



Determining Deterioration Models Using Inspection Data in Florida

**2011 Southeast Bridge Preservation Partnership
(SEBPP) Meeting**

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By

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Acknowledgement

- Paul D. Thompson, Co-PI and consultant on the various research grants; primary developer of the bridge deterioration models.
- Richard Kerr, FDOT State Maintenance Office, project manager on the research grants.

Overview

- Historical perspectives on bridge deterioration models – Nationwide and Florida.
- Progressive research efforts on bridge deterioration at Florida DOT (1998 – 2010).
- Markov-based models based on expert judgment.
- Use of element-level condition data to show bridge preservation.
- NBI Translation of element-level condition data.
- Recent research efforts: Improved Markov models; action effectiveness models; and hybrid Weibull-Markov deterioration models.

Historical perspectives

- Component-based bridge inspection (NBI ratings) and original FHWA's linear deterioration models for bridge major components.
- Stochastic models of bridge deterioration.
- Bridge preservation models with deterioration and action improvement predictions.

Historical perspectives

- Element-level bridge inspection started in 1998 in Florida.
- Initial deterioration model in 1998 based on *Pontis* Default (California) data.
- Markov-based model developed from expert opinion in 2001.
- Project Level Analysis Tools (PLAT) and Network Analysis Tools (NAT) developed in 2004/2006.
- Improved deterioration/action effectiveness models developed in 2010.

Markovian Deterioration Models

- The state of an element can be described at any point in time as a distribution among a number of condition states.
- Assumes that the probability of making a transition from one condition state to another depends only on the initial state, and not on past conditions or any other information about the element.
- Model is expressed as simple matrix of transition probabilities for the element's environmental class (Benign, Low, Moderate, or Severe).

Markovian Deterioration Models

- Conditions at any future period can be predicted by simple matrix multiplication.

TRANSITION PROBABILITIES					PREDICTED CONDITIONS				
	ToState				Year	State1	State2	State3	State4
FromState	1	2	3	4					
1	96.93	3.07	0.00	0.00	2001	100.00	0.00	0.00	0.00
2	0.00	96.37	3.63	0.00	2002	96.93	3.07	0.00	0.00
3	0.00	0.00	92.38	7.62	2003	93.95	5.93	0.11	0.00
4	0.00	0.00	0.00	87.06	2004	91.07	8.60	0.32	0.01
					2005	88.27	11.09	0.61	0.03
					2006	85.56	13.39	0.96	0.08
Failure probability		12.94%			2007	82.94	15.53	1.38	0.15
All amounts in percent					2008	80.39	17.52	1.83	0.26
					2009	77.92	19.35	2.33	0.40
					2010	75.53	21.04	2.86	0.57
					2011	73.21	22.59	3.40	0.79

Markovian Deterioration Model: Expert Judgment (2001)

- Transition probabilities estimated based on the median no. of years between transition.
- If it takes T years for 50% of a population of elements to transition from one state to the next, then the probability in a one-year period of staying in the starting condition state can be calculated from:

$$P = 0.5^{(1/T)}$$

- For example, if it takes a median of 6 years to transition from state 1 to state 2, then the transition probability of staying in state 1 is 0.89 or 89%. If we assume that all the rest of the element deteriorates to state 2, then the transition probability from state 1 to state 2 is $(1-P) = 0.11$ or 11%.

Markovian Deterioration Model: Expert Judgment (2001)

- Expert opinions elicited from FDOT Bridge Engineers on 136 bridge elements.
- Summary of results by element category:

Category	Element Count	Do-Nothing		Do-Something		Median Years Out of State					Median Time to Failure
		Average Coef of Variation	Response Rate	Average Coef of Variation	Response Rate	1	2	3	4	5	
Decks/Slabs	12	0.28	65%	0.22	72%	11.5	8.8	8.1	4.7	3.0	50
Superstructure	32	0.14	38%	0.09	42%	17.6	10.4	6.6	4.7	4.0	59
Substructure	31	0.22	58%	0.16	58%	18.7	9.2	6.7	4.7		52
Joints	6	0.29	71%	0.14	67%	7.4	5.0	2.8			21
Bearings	5	0.20	75%	0.14	74%	18.3	12.5	7.8			50
Railing	5	0.19	62%	0.09	59%	17.1	13.3	9.0	8.3		64
Movable	29	0.43	71%	0.23	68%	7.9	6.9	4.9	4.1		33
Other Elements	16	0.20	44%	0.10	37%	17.1	14.6	11.5	6.8		68
Total	136	0.25	55%	0.15	55%						

Markov-based Deterioration Model: Expert Judgment (2001)

- Expert opinions elicited from FDOT Bridge Engineers on 136 bridge elements.
- Summary of results by material type:

Material	Element Count	Do-Nothing		Do-Something		Median Years Out of State					Median Time to Failure
		Average Coef of Variation	Response Rate	Average Coef of Variation	Response Rate	1	2	3	4	5	
Unpainted Steel	17	0.08	18%	0.04	18%	17.6	11.9	8.2	5.2		58
Painted Steel	17	0.22	59%	0.12	57%	14.0	8.1	7.2	5.2	4.8	55
Prestressed Concrete	8	0.28	62%	0.14	58%	25.1	11.5	7.5	4.6		63
Reinforced Concrete	18	0.29	78%	0.24	78%	24.0	13.4	9.0	5.8		69
Timber	11	0.12	29%	0.08	28%	11.4	9.8	6.1	4.7		44
Other	24	0.20	48%	0.10	48%	12.6	10.5	6.9			40
Decks	7	0.32	70%	0.25	77%	12.6	9.0	7.4	4.0	2.9	50
Slabs	5	0.24	58%	0.17	65%	9.9	8.6	9.1	5.9	3.2	51
Electrical	9	0.54	72%	0.20	67%	8.7	6.3	4.2			26
Hydraulic	4	0.39	75%	0.30	73%	4.7	4.1	3.0	2.7		21
Mechanical	16	0.37	69%	0.23	68%	8.3	7.9	5.7	4.6		37
Total	136	0.25	55%	0.15	55%						

Markovian Deterioration Model: Expert Judgment (2001)

- Example transition probability matrices for painted steel in severe environment:

		To Condition State					
		1	2	3	4	5	Fail
From State	1	93.5	6.5	0.0	0.0	0.0	0.0
	2		88.6	11.4	0.0	0.0	0.0
	3			91.2	8.8	0.0	0.0
	4				88.2	11.8	0.0
	5					82.8	17.2

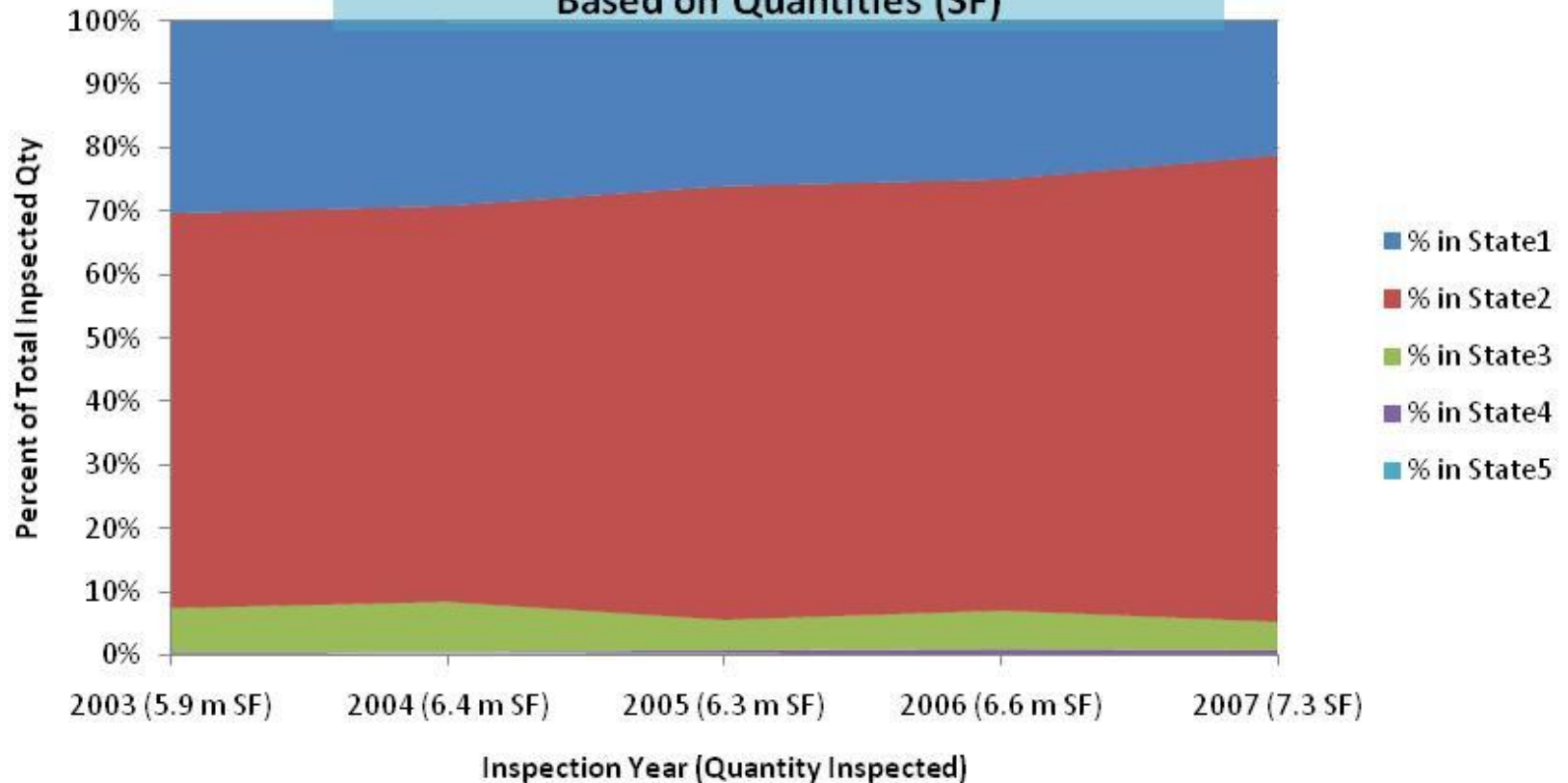
From State	Action	To Condition State				
		1	2	3	4	5
1	1 Surface clean	100.0	0.0	0.0	0.0	0.0
	2 Misc Maintenance	100.0	0.0	0.0	0.0	0.0
2	1 Surface clean	0.0	100.0	0.0	0.0	0.0
	2 Clean and paint	91.3	8.8	0.0	0.0	0.0
3	1 Spot blast, clean, and paint	93.8	6.3	0.0	0.0	0.0
4	1 Spot blast, clean, and paint	48.8	22.5	3.8	25.0	0.0
	2 Replace paint system	72.5	2.5	0.0	25.0	0.0
5	1 Rehab unit	86.3	11.3	2.5	0.0	0.0
	2 Replace unit	100.0	0.0	0.0	0.0	0.0

Trends in Element-level Condition of State-Maintained Bridge Inventory

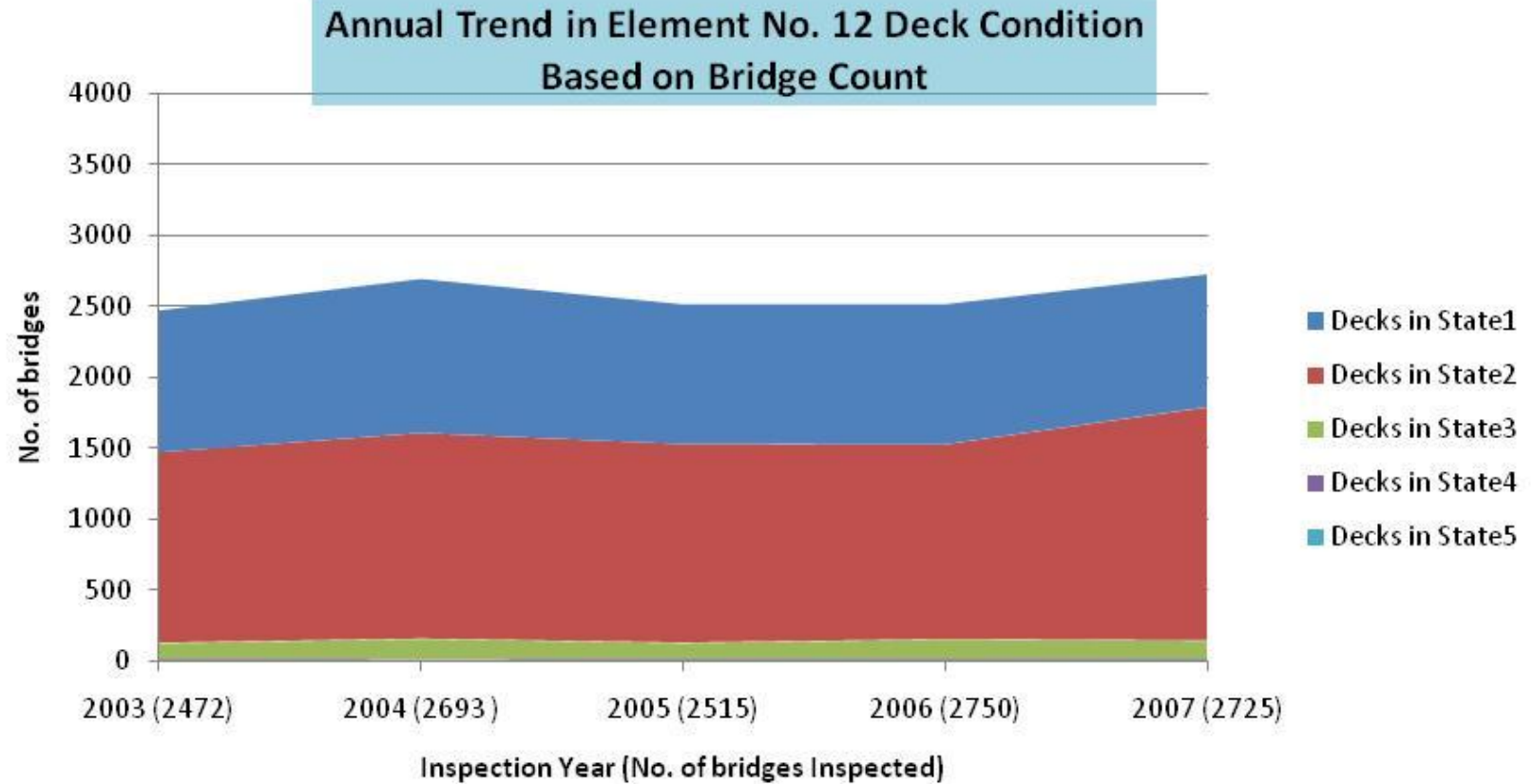
Inspection Year	Quantity (SF)	No of bridges	% in State 1	% in State 2	% in State 3	% in State 4	% in State 5
2003	5,892,527	2472	30.3%	62.2%	7.0%	0.3%	0.1%
2004	6,432,144	2693	29.1%	62.4%	7.9%	0.3%	0.3%
2005	6,321,547	2515	26.0%	68.4%	4.9%	0.6%	0.1%
2006	6,645,752	2750	24.9%	68.0%	6.1%	1.0%	0.0%
2007	7,303,416	2725	21.1%	73.6%	4.5%	0.7%	0.0%

Trends in Element-level Condition of State-Maintained Bridge Inventory

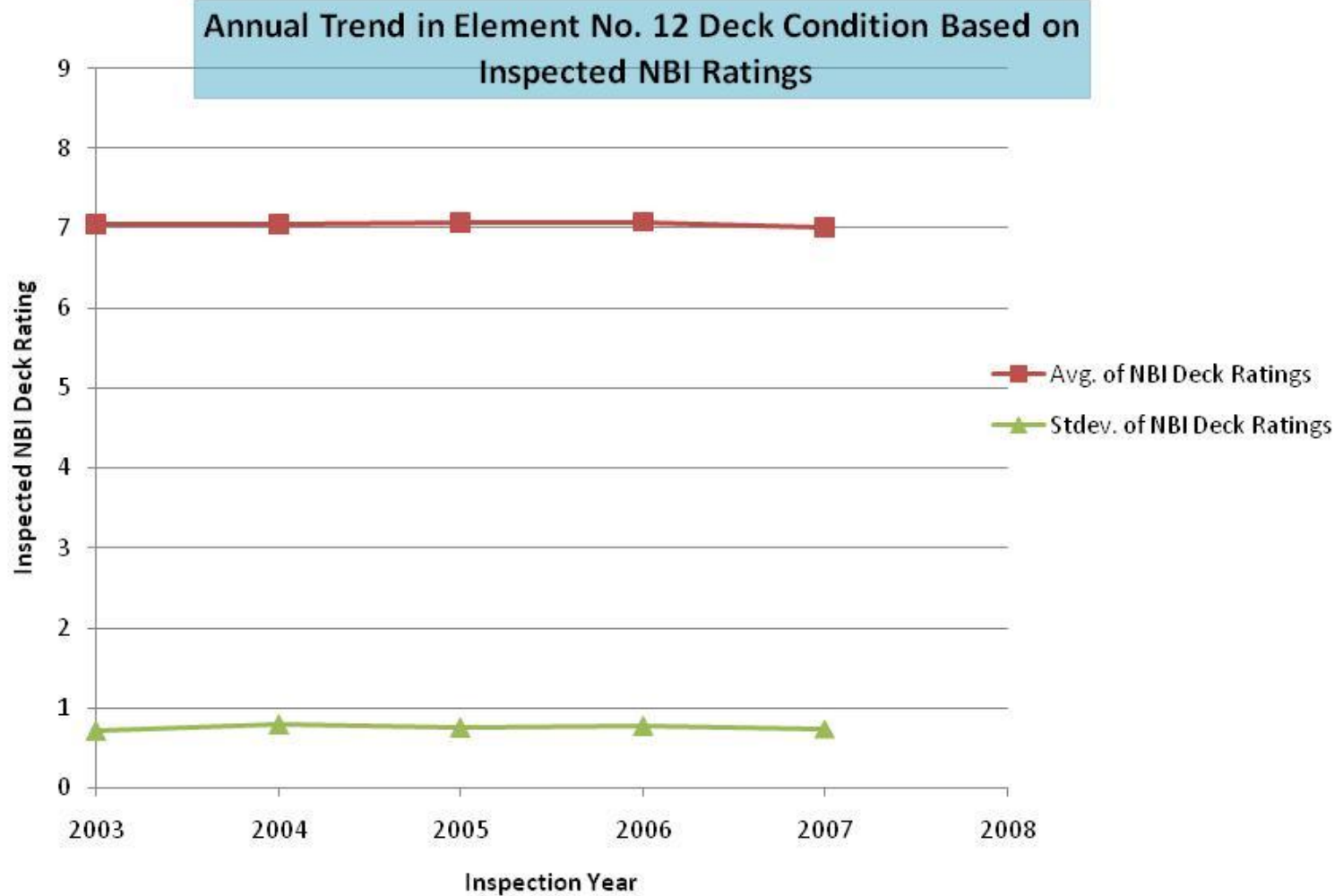
Annual Trend in Element No. 12 Deck Condition
Based on Quantities (SF)



Trends in Element-level Condition of State-Maintained Bridge Inventory

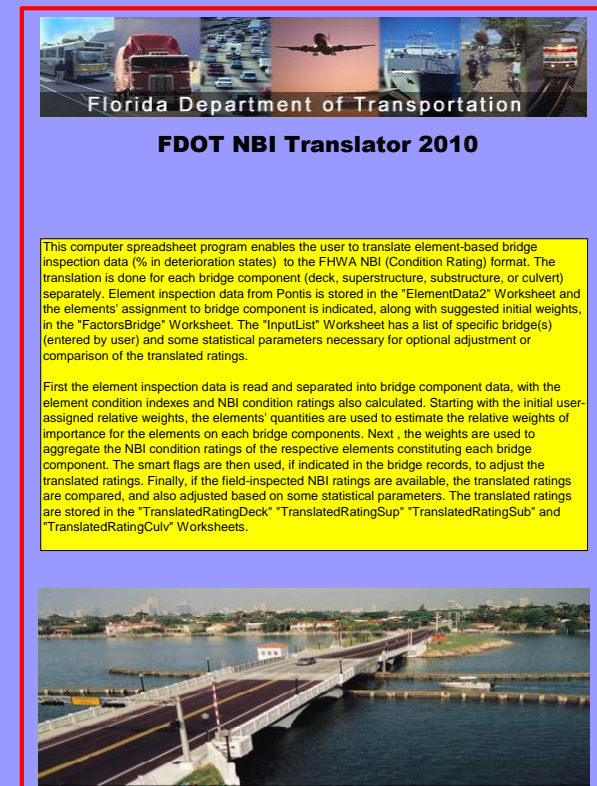
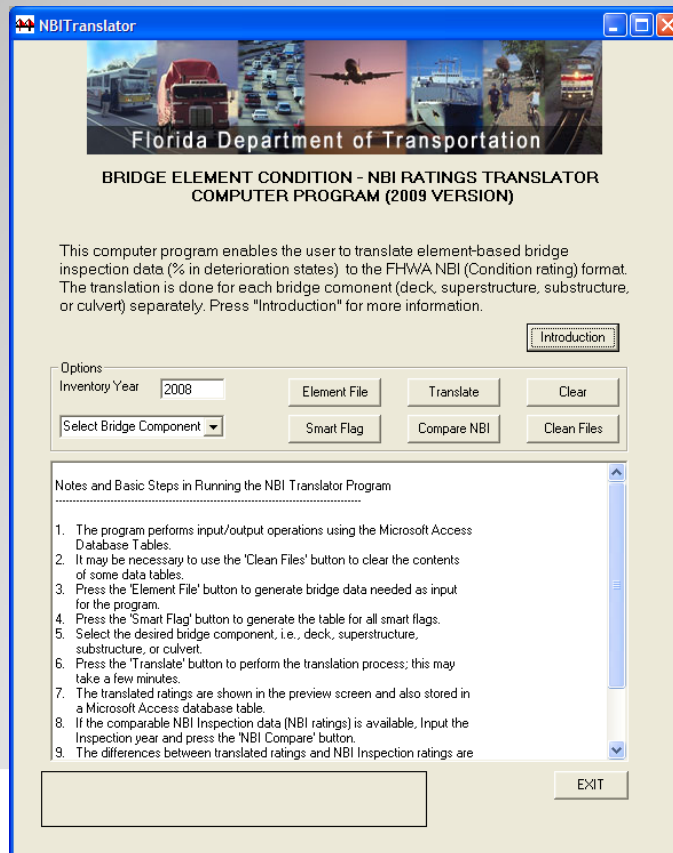


Trends in NBI Condition Ratings of State-Maintained Bridge Inventory



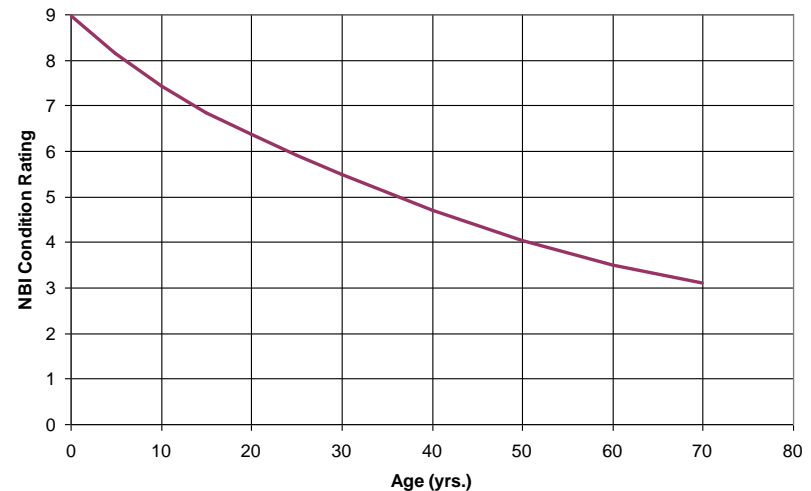
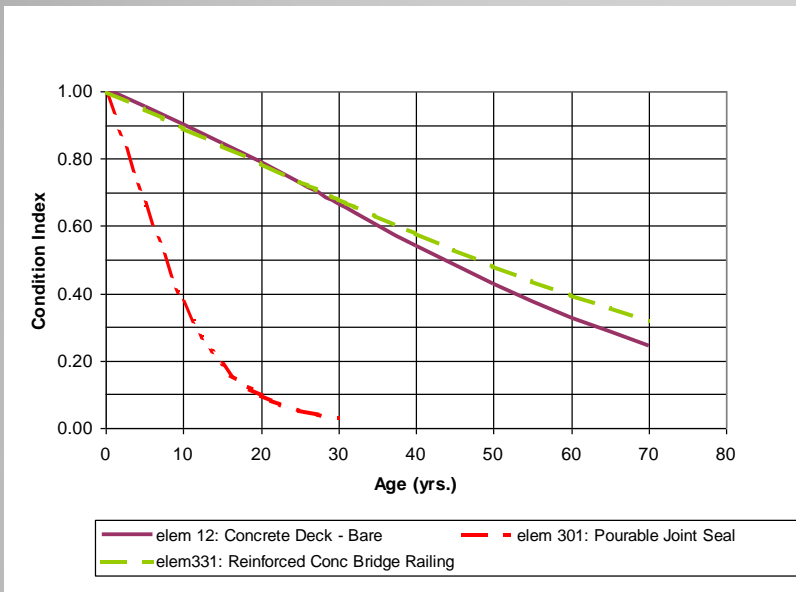
Improved NBI Translator (2010)

- New Translator Program developed to convert element-based inspection (distribution in condition states) to FHWA NBI Condition Rating.



Improved NBI Translator (2010)

- Markovian deterioration model for element condition states vs. translated NBI rating.

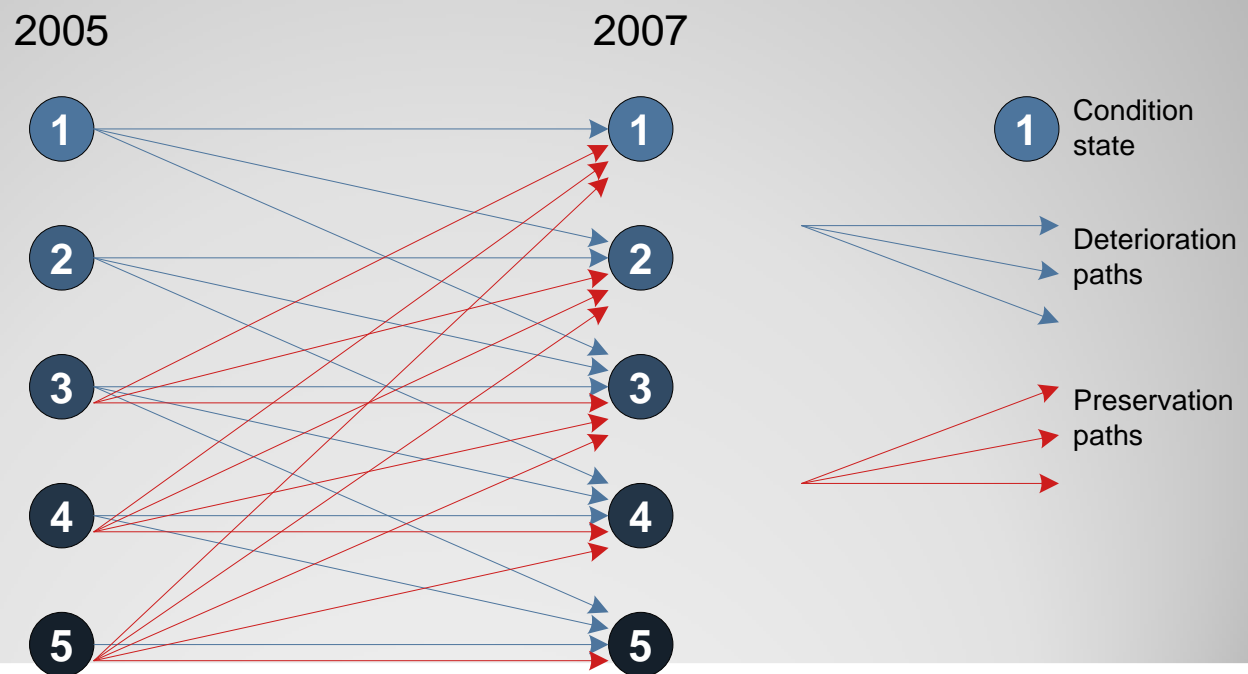


Improved Markovian Deterioration Models (2010)

- Markovian transition probabilities most recently updated in 2010 based entirely on Florida bridge inspection data.
- New simplified procedure developed for estimating one-step transition probabilities using significantly smaller sample sizes than traditional regression.
- New inspection-based models showed deterioration rates far slower than current expert elicitation models.

Improved Markovian Deterioration Models (2010)

- Models estimated from observed changes in element condition between two inspections.



Improved Markovian Deterioration Models (2010)

- Historical bridge activity (from FDOT's Maintenance Management System (MMS) and its AASHTO Trns•Port database) merged with bridge condition data from Pontis.
- Deterioration models estimated from sets of inspection pairs indicating no preservation activities between the dates.
- Regression-based method used to estimate transition probability matrices from inspection data.

Improved Markovian Deterioration Models (2010)

- Example result from regression-based model.

Element 107 – Painted steel open girder/beam
All environments

From	To state 1	State 2	State 3	State 4	State 5
State 1	93.5	4.9	1.2	0.4	0.0
State 2		96.7	2.5	0.9	0.0
State 3			97.2	2.7	0.1
State 4				99.5	0.5
State 5					100.0

All amounts in percent; $n=4947$; $r^2=0.761$

Improved Markovian Deterioration Models (2010)

- Deterioration model simplified by assuming one-step transition between states.
- New model compared with Markov model based on expert opinions (from 2001) -- state transition times.

By element category*		By element material*	
Joints	3.2	Unpainted steel	1.8
Railing	1.6	Painted steel	1.9
Superstructure	1.7	Prestressed concrete	1.7
Bearings	2.2	Reinforced concrete	2.1
Substructure	2.0	Timber	1.8
Movable bridge equip	1.8	Other material	2.1
Channel	1.4	Decks	1.9
Other elements	1.4	Slabs	3.3
By condition state**		By environment**	
From state 1 to 2	1.8	Benign	2.2
From state 2 to 3	2.6	Low	2.6
From state 3 to 4	3.8	Moderate	2.7
From state 4 to 5	6.1	Severe	2.9

Unweighted averages over the elements in each category

* Based on decay life

** Based on state-to-state transition times

Improved Markovian Deterioration Models (2010)

- Markovian models used in *Pontis* have fairly rapid initial deterioration.
- New method developed to model the ***onset of deterioration***, i.e., the period when a bridge is new, before it starts to exhibit visible defects.
- Weibull survival function used to model the probability of remaining in condition state 1, as a function of age.
- Development of hybrid Markov-Weibull models.

Improved Markovian Deterioration Models (2010)

- Weibull survival function used to model the probability of remaining in condition state 1, as a function of age.
- Weibull function:
$$y_{1g} = \exp\left(-\left(g/\alpha\right)^\beta\right)$$
- where y_{1g} is the state probability of condition state 1 at age g , if no intervening repair action is taken between year 0 and year g ; β is the shaping parameter, which determines the initial slowing effect on deterioration; and α is the scaling parameter.

Improved Markovian Deterioration Models (2010)

- Development of hybrid Markov-Weibull models: weibull survival functions for state 1 and Markov for remaining states. Sample results shown.

Element type	States	Elemts	Median transition times (from-to states, in years)					Count (r^2)	Beta
			1-2	2-3	3-4	4-5	1-5		
A1- Concrete deck	5	3	5.8	47.1	35.9	23.4	146	19064 (0.72)	1.3
A2- Concrete slab	5	2	4.3	44.6	13.9	15.0	98	6852 (0.66)	1.3
A3- Prestressed concrete slab	5	1	5.2	72.3	21.3	39.3	174	4785 (0.71)	1.3
A4- Steel deck	5	3	3.4	1.8	11.3	10.9	37	3990 (0.50)	1.1
A5- Timber deck/slab	4	4	5.1	11.7	14.7	0.0	41	2739 (0.60)	1.9
A6- Approach slabs	4	2	11.6	25.0	27.9	0.0	83	38434 (0.71)	1.0
B1- Strip Seal expansion joint	3	1	12.8	45.4	0.0	0.0	67	1992 (0.62)	1.0
B2- Pourable joint seal	3	1	9.9	8.3	0.0	0.0	23	20091 (0.76)	1.0
B3- Compression joint seal	3	1	6.2	10.7	0.0	0.0	21	7391 (0.68)	1.4
B4- Assembly joint/seal	3	1	13.9	13.7	0.0	0.0	34	1170 (0.65)	1.4
B5- Open expansion joint	3	1	18.1	30.1	0.0	0.0	58	2738 (0.70)	1.4
B6- Other expansion joint	3	1	19.2	60.4	0.0	0.0	92	757 (0.75)	1.4

States = number of condition states in the element definitions

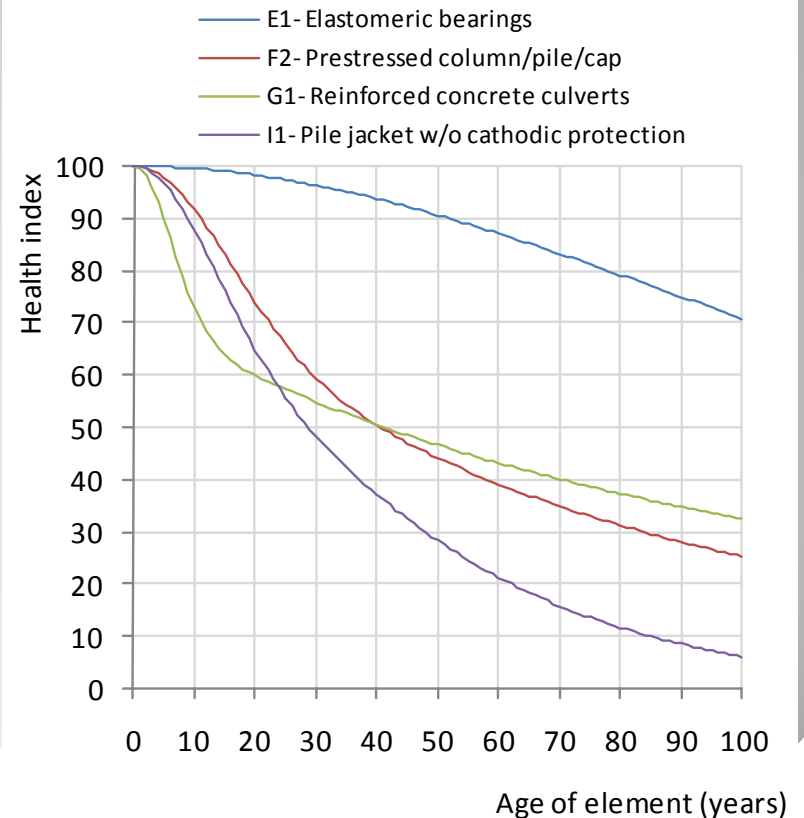
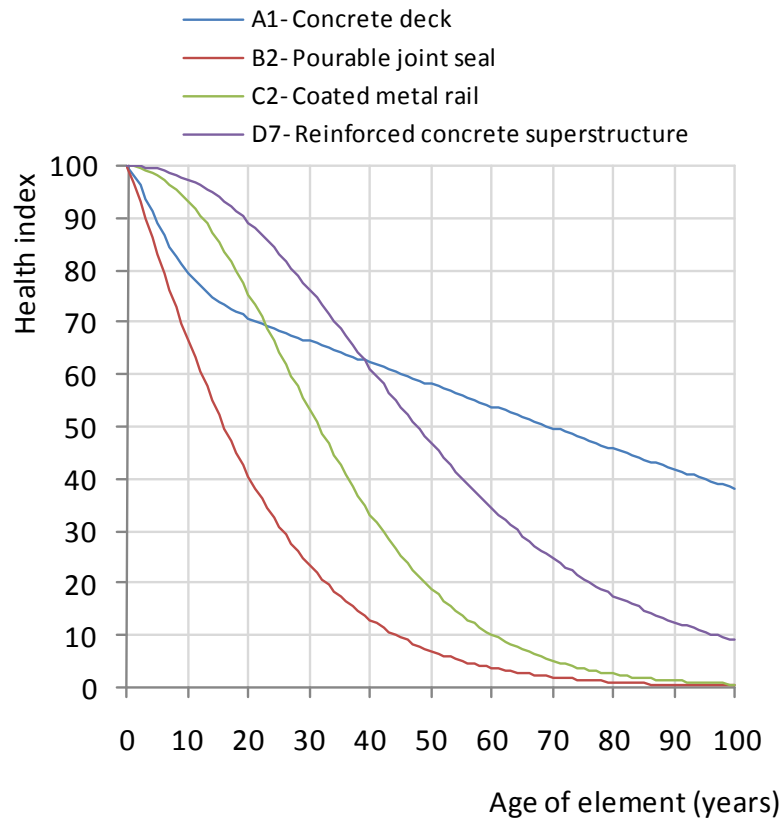
Elmts = number of elements belonging to the element type

Median transition time from state 1 to state 5 is the decay life

Beta = Weibull model shaping parameter

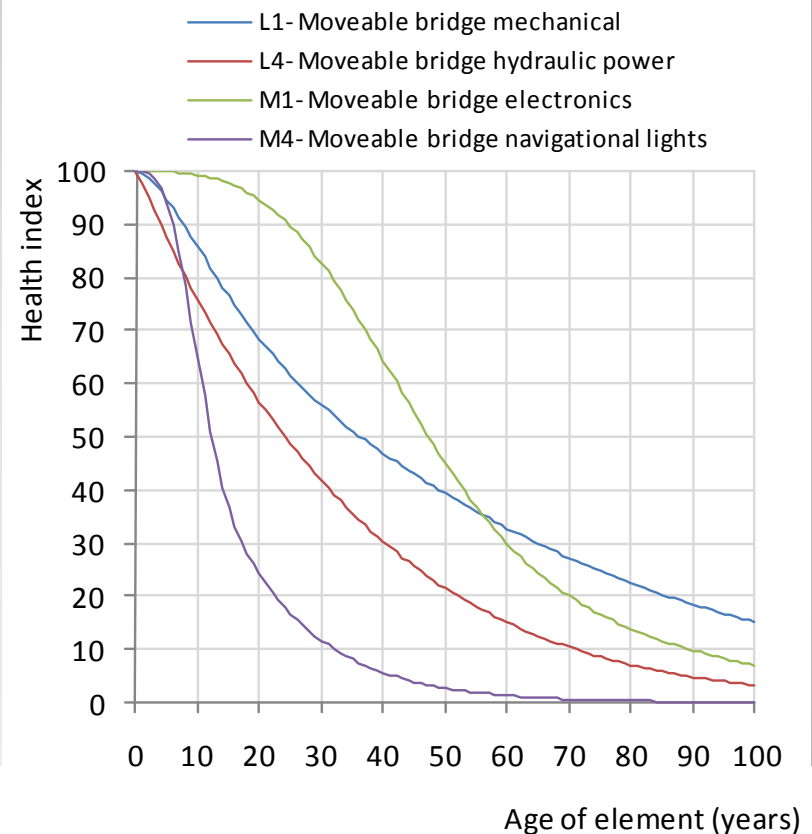
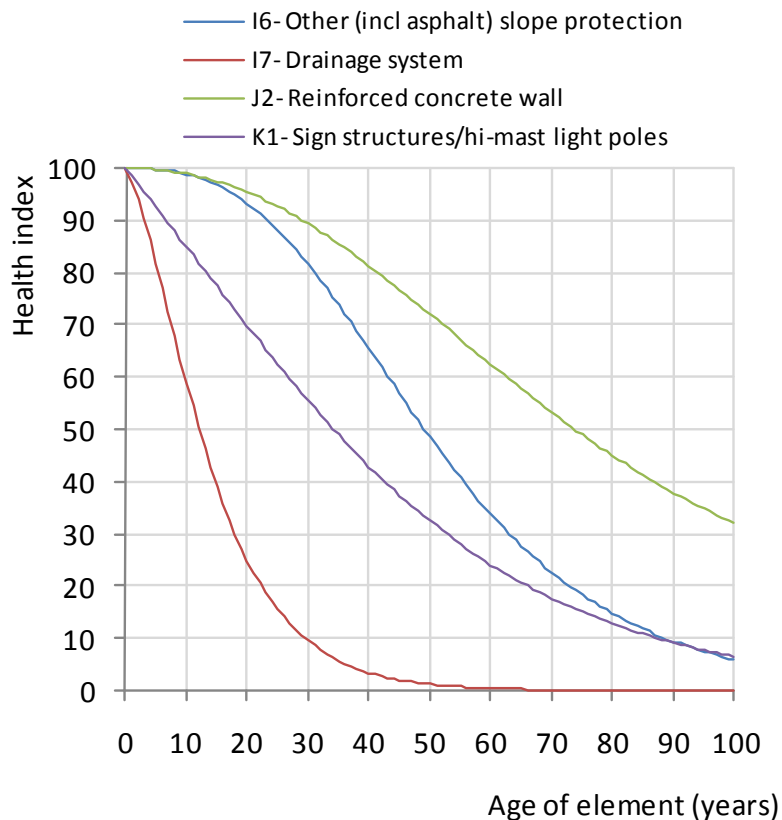
Improved Markovian Deterioration Models (2010)

- Hybrid Markov-Weibull Models (using health index).



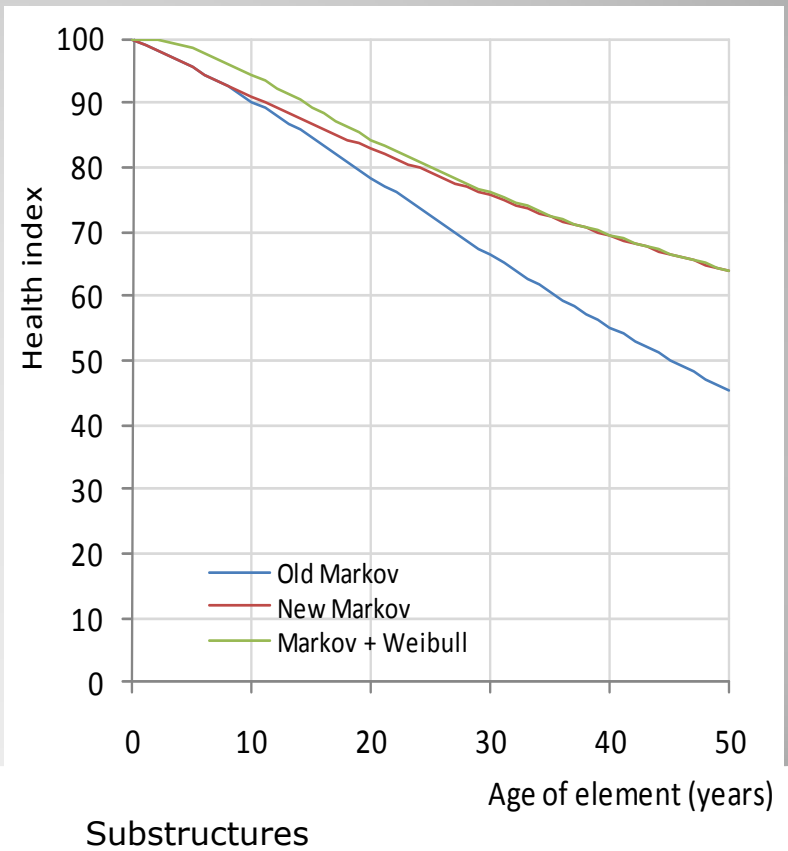
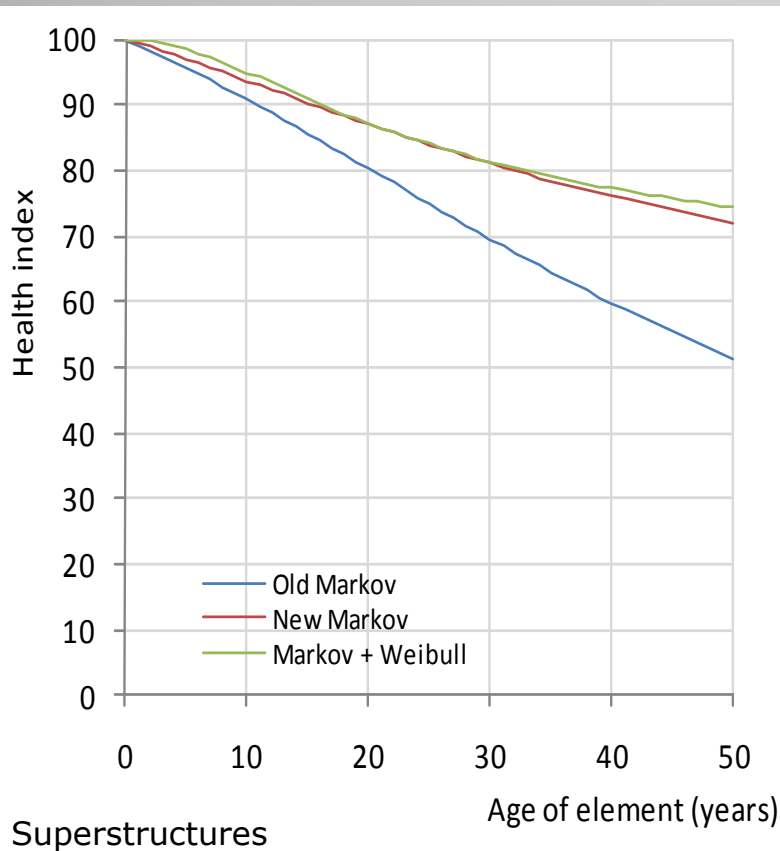
Improved Markovian Deterioration Models (2010)

- Hybrid Markov-Weibull Models (using health index).



Improved Markovian Deterioration Models (2010)

- Hybrid Markov-Weibull Models (using health index).



Improved Markovian Deterioration Models (2010)

- Development of the “do-something” Markovian transition probabilities.

Action sub-category		States	Usage	New model - recommended results				
				State1	State2	State3	State4	State5
201	Rehab deck/replace overlay	4	2	43.88	56.12	0.00	0.00	0.00
201	Rehab deck/replace overlay	5	7	43.88	56.12	0.00	0.00	0.00
202	Rehab steel	4	24	41.03	1.85	56.44	0.68	0.00
202	Rehab steel	5	26	57.82	38.15	4.03	0.00	0.00
203	Rehab concrete	4	28	45.85	45.55	8.52	0.08	0.00
204	Rehab timber	3	1	33.96	59.49	6.56	0.00	0.00
204	Rehab timber	4	41	33.96	59.49	6.56	0.00	0.00
205	Rehab masonry	3	2	100.00	0.00	0.00	0.00	0.00
205	Rehab masonry	4	15	100.00	0.00	0.00	0.00	0.00
206	Rehab MSE	4	3	94.58	0.00	5.42	0.00	0.00
211	Rehab joint	3	7	88.57	11.31	0.12	0.00	0.00
213	Rehab bearing	3	11	68.60	31.40	0.00	0.00	0.00
221	Rehab slope protection	4	3	72.93	26.98	0.09	0.00	0.00
222	Rehab channel	4	4	98.70	0.00	1.30	0.00	0.00
223	Rehab drainage system	5	1	57.82	38.15	4.03	0.00	0.00
231	Rehab machinery	3	22	93.53	6.47	0.00	0.00	0.00
231	Rehab machinery	4	12	93.53	6.47	0.00	0.00	0.00
231	Rehab machinery	5	3	93.53	6.47	0.00	0.00	0.00
243	Rehab cable	4	1	41.03	1.85	56.44	0.68	0.00
243	Rehab cable	5	2	57.82	38.15	4.03	0.00	0.00
246	Mudjacking	4	2	95.79	4.21	0.00	0.00	0.00
301	Repair deck and substrate	4	4	89.71	9.73	0.56	0.00	0.00
301	Repair deck and substrate	5	12	89.71	9.73	0.56	0.00	0.00
302	Spot paint	3	2	91.56	8.44	0.00	0.00	0.00
302	Spot paint	4	30	41.96	57.78	0.26	0.00	0.00
302	Spot paint	5	55	75.33	17.76	6.83	0.08	0.00
303	Clean rebar and patch	4	19	84.09	0.52	15.39	0.00	0.00
311	Repair joint	3	2	62.36	37.64	0.00	0.00	0.00
331	Repair/lubricate machinery	3	2	100.00	0.00	0.00	0.00	0.00
331	Repair/lubricate machinery	4	6	92.94	7.06	0.00	0.00	0.00

By definition, all 100-series replacement actions have a 100% probability of state 1.

By definition, all 400-series routine maintenance actions are not modeled.

Usage = number of Pontis MR.&R. action definitions that use each action sub-category

New model - recommended results

Action sub-category		States	Usage	State1	State2	State3	State4	State5
201	Rehab deck/replace overlay	4	2	43.88	56.12	0.00	0.00	0.00
201	Rehab deck/replace overlay	5	7	43.88	56.12	0.00	0.00	0.00
202	Rehab steel	4	24	41.03	1.85	56.44	0.68	0.00
202	Rehab steel	5	26	57.82	38.15	4.03	0.00	0.00
203	Rehab concrete	4	28	45.85	45.55	8.52	0.08	0.00
204	Rehab timber	3	1	33.96	59.49	6.56	0.00	0.00
204	Rehab timber	4	41	33.96	59.49	6.56	0.00	0.00
205	Rehab masonry	3	2	100.00	0.00	0.00	0.00	0.00
205	Rehab masonry	4	15	100.00	0.00	0.00	0.00	0.00
206	Rehab MSE	4	3	94.58	0.00	5.42	0.00	0.00
211	Rehab joint	3	7	88.57	11.31	0.12	0.00	0.00
213	Rehab bearing	3	11	68.60	31.40	0.00	0.00	0.00
221	Rehab slope protection	4	3	72.93	26.98	0.09	0.00	0.00
222	Rehab channel	4	4	98.70	0.00	1.30	0.00	0.00
223	Rehab drainage system	5	1	57.82	38.15	4.03	0.00	0.00
231	Rehab machinery	3	22	93.53	6.47	0.00	0.00	0.00
231	Rehab machinery	4	12	93.53	6.47	0.00	0.00	0.00
231	Rehab machinery	5	3	93.53	6.47	0.00	0.00	0.00
243	Rehab cable	4	1	41.03	1.85	56.44	0.68	0.00
243	Rehab cable	5	2	57.82	38.15	4.03	0.00	0.00
246	Mudjacking	4	2	95.79	4.21	0.00	0.00	0.00
301	Repair deck and substrate	4	4	89.71	9.73	0.56	0.00	0.00
301	Repair deck and substrate	5	12	89.71	9.73	0.56	0.00	0.00
302	Spot paint	3	2	91.56	8.44	0.00	0.00	0.00
302	Spot paint	4	30	41.96	57.78	0.26	0.00	0.00
302	Spot paint	5	55	75.33	17.76	6.83	0.08	0.00
303	Clean rebar and patch	4	19	84.09	0.52	15.39	0.00	0.00
311	Repair joint	3	2	62.36	37.64	0.00	0.00	0.00
331	Repair/lubricate machinery	3	2	100.00	0.00	0.00	0.00	0.00
331	Repair/lubricate machinery	4	6	92.94	7.06	0.00	0.00	0.00

By definition, all 100-series replacement actions have a 100% probability of state 1.

By definition, all 400-series routine maintenance actions are not modeled.

Usage = number of Pontis MR&R action definitions that use each action sub-category

		New model - raw results							Old model				
Action sub-category	States	Sample	State1	State2	State3	State4	State5	State1	State2	State3	State4	State5	
201	Rehab deck/replace overlay	4	6	43.88	56.12	0.00	0.00	0.00	35.57	61.03	3.41	0.00	0.00
201	Rehab deck/replace overlay	5	0						60.18	13.18	1.55	6.63	18.47
202	Rehab steel	4	21	41.03	1.85	56.44	0.68	0.00	68.27	26.84	4.60	0.30	0.00
202	Rehab steel	5	47	57.82	38.15	4.03	0.00	0.00	66.97	17.36	10.66	3.93	1.08
203	Rehab concrete	4	237	45.85	45.55	8.52	0.08	0.00	62.33	22.92	11.79	2.96	0.00
204	Rehab timber	3	0						94.10	5.90	0.00	0.00	0.00
204	Rehab timber	4	18	33.96	59.49	6.56	0.00	0.00	10.80	52.74	26.36	10.10	0.00
205	Rehab masonry	3	30	100.00	0.00	0.00	0.00	0.00	75.45	23.81	0.75	0.00	0.00
205	Rehab masonry	4	3	100.00	0.00	0.00	0.00	0.00	7.16	52.36	23.92	16.56	0.00
206	Rehab MSE	4	31	94.58	0.00	5.42	0.00	0.00	25.88	57.86	15.66	0.60	0.00
211	Rehab joint	3	45	88.57	11.31	0.12	0.00	0.00	33.00	45.83	21.18	0.00	0.00
213	Rehab bearing	3	40	68.60	31.40	0.00	0.00	0.00	73.19	23.47	3.34	0.00	0.00
221	Rehab slope protection	4	143	72.93	26.98	0.09	0.00	0.00	80.66	17.08	2.13	0.14	0.00
222	Rehab channel	4	154	98.70	0.00	1.30	0.00	0.00	61.30	28.34	9.71	0.65	0.00
223	Rehab drainage system	5	0						87.52	11.97	0.51	0.00	0.00
231	Rehab machinery	3	149	93.53	6.47	0.00	0.00	0.00	59.58	23.85	16.57	0.00	0.00
231	Rehab machinery	4	2	0.00	100.00	0.00	0.00	0.00	52.54	20.65	22.28	4.53	0.00
231	Rehab machinery	5	0						51.42	10.74	4.16	29.78	3.90
243	Rehab cable	4	0						91.84	7.03	1.11	0.02	0.00
243	Rehab cable	5	0						49.89	0.11	0.00	48.88	1.13
246	Mudjacking	4	215	95.79	4.21	0.00	0.00	0.00	69.57	28.84	1.59	0.00	0.00
301	Repair deck and substrate	4	0						42.61	24.34	3.70	25.40	3.95
301	Repair deck and substrate	5	82	89.71	9.73	0.56	0.00	0.00	17.53	24.46	21.89	21.62	14.50
302	Spot paint	3	89	91.56	8.44	0.00	0.00	0.00	59.69	38.41	1.90	0.00	0.00
302	Spot paint	4	38	41.96	57.78	0.26	0.00	0.00	65.88	24.27	9.22	0.63	0.00
302	Spot paint	5	805	75.33	17.76	6.83	0.08	0.00	57.25	28.02	9.80	4.35	0.58
303	Clean rebar and patch	4	1974	84.09	0.52	15.39	0.00	0.00	42.10	38.20	17.97	1.73	0.00
311	Repair joint	3	198	62.36	37.64	0.00	0.00	0.00	65.90	28.60	5.50	0.00	0.00
331	Repair/lubricate machinery	3	35	100.00	0.00	0.00	0.00	0.00	51.00	45.01	3.99	0.00	0.00
331	Repair/lubricate machinery	4	271	92.94	7.06	0.00	0.00	0.00	49.95	46.74	3.31	0.00	0.00

By definition, all 100-series replacement actions have a 100% probability of state 1.

By definition, all 400-series routine maintenance actions are not modeled.

Conclusions

- Florida DOT has developed one of the first comprehensive bridge deterioration and action effectiveness models based entirely on historical condition state and activity data.
- The models have very strong statistical characteristics due to large sample sizes.
- The historical activity data were difficult to process because of unclear categorization of action types, and imprecise dating.
- Manual categorization and algorithms developed to identify activity completion dates relative to bridge element condition.

Conclusions

- New simplified procedure developed for estimating one-step Markovian models.
 - produces usable results with significantly smaller sample sizes than traditional regression.
 - enabled the estimation of even relatively uncommon elements.
- New inspection-based models show for most cases, deterioration rates far slower than the expert elicitation models that have been used to-date.
- Further investigation is needed for the deck and culvert models.

Conclusions

- The survival probability concept (Weibull model) was investigated for its usefulness modeling the onset of deterioration; the Weibull parameters appear to make models more realistic.
- New methodology was developed for the estimation of action effectiveness models from historical activity and condition data.
- Actual effectiveness of Florida DOT repair and rehabilitation actions estimated to be greater than those originally estimated by the panel of experts for Florida's models in 2001.

Acknowledgement

- Paul D. Thompson, Co-PI and consultant on the various research grants; primary developer of the bridge deterioration models.
- Richard Kerr, FDOT State Maintenance Office, project manager on the research grants.

References

- Copies of the final report on the research grants discussed are available for view or download at:
- http://www.dot.state.fl.us/research-center/Completed_Maintenance.shtm

Thank you!!!
Any questions



New model - recommended results

Action sub-category		States	Usage	State1	State2	State3	State4	State5
201	Rehab deck/replace overlay	4	2	43.88	56.12	0.00	0.00	0.00
201	Rehab deck/replace overlay	5	7	43.88	56.12	0.00	0.00	0.00
202	Rehab steel	4	24	41.03	1.85	56.44	0.68	0.00
202	Rehab steel	5	26	57.82	38.15	4.03	0.00	0.00
203	Rehab concrete	4	28	45.85	45.55	8.52	0.08	0.00
204	Rehab timber	3	1	33.96	59.49	6.56	0.00	0.00
204	Rehab timber	4	41	33.96	59.49	6.56	0.00	0.00
205	Rehab masonry	3	2	100.00	0.00	0.00	0.00	0.00
205	Rehab masonry	4	15	100.00	0.00	0.00	0.00	0.00
206	Rehab MSE	4	3	94.58	0.00	5.42	0.00	0.00
211	Rehab joint	3	7	88.57	11.31	0.12	0.00	0.00
213	Rehab bearing	3	11	68.60	31.40	0.00	0.00	0.00
221	Rehab slope protection	4	3	72.93	26.98	0.09	0.00	0.00
222	Rehab channel	4	4	98.70	0.00	1.30	0.00	0.00
223	Rehab drainage system	5	1	57.82	38.15	4.03	0.00	0.00
231	Rehab machinery	3	22	93.53	6.47	0.00	0.00	0.00
231	Rehab machinery	4	12	93.53	6.47	0.00	0.00	0.00
231	Rehab machinery	5	3	93.53	6.47	0.00	0.00	0.00
243	Rehab cable	4	1	41.03	1.85	56.44	0.68	0.00
243	Rehab cable	5	2	57.82	38.15	4.03	0.00	0.00
246	Mudjacking	4	2	95.79	4.21	0.00	0.00	0.00
301	Repair deck and substrate	4	4	89.71	9.73	0.56	0.00	0.00
301	Repair deck and substrate	5	12	89.71	9.73	0.56	0.00	0.00
302	Spot paint	3	2	91.56	8.44	0.00	0.00	0.00
302	Spot paint	4	30	41.96	57.78	0.26	0.00	0.00
302	Spot paint	5	55	75.33	17.76	6.83	0.08	0.00
303	Clean rebar and patch	4	19	84.09	0.52	15.39	0.00	0.00
311	Repair joint	3	2	62.36	37.64	0.00	0.00	0.00
331	Repair/lubricate machinery	3	2	100.00	0.00	0.00	0.00	0.00
331	Repair/lubricate machinery	4	6	92.94	7.06	0.00	0.00	0.00

By definition, all 100-series replacement actions have a 100% probability of state 1.

By definition, all 400-series routine maintenance actions are not modeled.

Usage = number of Pontis MR&R action definitions that use each action sub-category