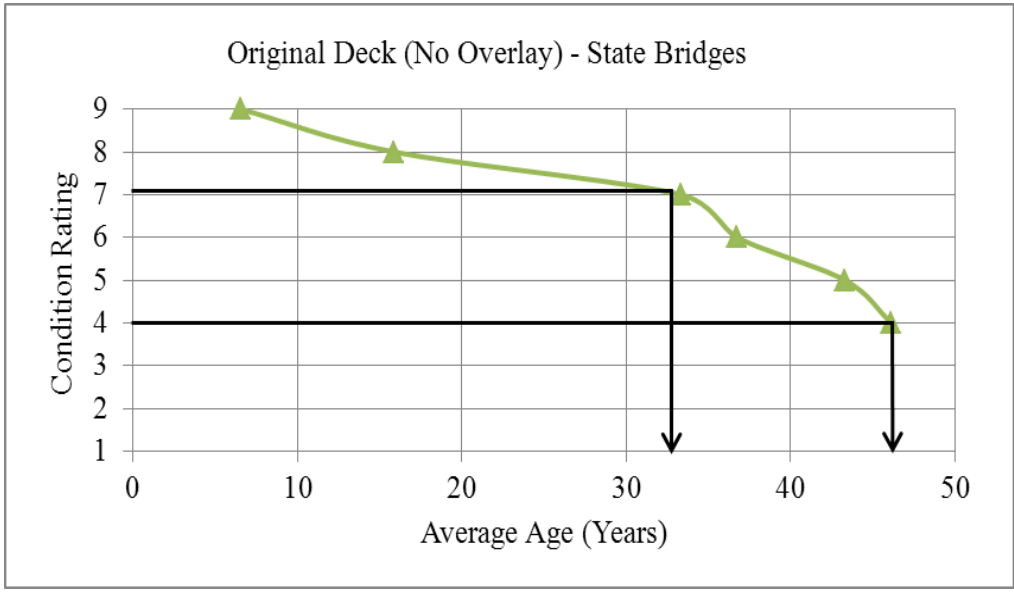
Bare Deck = 47 years (NDOT Data)
Replacement Deck = 37 years (NDOT Data)

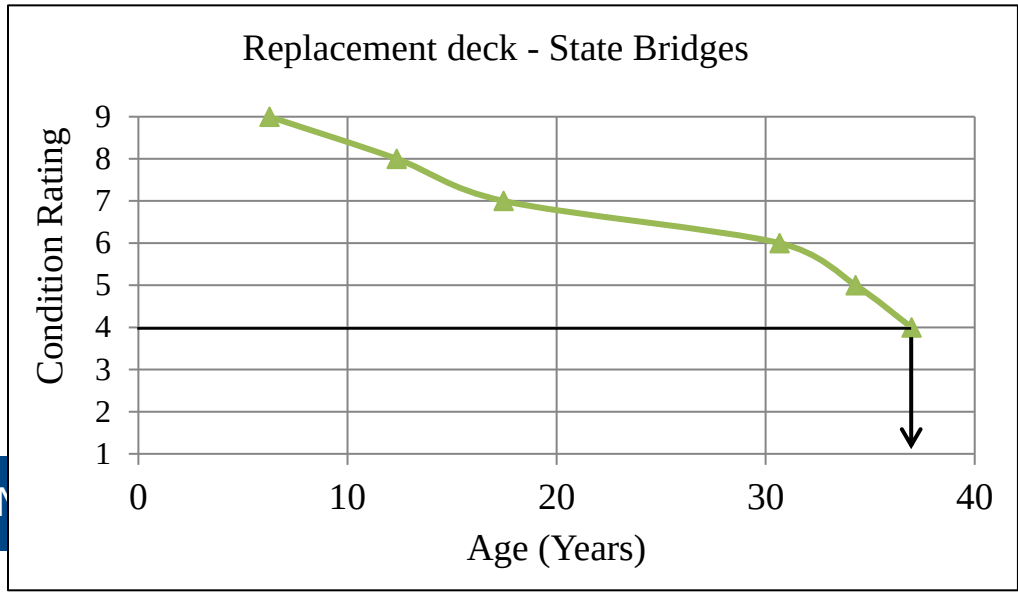
Maintenance Sequence

There is no action for 47 years then deck will be replaced at that time.

Cost

Deck Replacement = 50$/SF



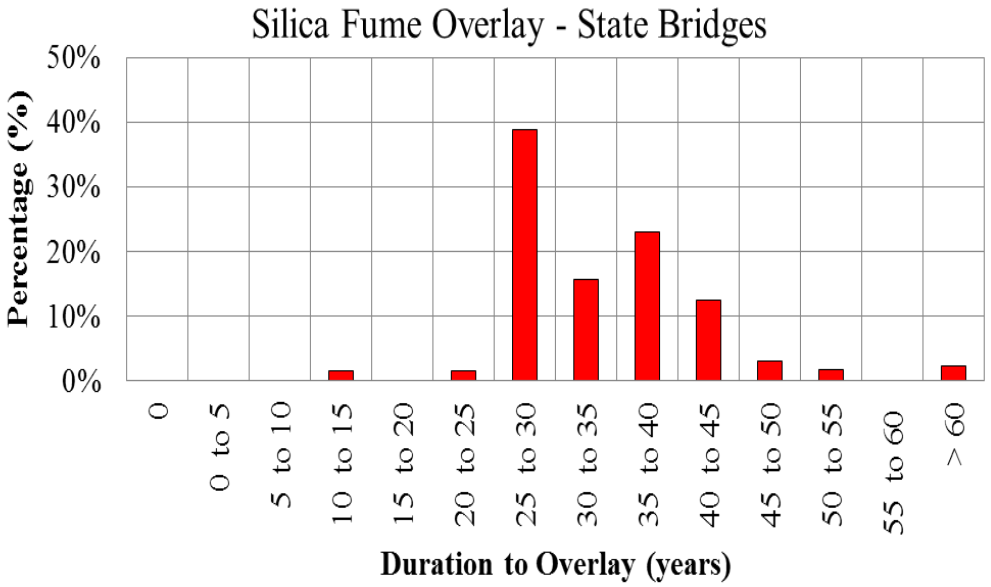


Alternative 2) SFO on Deck at Condition 5

Service Life

SFO= 25 years (NDOT Data)

Deck age at condition 5 = 42 years



Maintenance Sequence

There is no action for 42 years then SFO will be applied

Cost

SFO= 30$/SF (Including deck repair)

Alternative 3) SFO on Deck at Condition 6

Service Life

SFO= 25 years (NDOT Data)

Deck age at condition 6 = 37 years

Maintenance Sequence

There is no action for 37 years then SFO will be applied

Cost

SFO= 25.3$/SF (Including deck repair)

Alternative 4) EPO on Deck at Condition 7

Service Life

EPO= 15 years (NCHRP 423)
Deck age at condition 7 = 32 years

Maintenance Sequence

First application: condition 7 or year 15, whichever is first.

Cost

EPO= 6$/SF
After 2 EPO applications, add cost of 3$/SF for removal at time of next application.

Alternative 5) PO on Deck at Condition 7

Service Life

PO= 20 years (NCHRP 423)

Deck age at condition 7 = 32 years

Maintenance Sequence

First application: condition 7 or year 15, whichever is first.

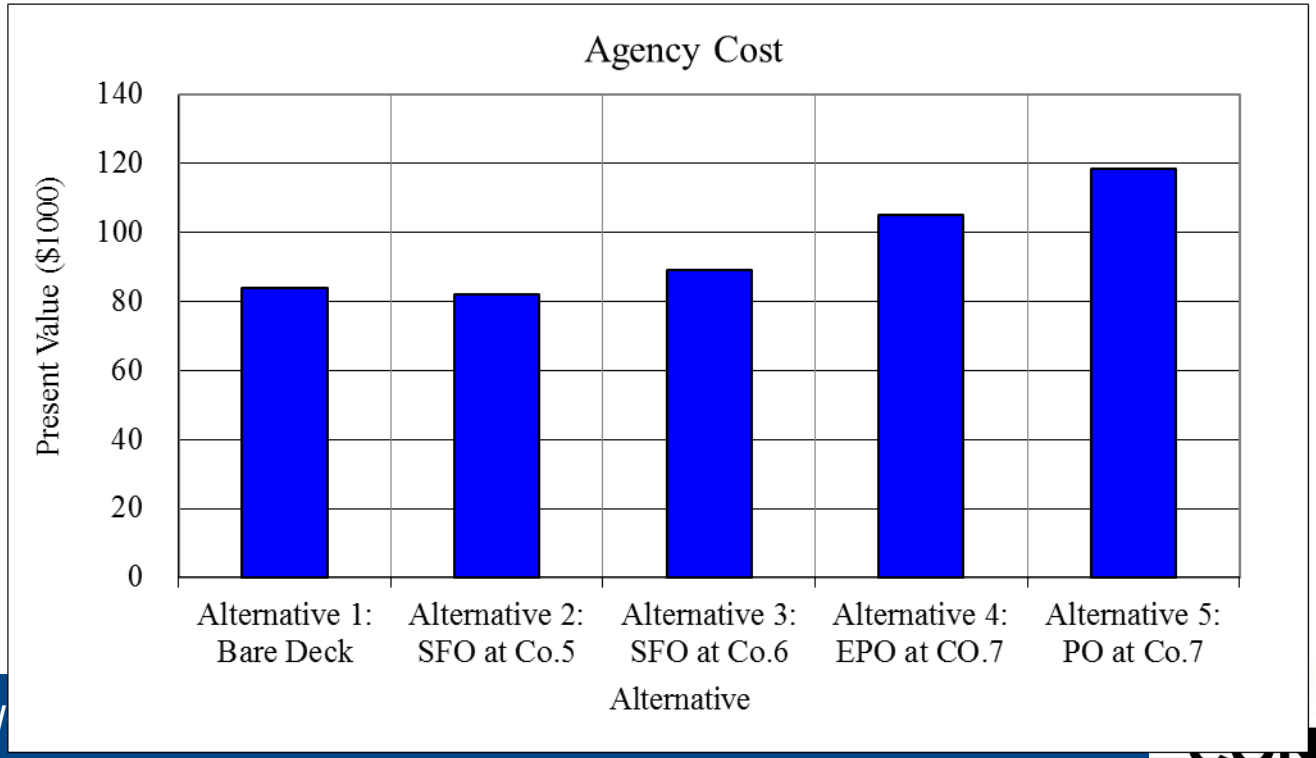
Cost

EPO= 9$/SF

After 2 PO applications, add cost of 3$/SF for removal at time of next application.

RealCost Results

Total Cost	Agency Cost ($1,000)				
	Alternative 1: Bare Deck	Alternative 2: SFO at Co.5	Alternative 3: SFO at Co.6	Alternative 4: EPO at Co.7	Alternative 5: PO at Co.7
Undiscounted Sum	$212.20	$246.41	$255.59	$253.66	253.66
Present Value	$84.05	$81.98	$89.29	$105.12	$118.48
EUAC	$3.04	$2.96	$3.23	$3.80	$4.28



7- Conclusions

1. Deterioration rate for original concrete decks in state of Nebraska is slightly lower than the national average.

2. The higher the traffic volume (ADT and ADTT), the higher the deterioration rate of concrete bridge decks. Therefore, Bridge decks in state bridges in highway district 2 have higher deterioration rates than those in districts 1, 3, and 4, which is higher than those in districts 5, 6, 7, and 8.

3. Silica Fume Overlay (SFO) on bridge deck at condition 5 has the lowest net present value (NPV) compared to other deck overlay alternatives.

Thank You

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