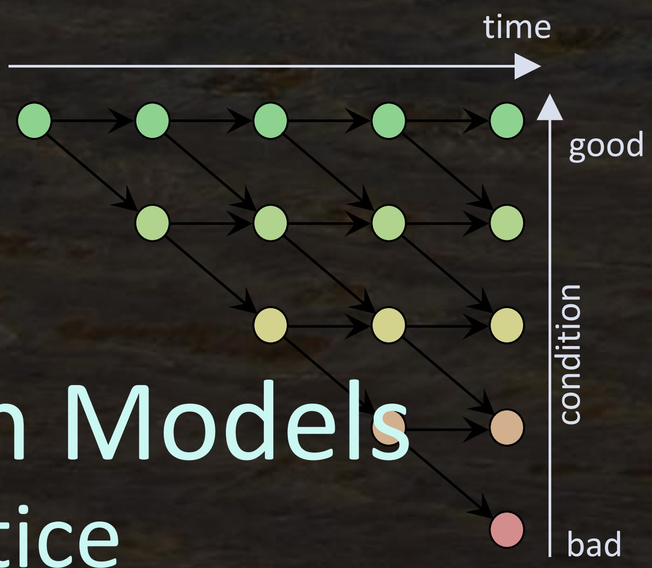


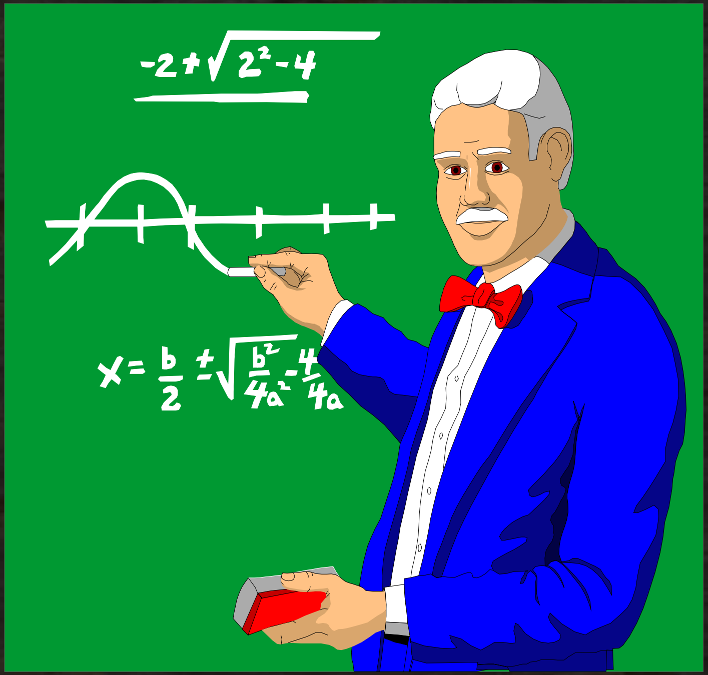
Bridge Deterioration Models

Theory and Practice

Examples from Florida and Virginia

Paul D. Thompson, Consultant

Paul D. Thompson



Bridge deterioration models

PRINCIPLES

CoRe element inspection

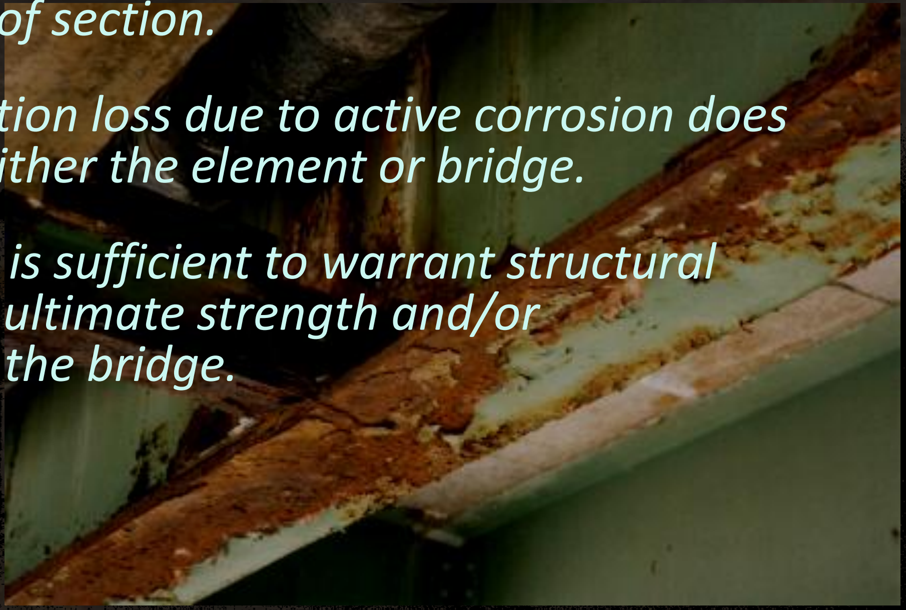
1. *There is no evidence of active corrosion, and the paint system is sound and functioning as intended to protect the metal surface.*

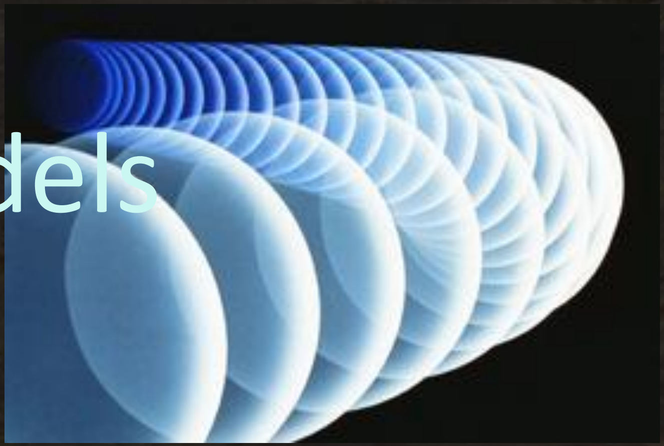
2. *There is little or no active corrosion. Surface corrosion has formed or is forming. The paint system may be chalking, peeling, curling, or showing other early evidence of paint system distress but there is no exposure of metal.*

3. *Surface corrosion is prevalent. There may be exposed metal, but there is no active corrosion which is causing loss of section.*

4. *Corrosion may be present but any section loss due to active corrosion does not yet warrant structural review of either the element or bridge.*

5. *Corrosion has caused section loss and is sufficient to warrant structural review to ascertain the impact on the ultimate strength and/or serviceability of either the element or the bridge.*

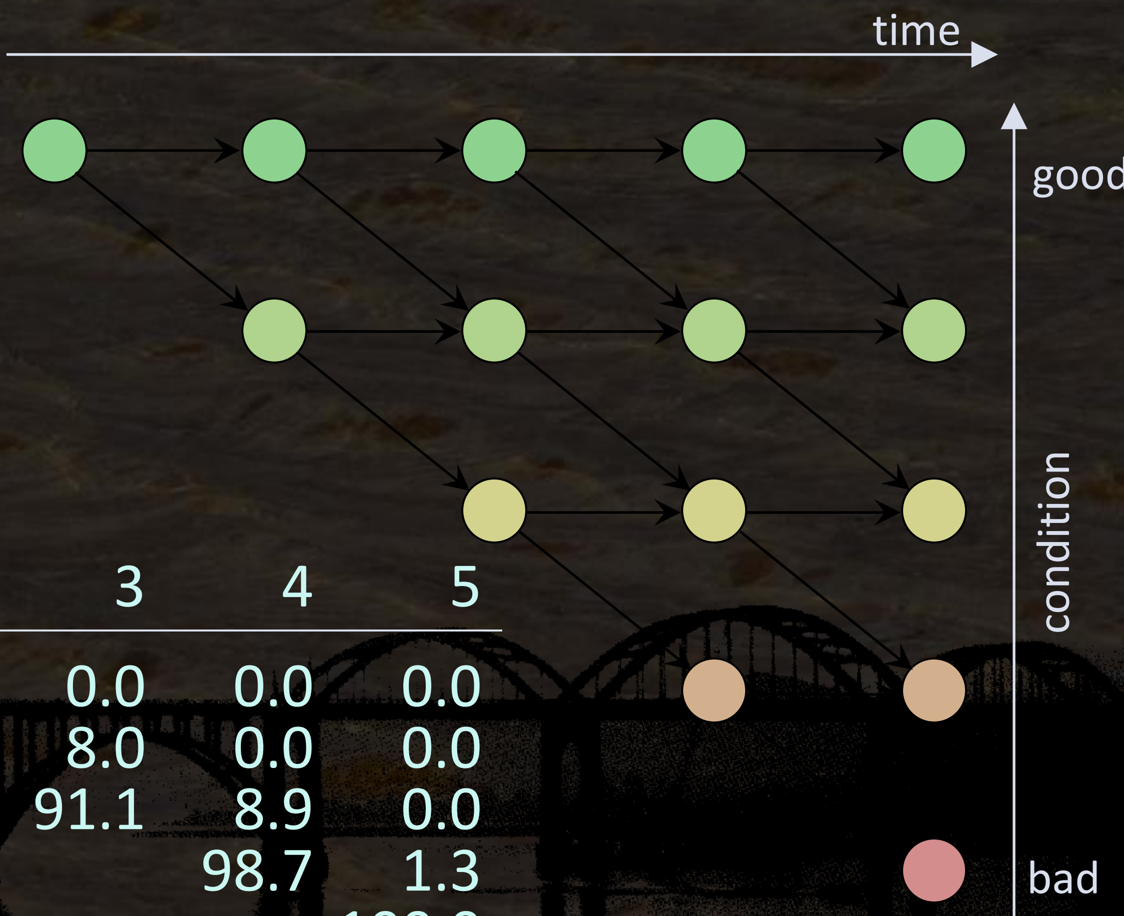




Markovian Models

- Assumptions
  - Uniform time intervals between decisions
  - Small number of condition states
  - Each state is self-contained:
    - Contains all information needed to predict future deterioration
    - Does not require information about past states
    - Rates change with condition rather than time

Markov model



Condition states

From	To 1	2	3	4	5
1	93.6	6.4	0.0	0.0	0.0
2		92.0	8.0	0.0	0.0
3			91.1	8.9	0.0
4				98.7	1.3
5					100.0

All amounts in percent

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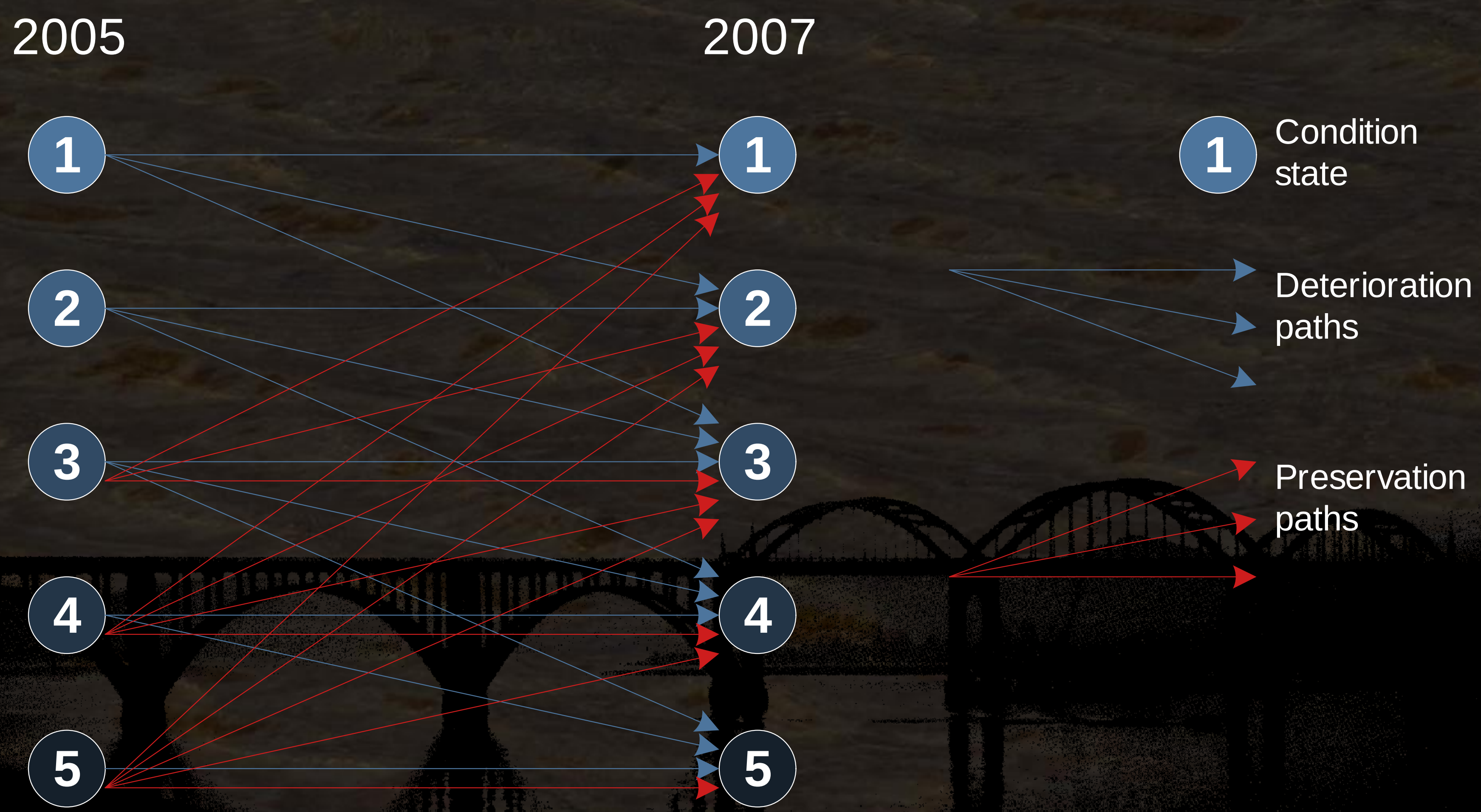
Changes in condition



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Bridge deterioration models

DEVELOPING VALID MODELS

Background

- Florida DOT
  - 19,213 structures (bridges, culverts, sign structures, high-mast light poles)
  - 884,678 element inspections over 14 years
  - 93,615 maintenance activities
- Virginia DOT
  - Similar number of structures and inspections
  - No maintenance data

Activity classification

	Object	Action Category: 100-Replace	200-Rehab	300-Repair	400-Maint
Materials	0 Other material				400 (1)
	1 Deck	101	201 (2)	301 (3)	401 (4)
	2 Steel/coat (incl metal)	102 (5)	202	302 (6)	402 (7)
	3 Concrete		203	303 (8)	403 (9)
	4 Timber		204		404
	5 Masonry		205		405
	6 MSE		206		406
Hi-Maint	10 Other element				
	11 Joint	111	211	311	411
	12 Joint seal	112			
	13 Bearing (incl p/h)	113	213		413
	14 Railing	114			
Drainage	21 Slope prot	121	221		
	22 Channel		222		422
	23 Drain sys	123	223		423
Machinery	31 Machinery	131 (10)	231 (10)	331 (10,11)	431 (10)
	32 Cath prot	132			
Major	41 Beam	141			
	42 Truss/arch/box	142			
	43 Cable	143	243		
	44 Substr elem (exc cap)	144 (12)			
	45 Culvert	145			
	46 Appr slab	146	246 (13)		
Appurtenances	51 Pole/sign	151			

White cells represent valid sub-categories; numbers in parentheses refer to footnotes

Footnotes

1. Wash structure
2. Rehab deck and replace overlay
3. Repair deck and substrate
4. Repair potholes
5. Replace paint system
6. Spot paint
7. Restore top coat
8. Clean rebar and patch
9. Patch minor spalls
10. Incl. elec, hydraulic, and mech elements
11. Repair and lubricate
12. Incl. fenders, dolphins, and pile jackets
13. Mudjacking

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Markov model estimation

Linear regression

- Traditional method
- Transition to any worse state
- Usable models: 172

One-step

- New method
- Transition to just next-worse state
- Usable models: 253

(Out of 755 models at the element/environment level)

Linear regression

- Min sample: 1500
- r^2: 0.7213

One-step

- Min sample: 500
- r^2: 0.7217

One-step method makes better use of data without sacrificing explanatory power.

Markov model estimation

- One-step model solved algebraically
- Simpler method with fewer numerical problems

$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \end{bmatrix} = \begin{bmatrix} p_{11} & p_{12} & 0 & 0 \\ & p_{22} & p_{23} & 0 \\ & & p_{33} & p_{34} \\ & & & p_{44} \end{bmatrix}^2 \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix}$$

Beefing up sample size

Sample: 559,311 inspection pairs

- Performance improved by combining models

Level of model	% Valid
151 elements × 4 environments	33.5
151 elements	57.0
72 element types	98.6

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Onset of deterioration

- Weibull survival probability model
  - For transition from state 1 to state 2 only
  - Extension of Markov model
  - Transition probability is age-dependent

$$y_{1g} = \exp\left(-\left(g/\alpha\right)^{\beta}\right) \qquad \alpha = \frac{t}{(\ln 2)^{1/\beta}}$$

g = age (years)
t = median transition time (years), states 1 to 2
β = shaping parameter, to be estimated

Weibull shaping parameter

Shaping parameter (beta) slows the onset of deterioration

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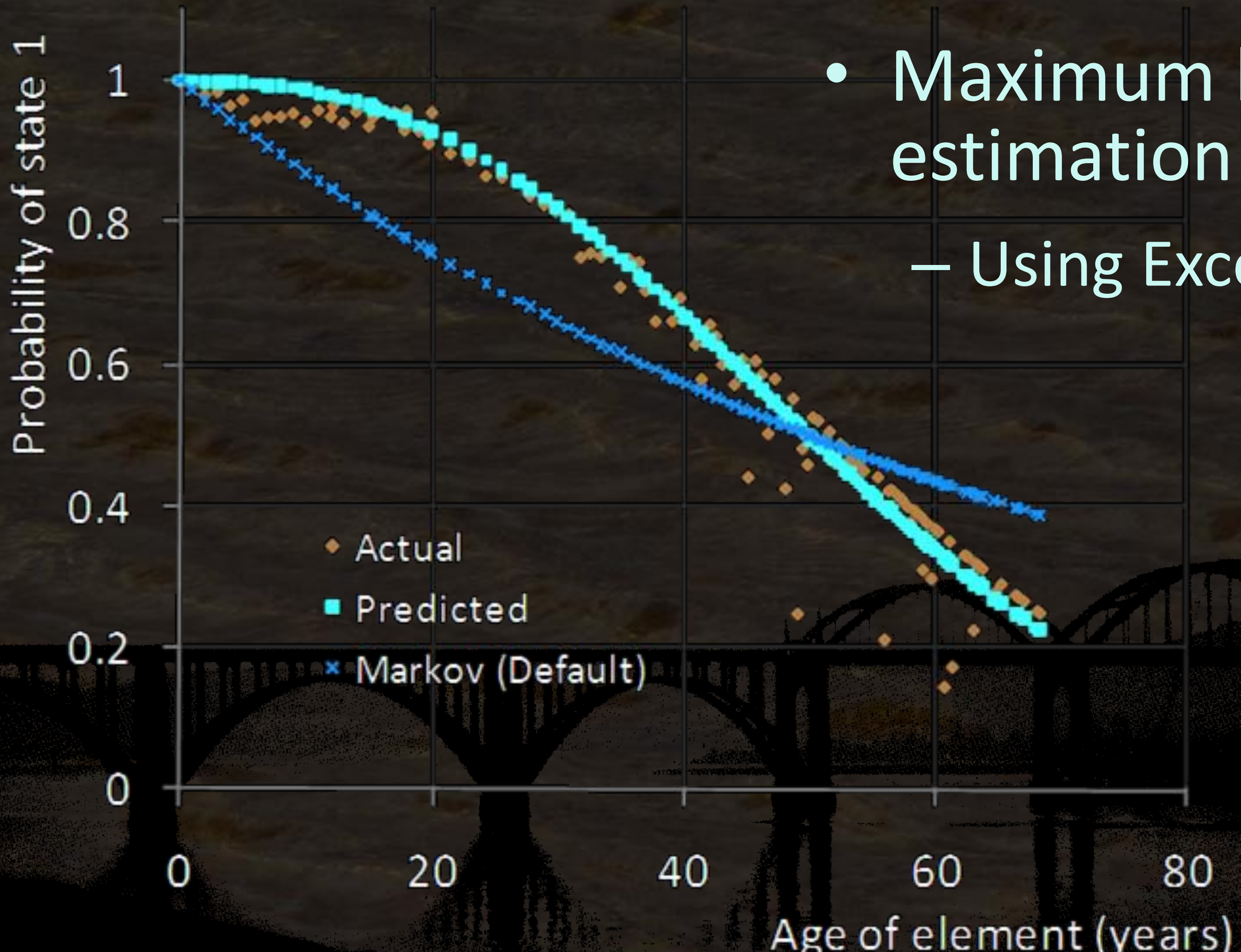
Estimation of beta



- Maximum likelihood estimation
  - Using Excel Solver

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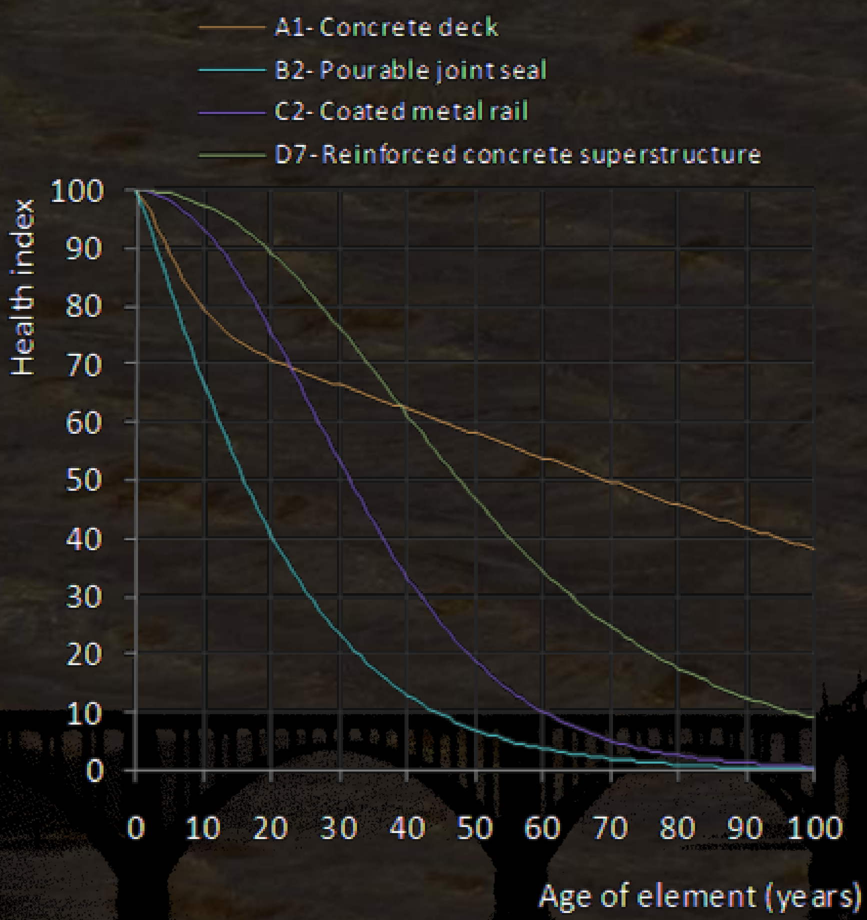
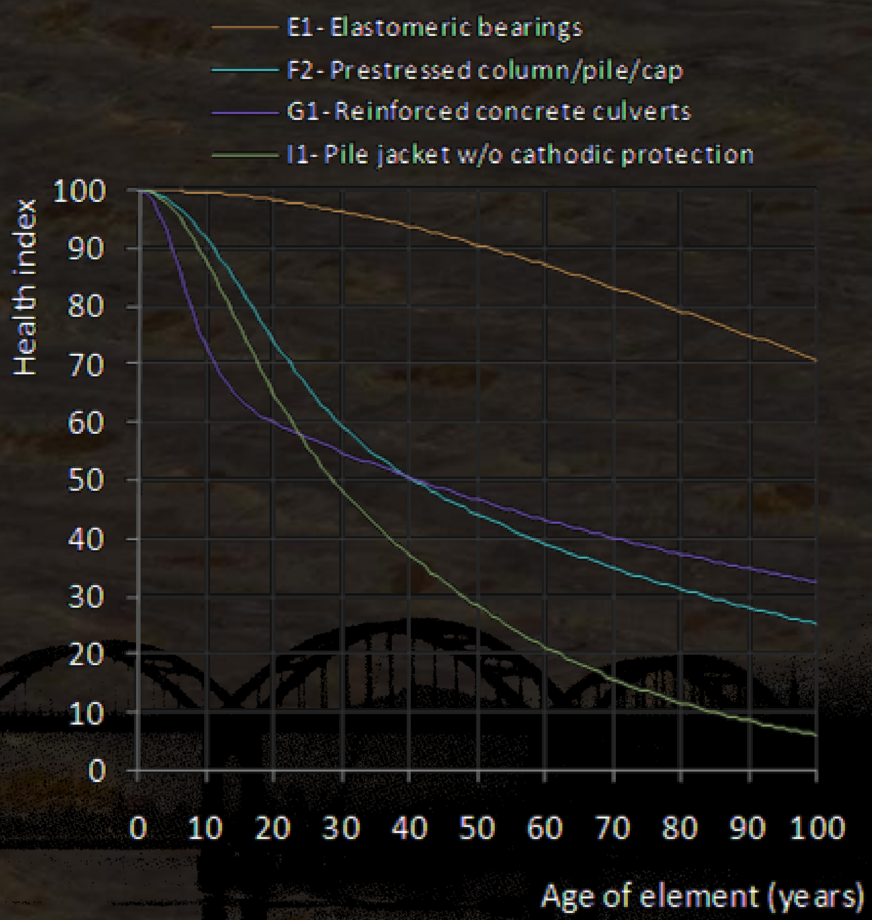
New deterioration models





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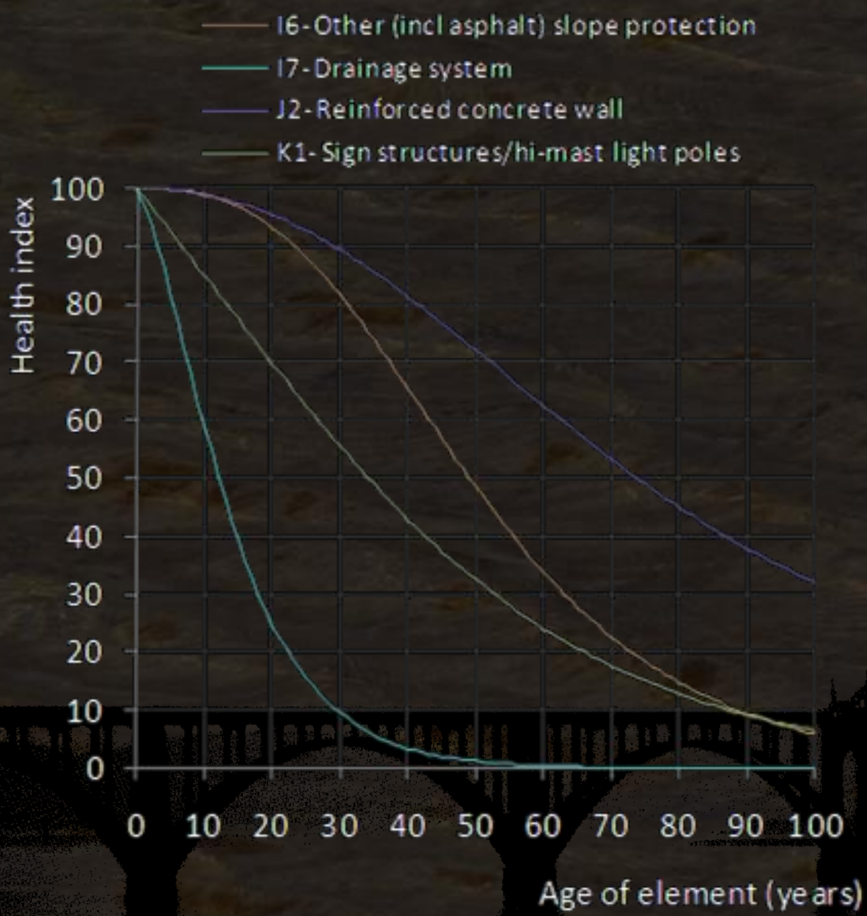
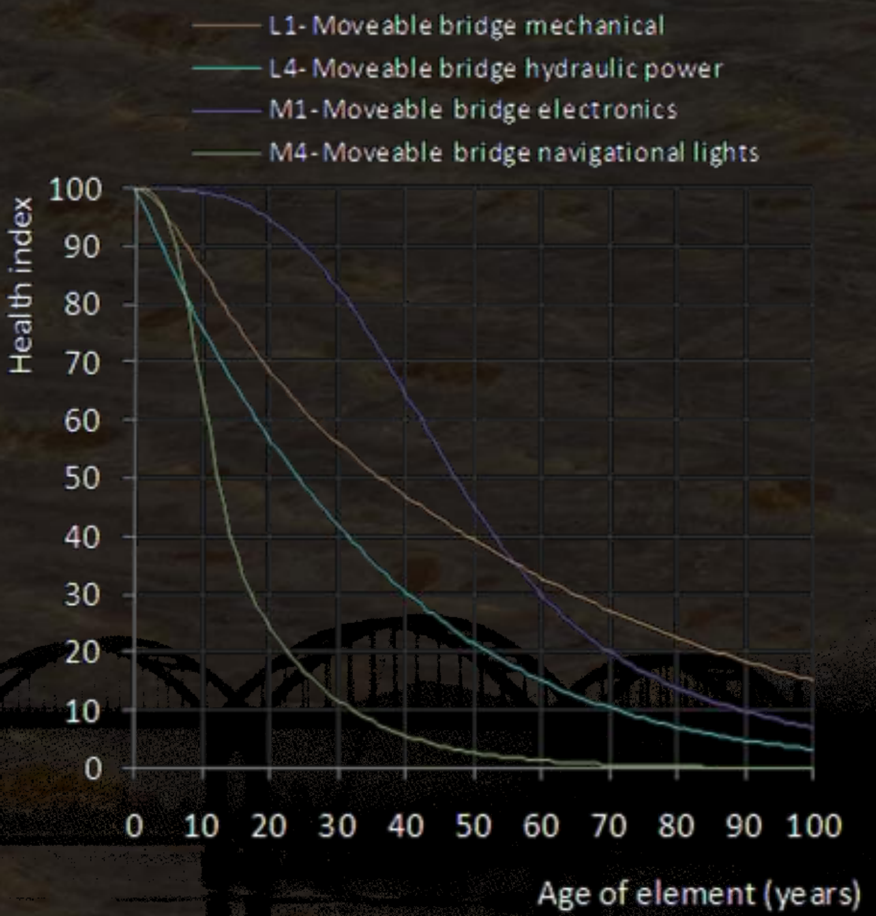
New deterioration models





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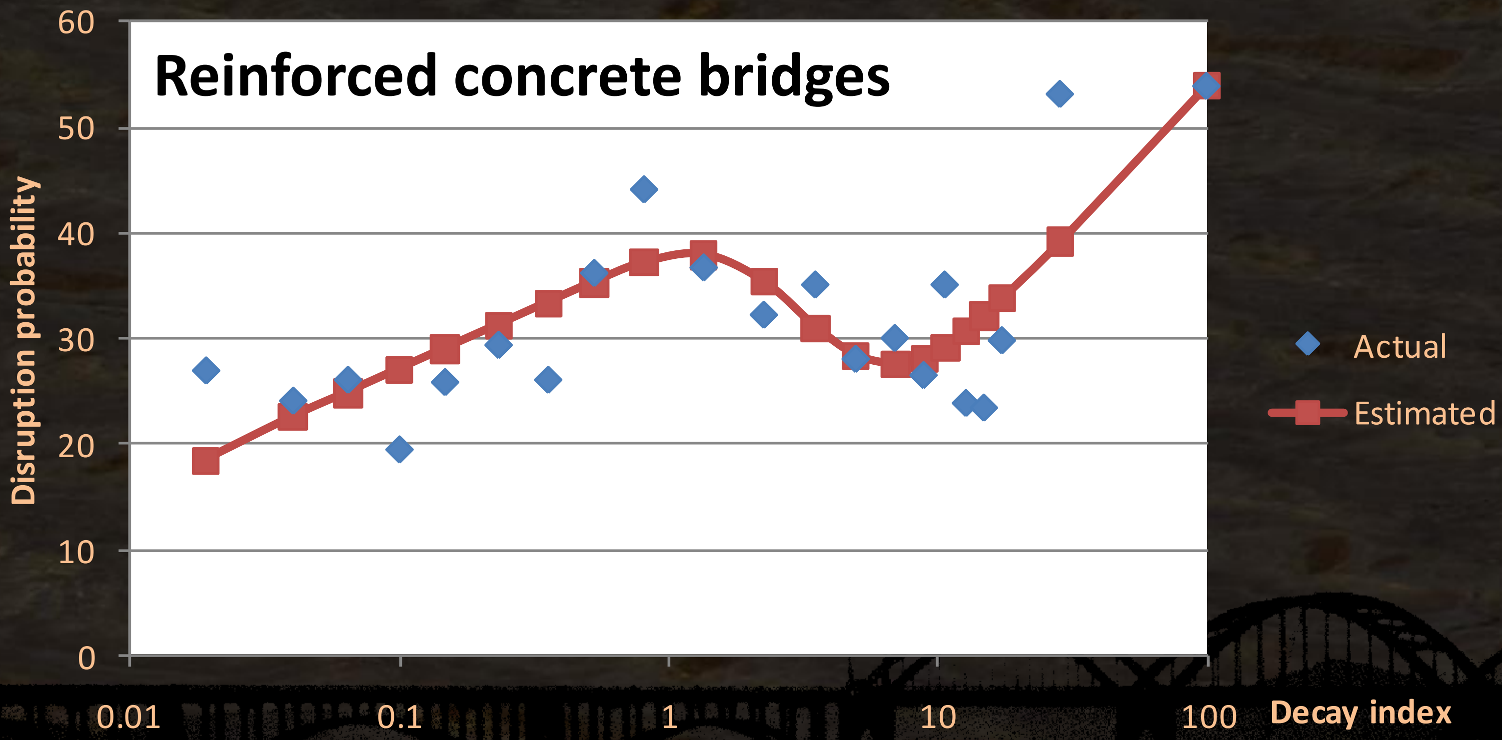
Bridge deterioration models

RISK FROM ADVANCED DETERIORATION

Lognormal risk model

- Appropriate when explanatory variable is built up by multiplication
- Based on log of weighted percent in worst and 2nd- worst states for each inspection
- For each inspection indicate if bridge underwent retirement, replacement, reconstruction, or posting before next inspection
- Compute **lognormal hazard function** and element weights using maximum likelihood estimation

Example model



Decay index: Weighted condition similar to health index, but emphasizes the worst and 2nd-worst states. 100=worst

Bridge deterioration models

CONCLUSIONS

Comparison with experts

Ratio of new transition times to old (2000) expert judgment models

By element category	
Joints	3.2
Railing	1.6
Superstructure	1.7
Bearings	2.2
Substructure	2.0
Movable bridge equip	1.8
Channel	1.4
Other elements	1.4

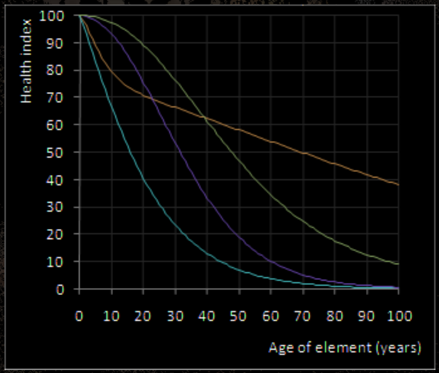
By element material	
Unpainted steel	1.8
Painted steel	1.9
Prestressed concrete	1.7
Reinforced concrete	2.1
Timber	1.8
Other material	2.1
Decks	1.9
Slabs	3.3

Expert panel under-estimated transition times by a factor of 1.97 on average.

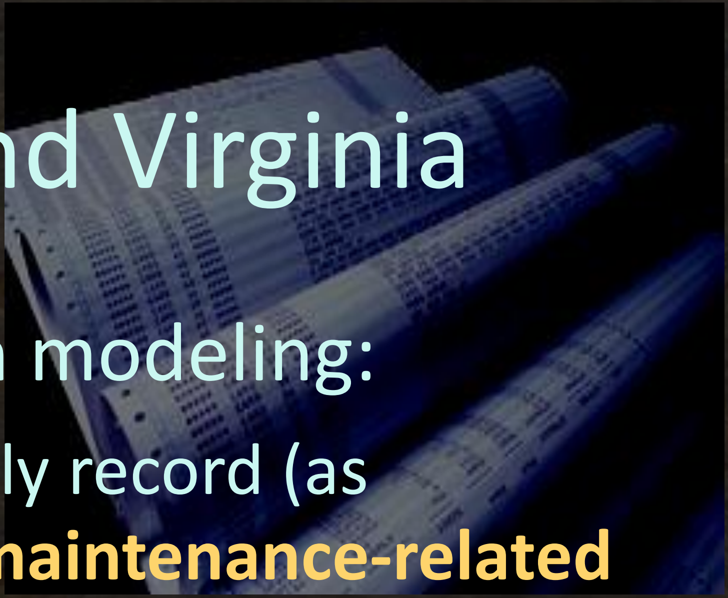
Other conclusions

- It is feasible to estimate Pontis deterioration and action effectiveness models entirely from historical data.
- New techniques have been developed to reduce data requirements and improve model quality.
- New Markov models explained 72% of variability in inspection data. Weibull refinement explained up to 37% of the remainder of variability.

The new models should greatly improve the credibility and realism of the life cycle cost analysis and the programming decisions that it supports.

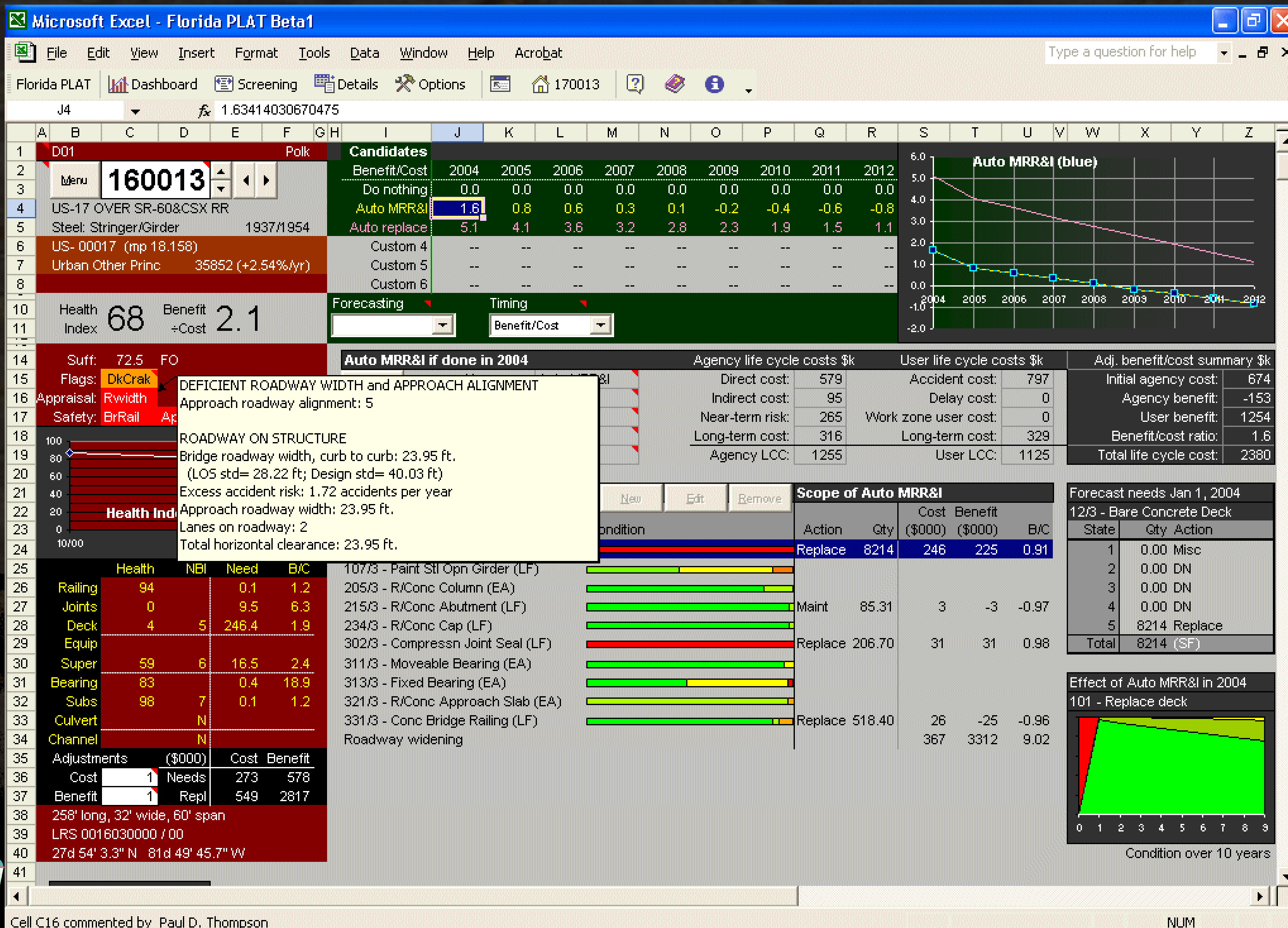


Lessons: Florida and Virginia



- Success factors for condition modeling:
  - Inspections should consistently record (as condition state data) severe **maintenance-related defects** as well as safety and function defects
  - **Need a reliable way to identify past actions:** maintenance, repair, rehabilitation, improvement, and replacement
  - Need to control for relatively **new materials** (e.g. weathering steel and prestressed concrete)

Florida
Project Level Analysis Tool



Thank you!

Paul D. Thompson

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