# Determining Deterioration Models Using Inspection Data in Florida

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

**Raleigh, North Carolina**

**By**


**John Sobanjo**
**Florida State University**
**Tallahassee, Florida**


**April 14, 2011**

# 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 | | | | |
|---|---|---|---|---|
| | ToState | | | |
| FromState | 1 | 2 | 3 | 4 |
| 1 | 96.93 | 3.07 | 0.00 | 0.00 |
| 2 | 0.00 | 96.37 | 3.63 | 0.00 |
| 3 | 0.00 | 0.00 | 92.38 | 7.62 |
| 4 | 0.00 | 0.00 | 0.00 | 87.06 |
| | | | | |
| Failure probability | | 12.94% | | |
| All amounts in percent | | | | |

| PREDICTED CONDITIONS | | | | |
|---|---|---|---|---|
| Year | State1 | State2 | State3 | State4 |
| 2001 | 100.00 | 0.00 | 0.00 | 0.00 |
| 2002 | 96.93 | 3.07 | 0.00 | 0.00 |
| 2003 | 93.95 | 5.93 | 0.11 | 0.00 |
| 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 |
| 2007 | 82.94 | 15.53 | 1.38 | 0.15 |
| 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*:*

| | | Do-Nothing | | Do-Something | | Median Years Out of State | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Category | Element Count | Average Coef of Variation | Response Rate | Average Coef of Variation | Response Rate | 1 | 2 | 3 | 4 | 5 | Median Time to Failure |
| 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 | 56% | 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: Average Coef of Variation | Do-Nothing: Response Rate | Do-Something: Average Coef of Variation | Do-Something: Response Rate | Median Years Out of State: 1 | 2 | 3 | 4 | 5 | Median Time to Failure |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 | 0.26 | 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 | 46% | 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:

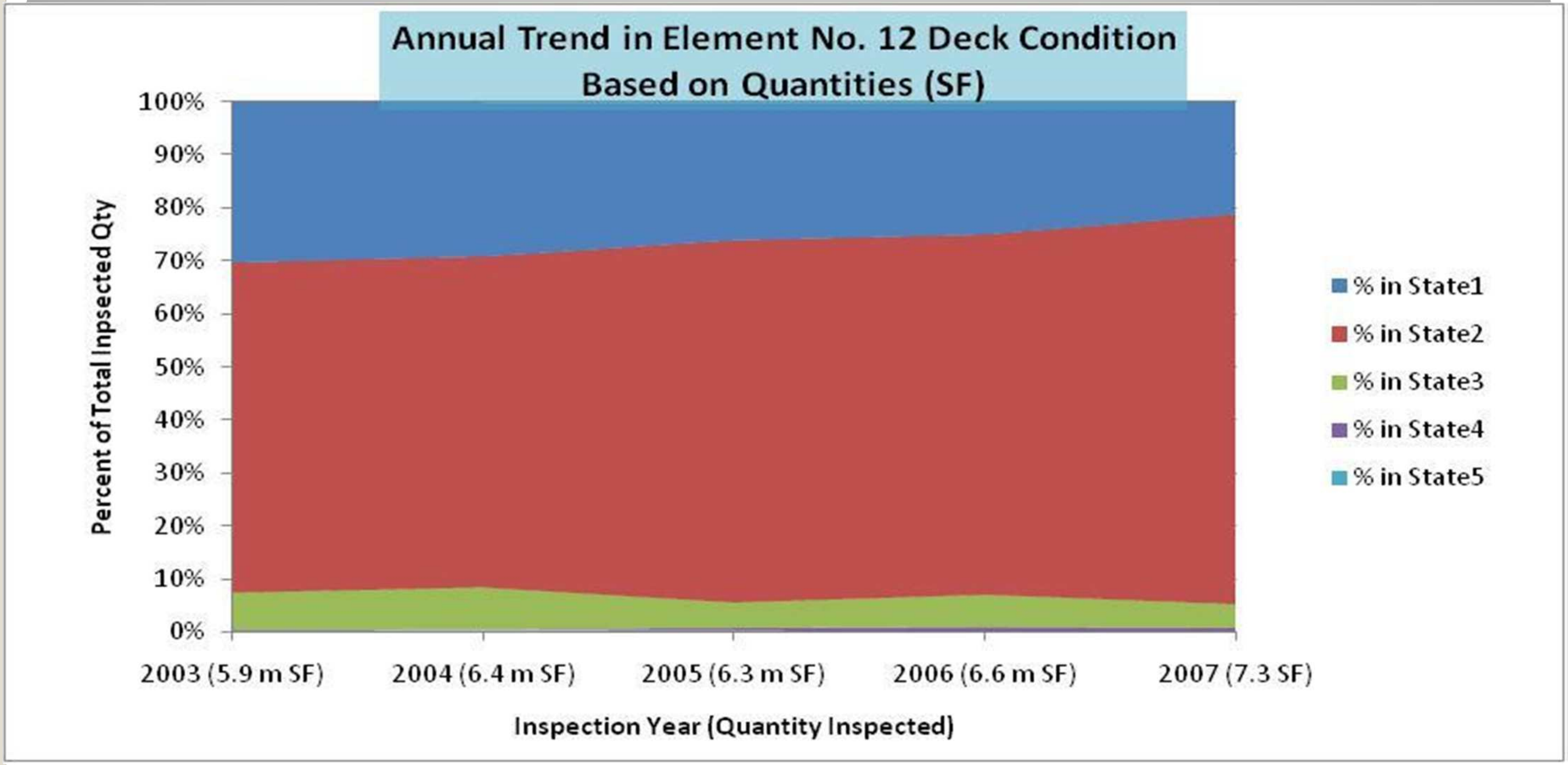
| From State | To Condition State 1 | 2 | 3 | 4 | 5 | Fail |
|---|---|---|---|---|---|---|
| 1 | 93.5 | 6.5 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2 | | 88.6 | 11.4 | 0.0 | 0.0 | 0.0 |
| 3 | | | 91.2 | 8.8 | 0.0 | 0.0 |
| 4 | | | | 88.2 | 11.8 | 0.0 |
| 5 | | | | | 82.8 | 17.2 |

| 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 |
| 1 | 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 | 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 |
| 4 | 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 |
| 5 | 2 Replace unit | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 |

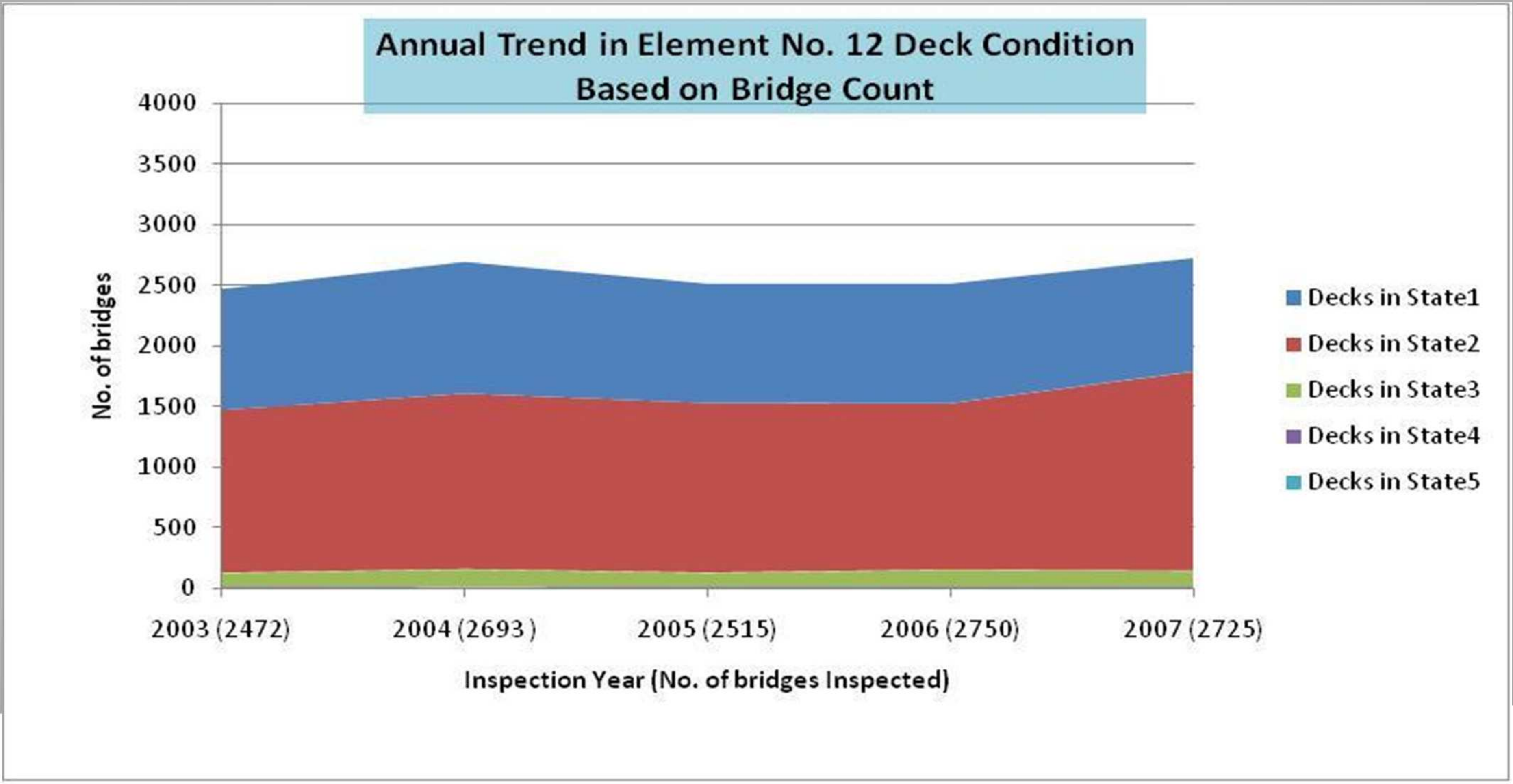
# Trends in Element-level Condition of State-Maintained Bridge Inventory

| 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% |

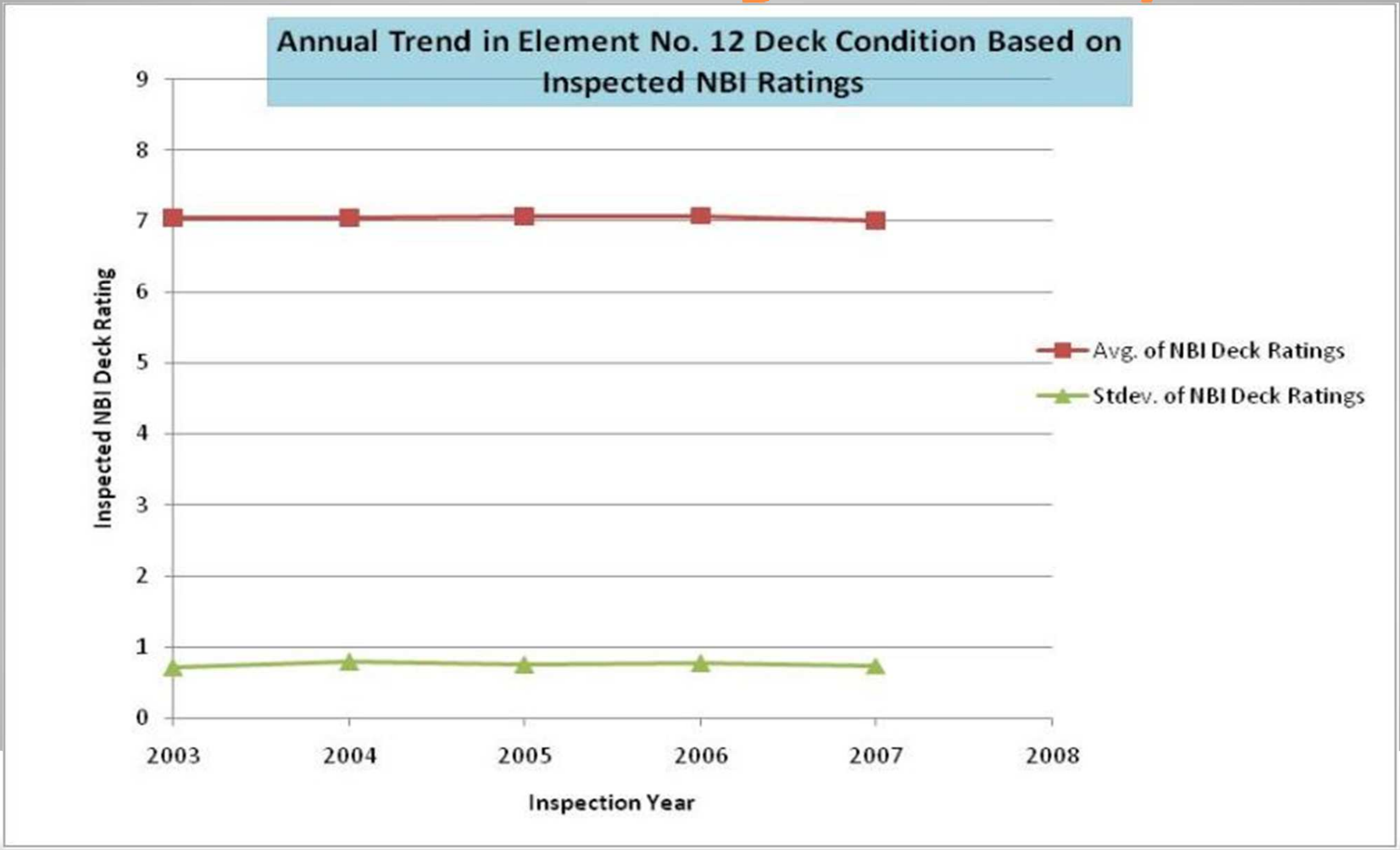
# Trends in Element-level Condition of State-Maintained Bridge Inventory



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

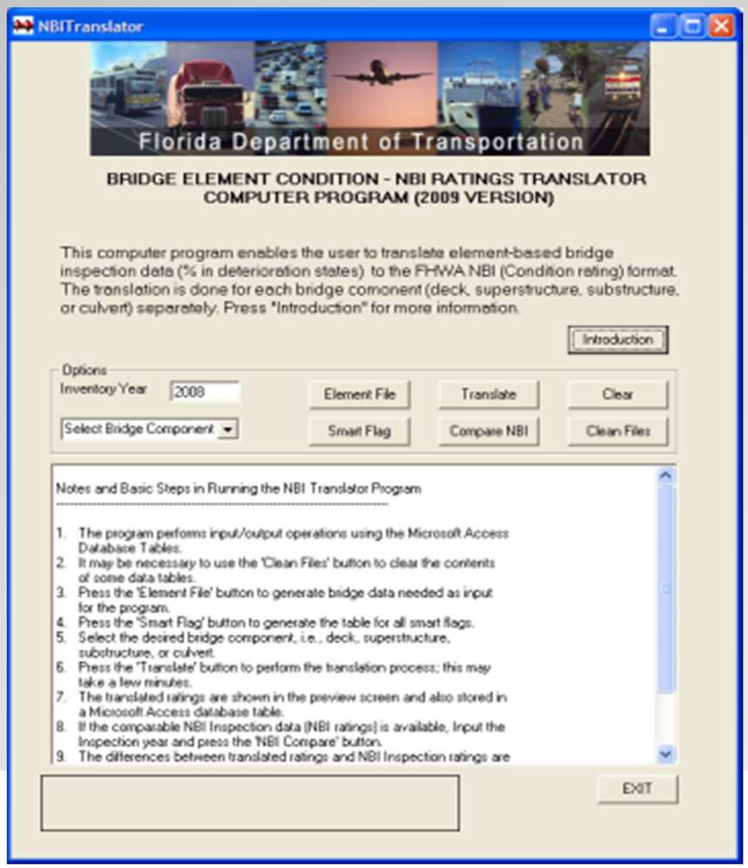


# Trends in NBI Condition Ratings of State-Maintained Bridge Inventory



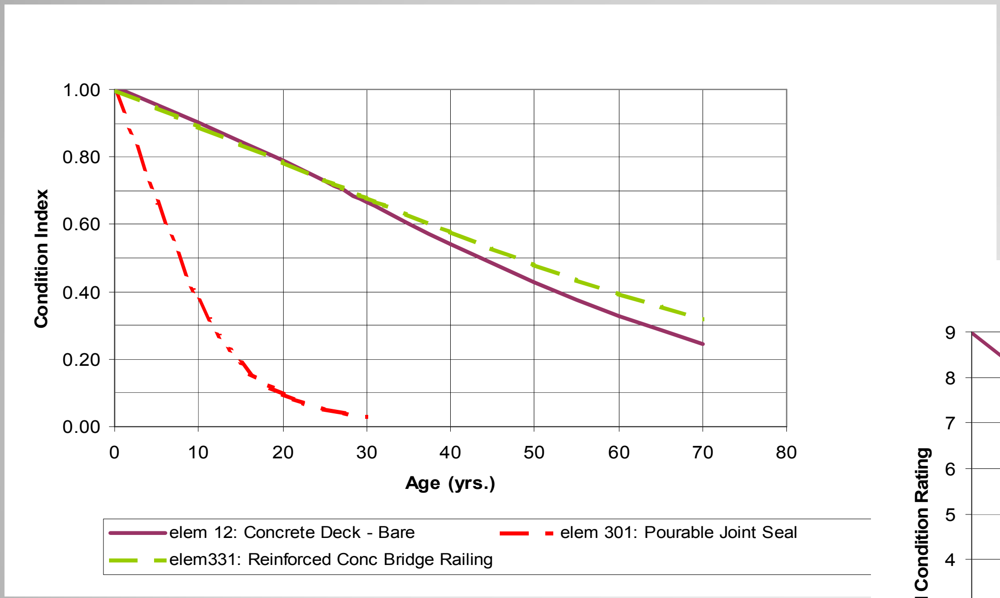
# Improved NBI Translator (2010)

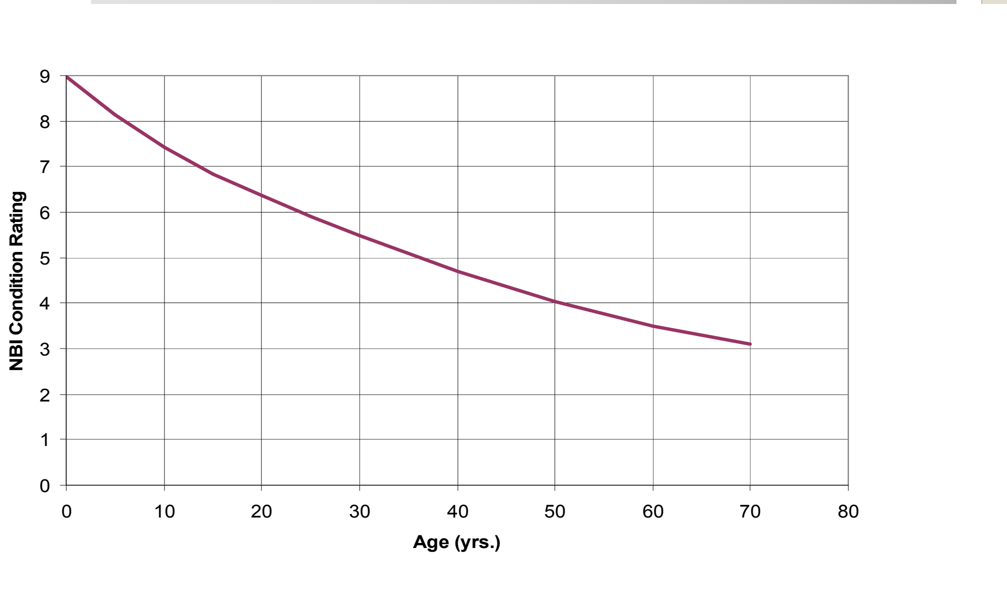
- New Translator Program developed to convert element-based inspection (distribution in condition states) to FHWA NBI Condition Rating.




# Improved NBI Translator (2010)

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



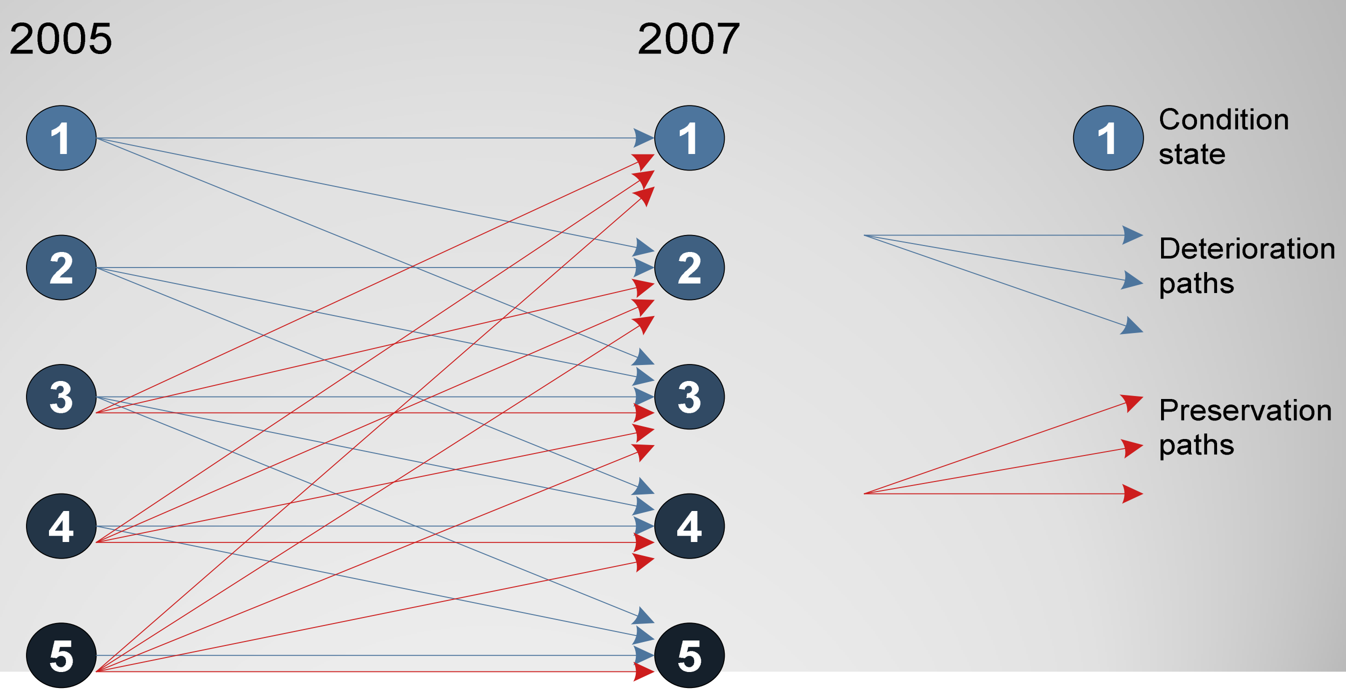



# Improved Markovian Deterioration Models (2010)

- 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:

$$y_{1g} = \exp\left(-(g/\alpha)^{\beta}\right)$$

- 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 $g$; $\beta$ is the shaping parameter, which determines the initial slowing effect on deterioration; and $\alpha$ is the scaling parameter.

# Improved Markovian Deterioration Models (2010)

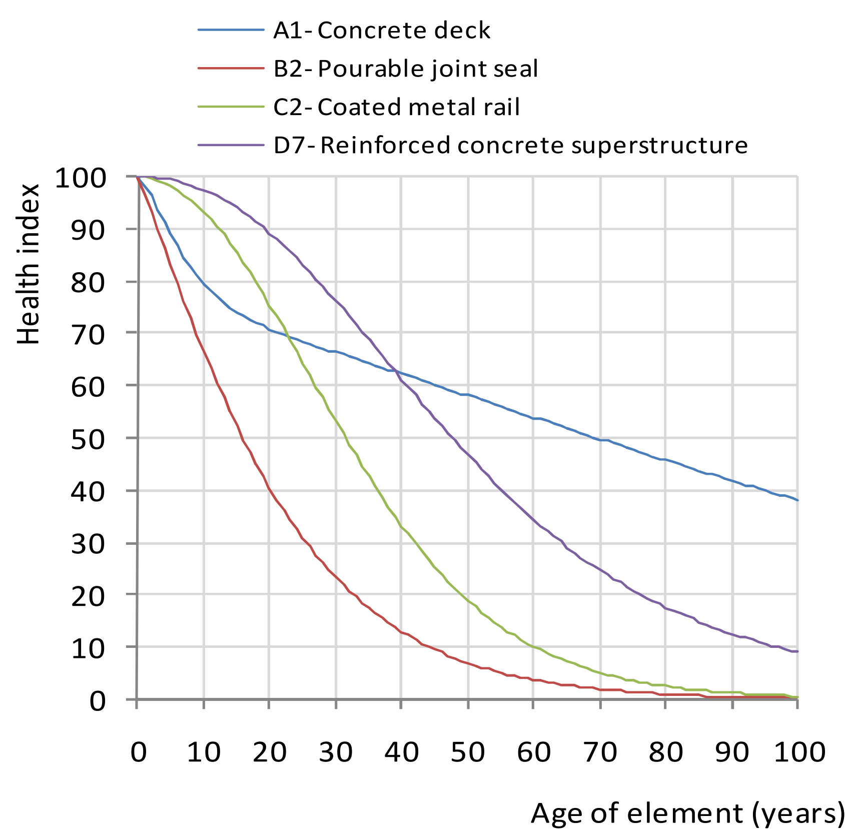
- Development of hybrid Markov-Weibull models: weibull survival functions for state 1 and Markov for remaining states. Sample results shown.

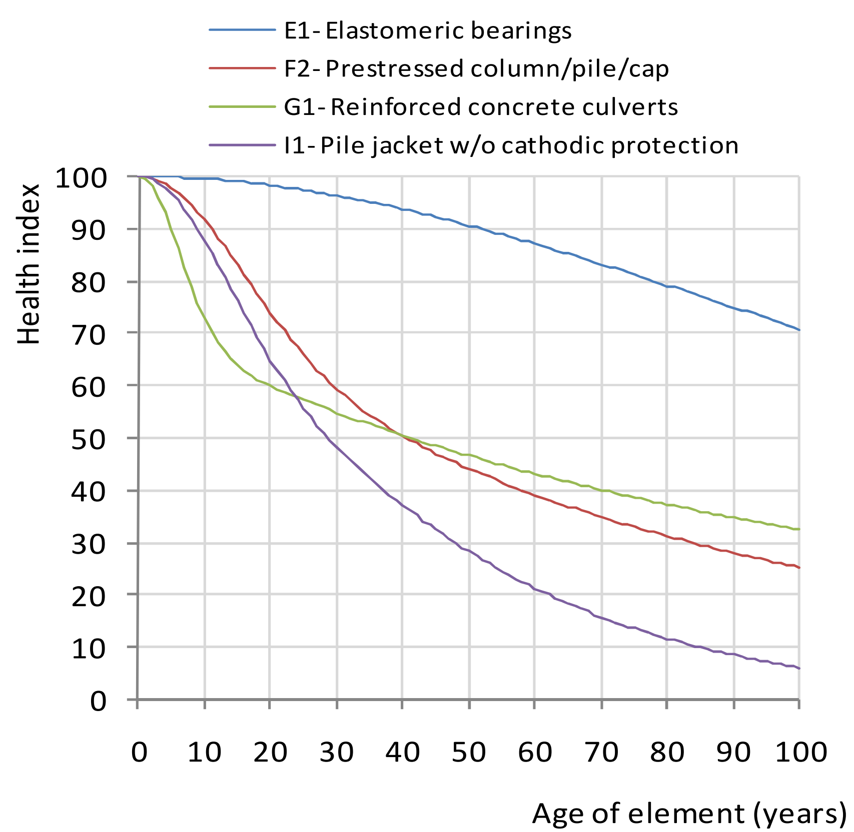
| | | | Median transition times (from-to states, in years) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Element type | States | Elemts | 1-2 | 2-3 | 3-4 | 4-5 | 1-5 | Count ($r^2$) | Beta |
| A1- Concrete deck | 5 | 3 | 5.8 | 47.1 | 35.9 | 23.4 | 146 | 19064 (0.72) | 1.3 |
| A2- Concrete 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)

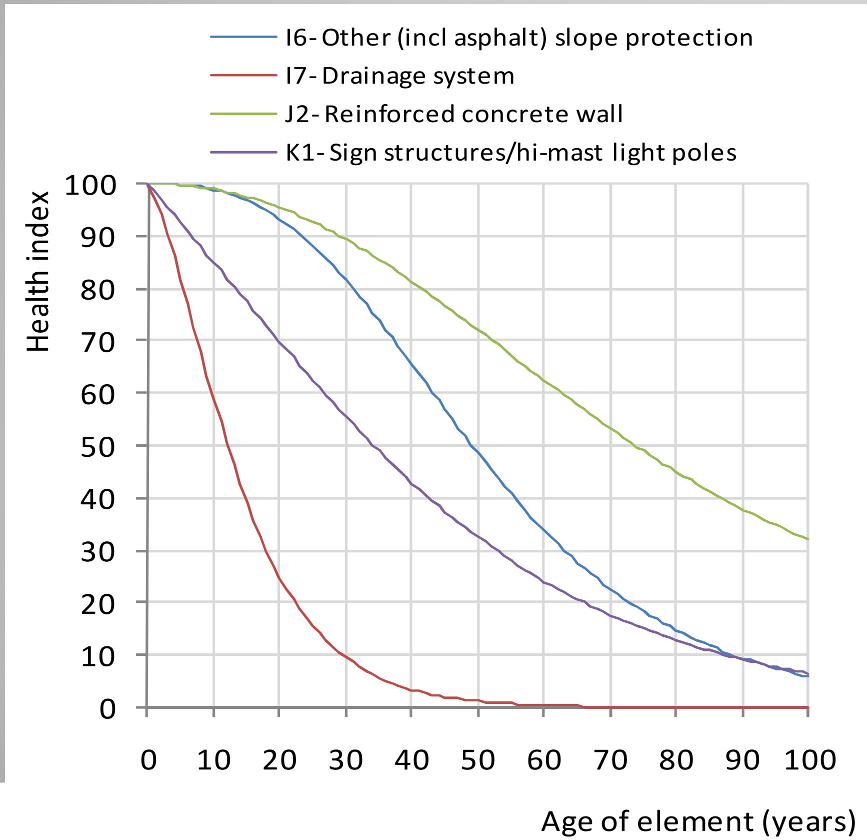
- Hybrid Markov-Weibull Models (using health index).

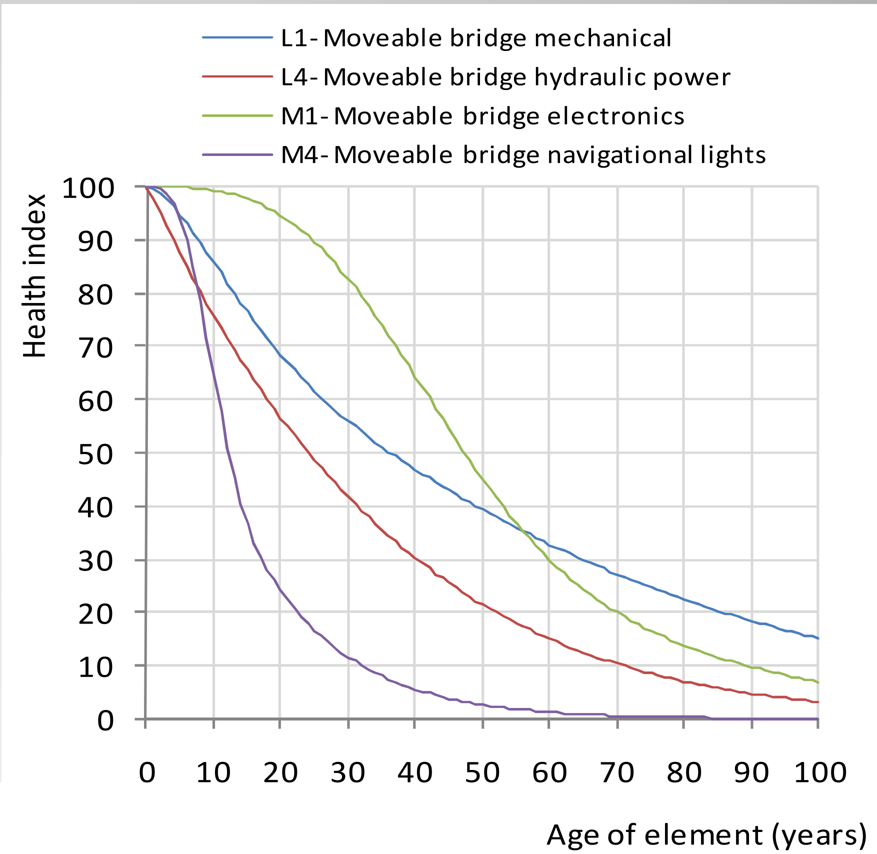


# Improved Markovian Deterioration Models (2010)

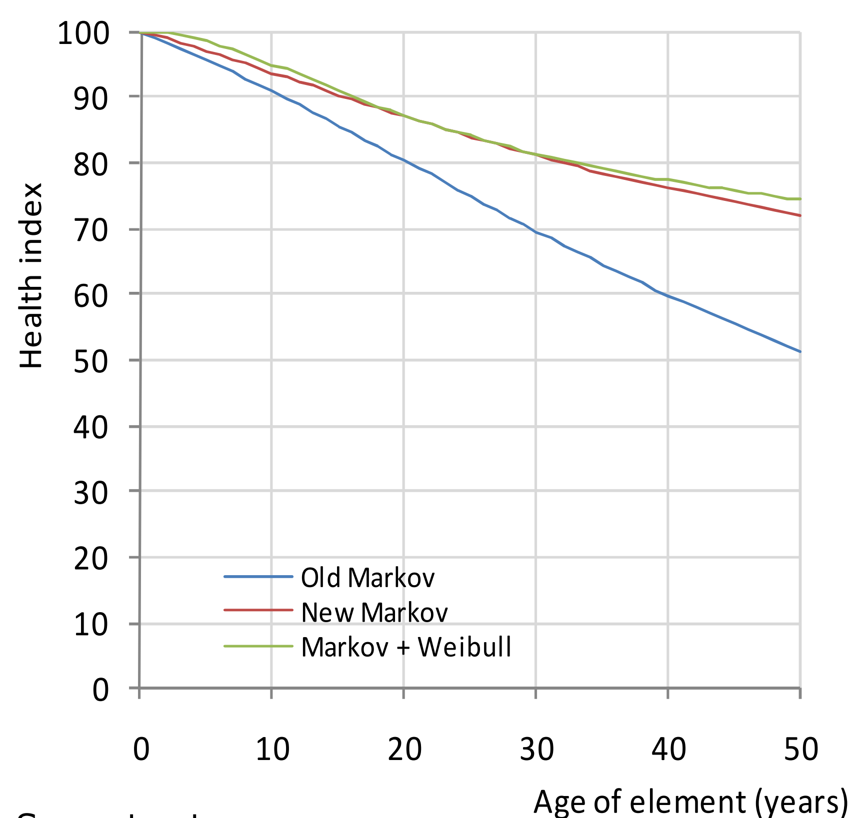
- Hybrid Markov-Weibull Models (using health index).



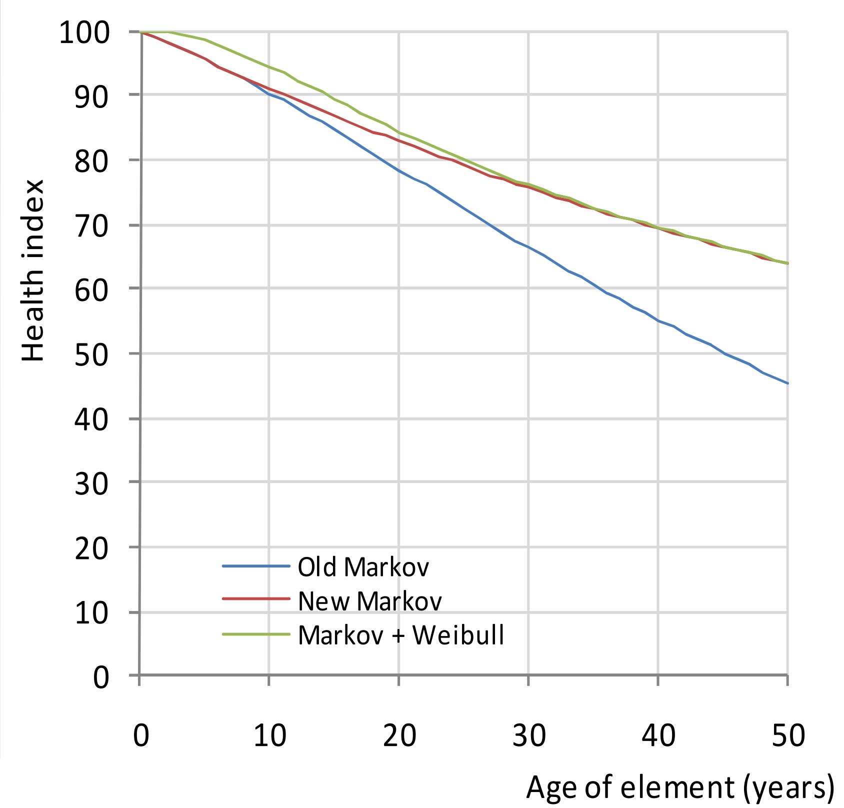



# Improved Markovian Deterioration Models (2010)

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




Superstructures




Substructures

# Improved Markovian Deterioration Models (2010)

- Development of the "do-something" Markovian transition probabilities.

| | | | | 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

| 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 - 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