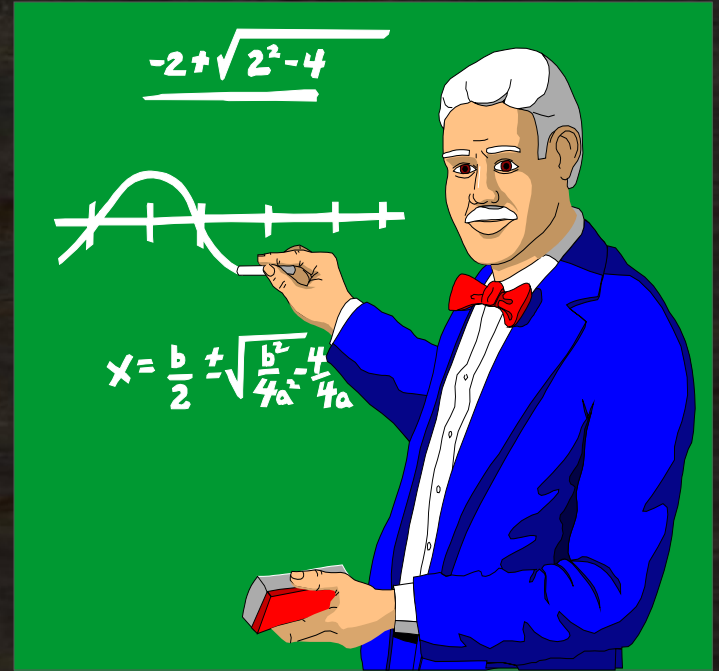


# Bridge Deterioration Models

## Theory and Practice

### Examples from Florida and Virginia

Paul D. Thompson, Consultant

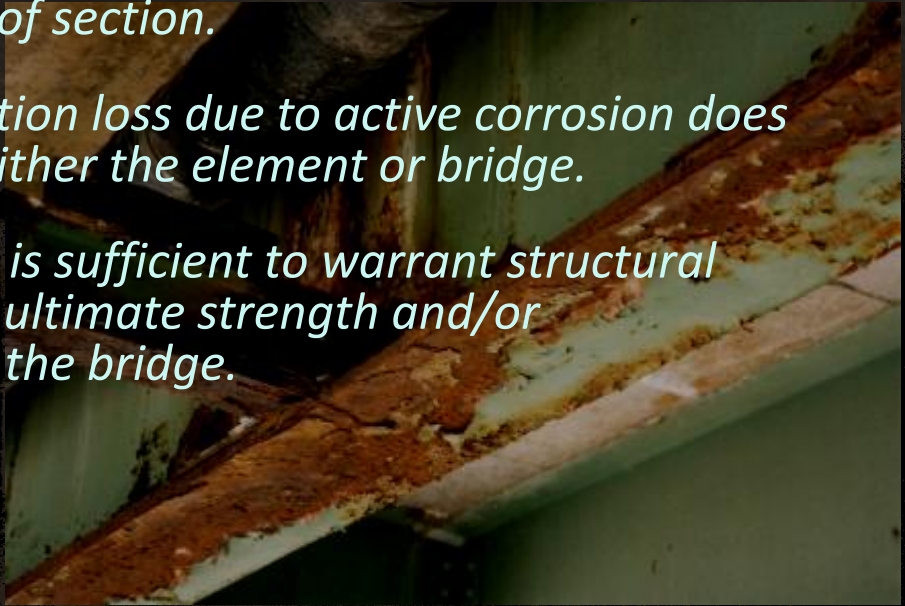


Bridge deterioration models

# PRINCIPLES

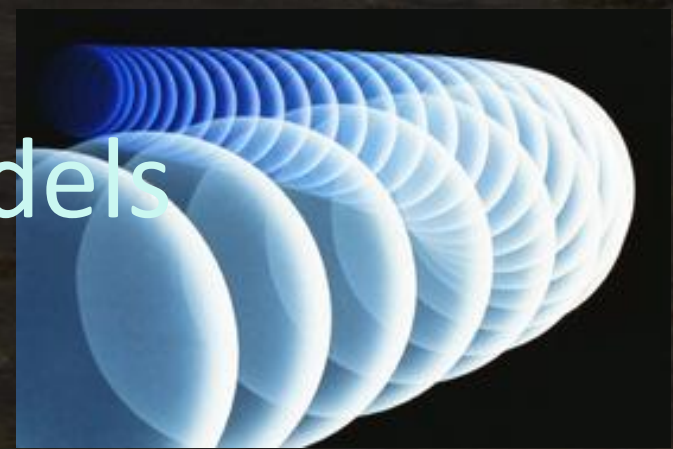


# CoRe element inspection

- 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

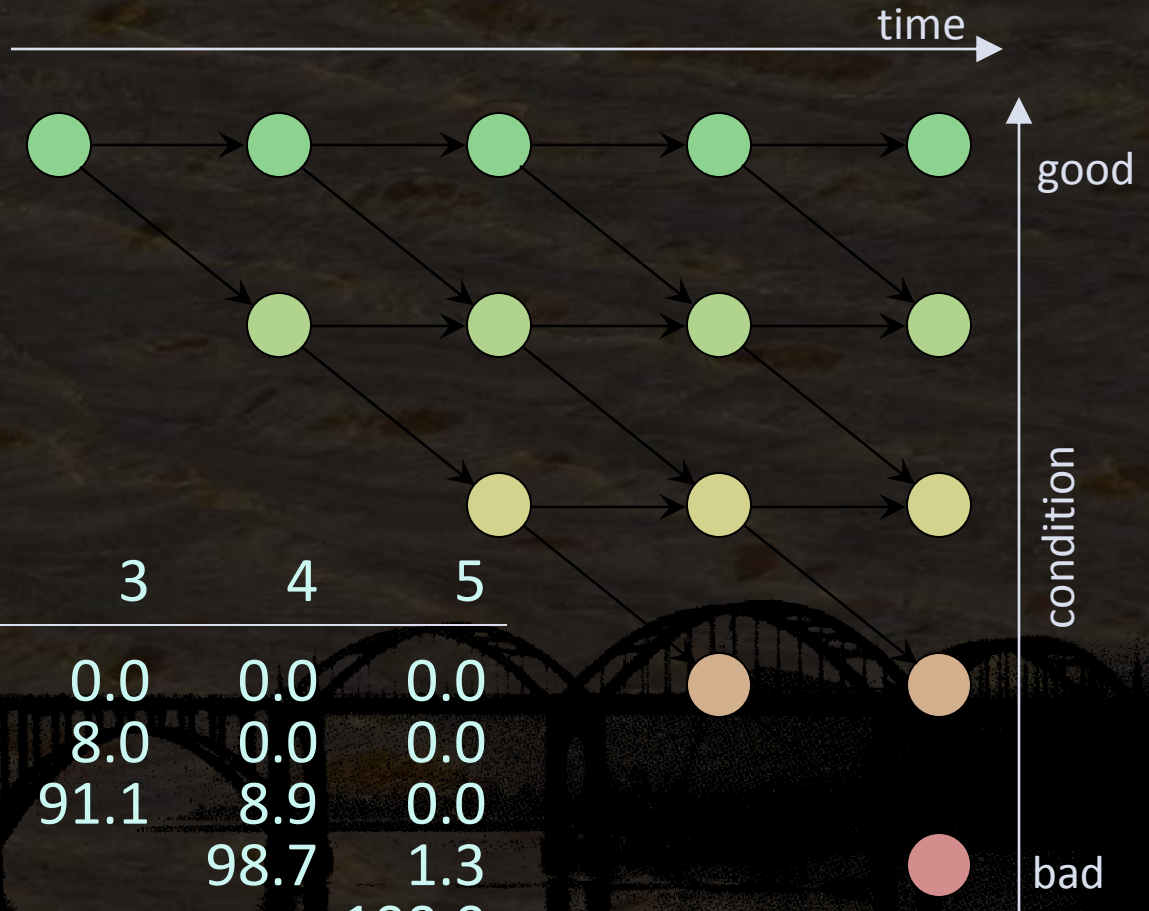


- Assumptions
  - Uniform time intervals between decisions
  - Small number of condition states
  - Each state is self-contained:
    - Contains all information needed to predict future deterioration
    - Does not require information about past states
    - Rates change with condition rather than time





# 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

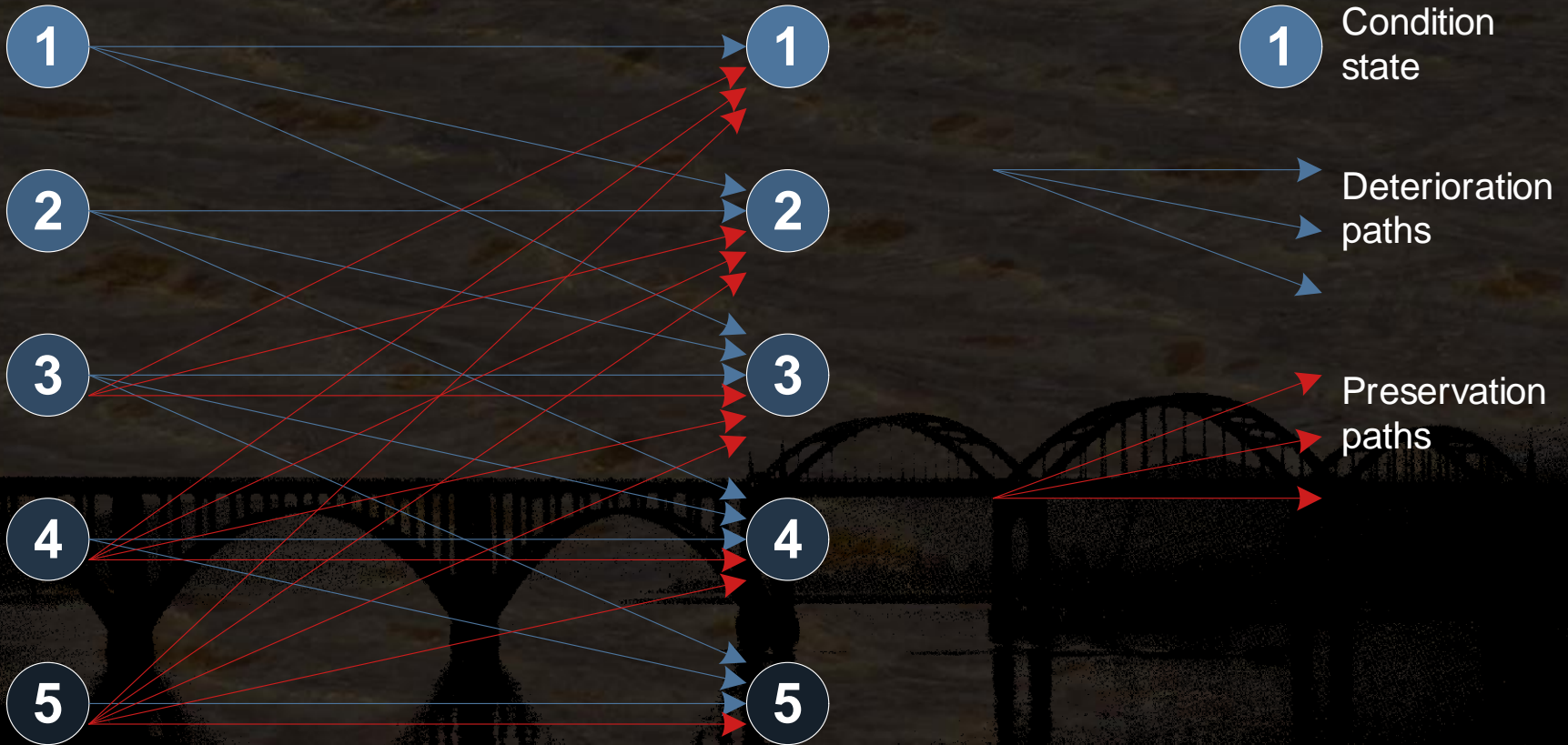
All amounts in percent



# Changes in condition

2005

2007





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
<b>Materials</b>	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
<b>Hi-Maint</b>	10 Other element				
	11 Joint	111	211	311	411
	12 Joint seal	112			
	13 Bearing (incl p/h)	113	213		413
	14 Railing	114			
<b>Drainage</b>	21 Slope prot	121	221		
	22 Channel		222		422
	23 Drain sys	123	223		423
<b>Machinery</b>	31 Machinery	131 (10)	231 (10)	331 (10,11)	431 (10)
	32 Cath prot	132			
<b>Major</b>	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)		
<b>Appurtenances</b>	51 Pole/sign	151			

## 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

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



# Markov model estimation

## Linear regression

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

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

- Min sample: 1500
- $r^2$ : 0.7213

## One-step

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

- 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





# 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

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

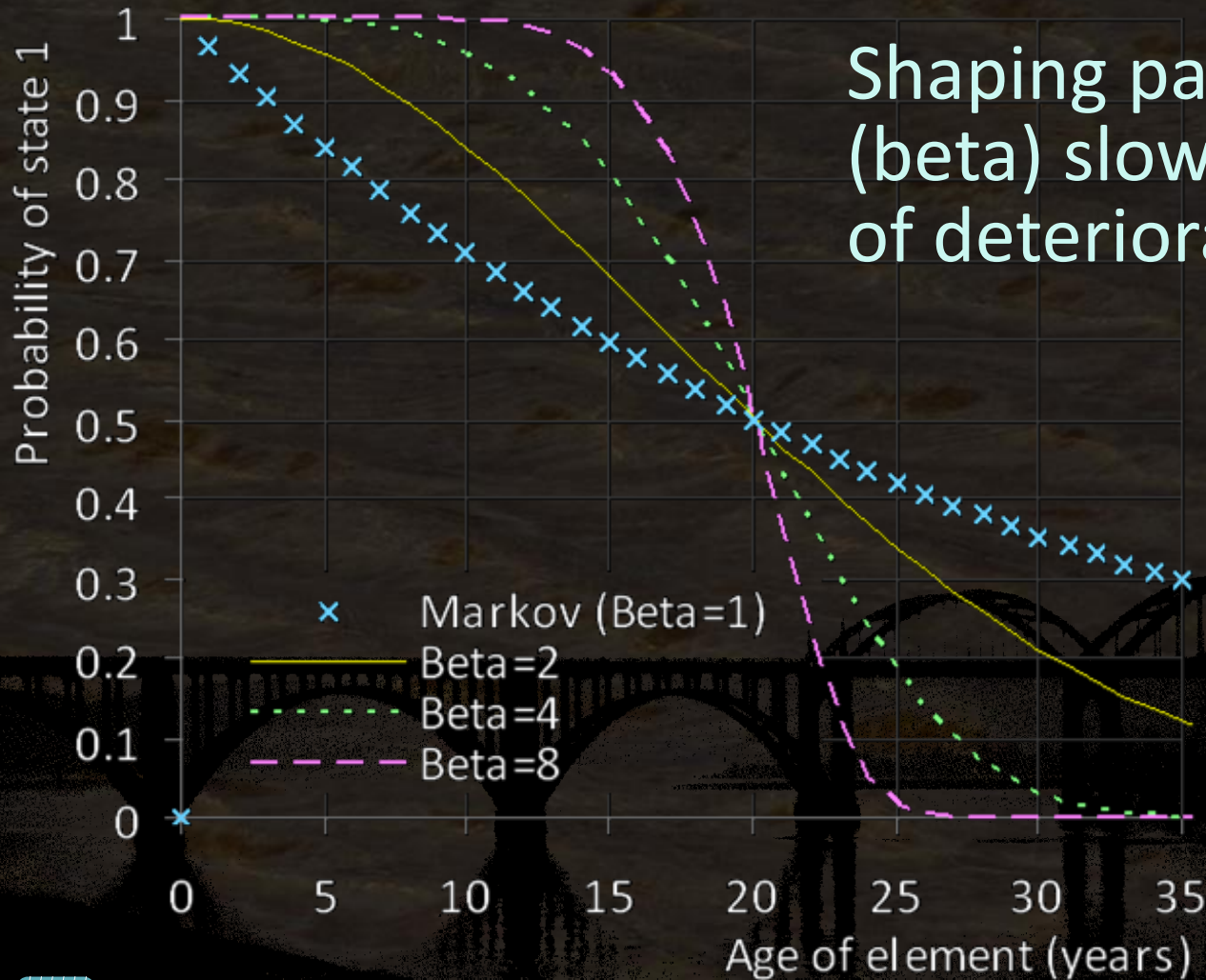
$g$  = age (years)

$t$  = median transition time (years), states 1 to 2

$\beta$  = shaping parameter, to be estimated

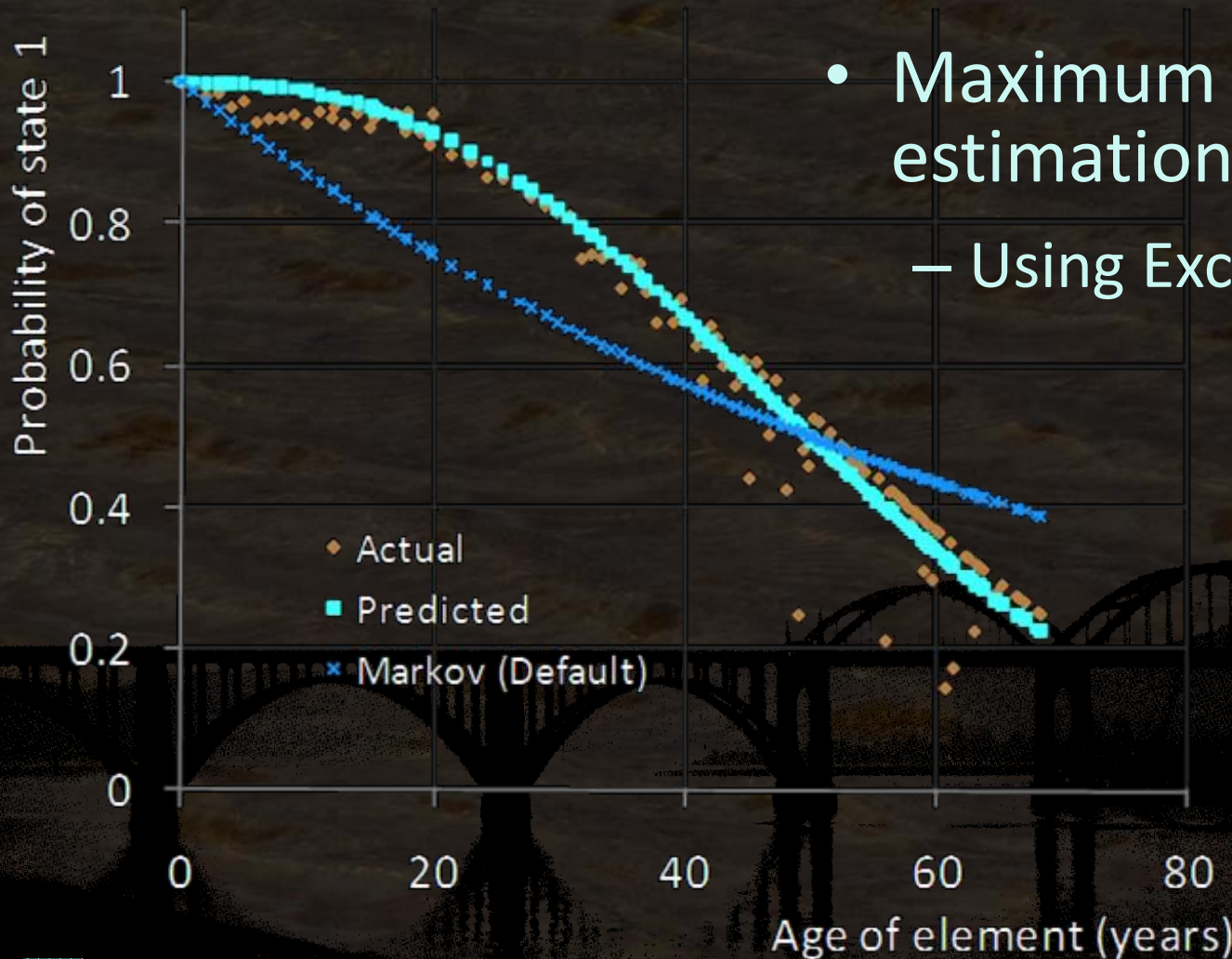


# Weibull shaping parameter





# Estimation of beta

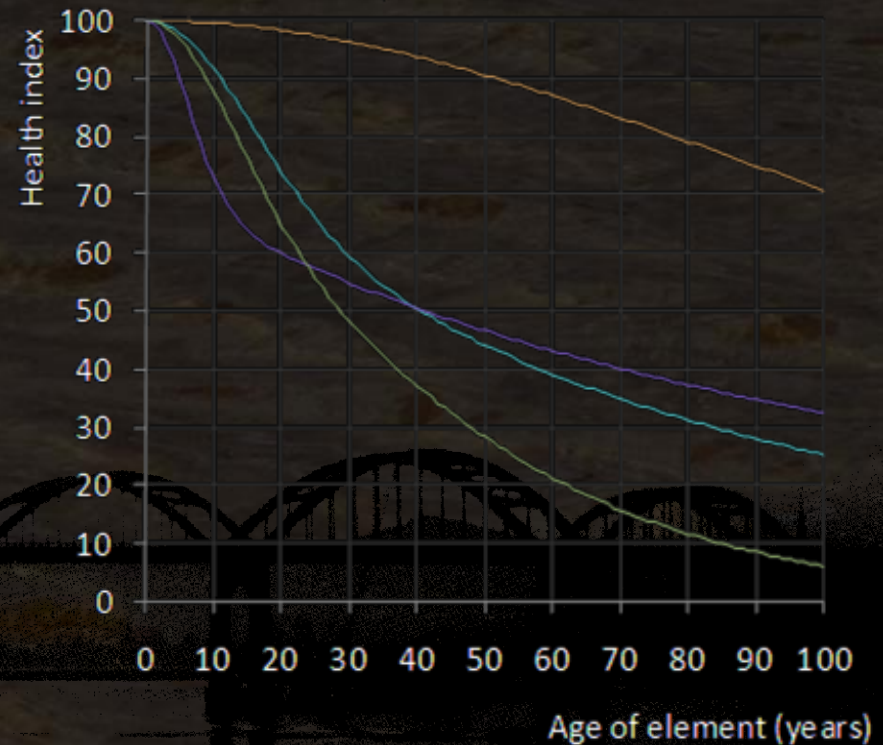
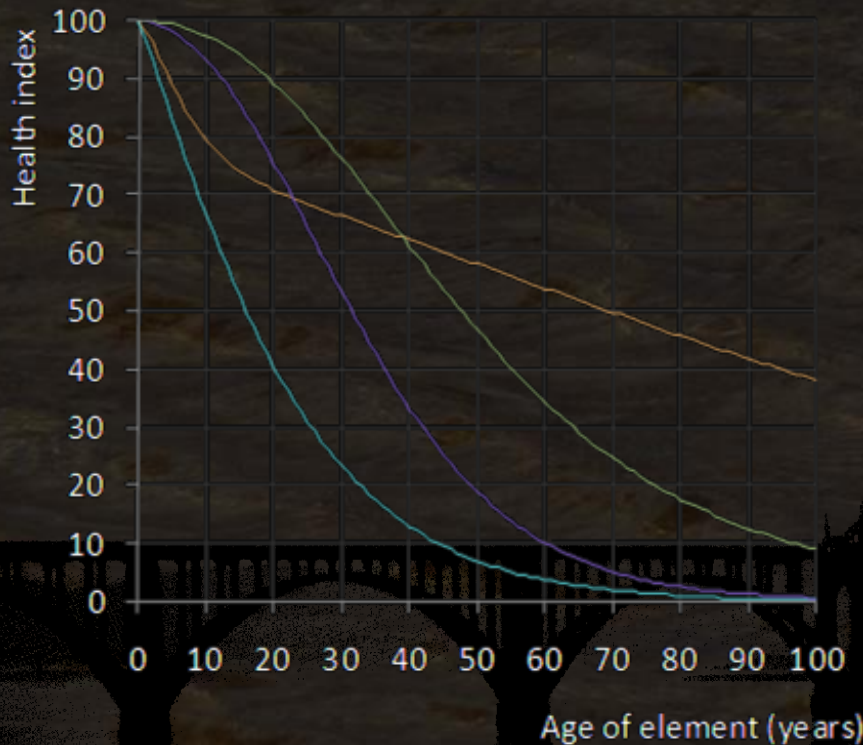


- Maximum likelihood estimation  
– Using Excel Solver

# New deterioration models

- A1- Concrete deck
- B2- Pourable joint seal
- C2- Coated metal rail
- D7- Reinforced concrete superstructure

- E1- Elastomeric bearings
- F2- Prestressed column/pile/cap
- G1- Reinforced concrete culverts
- I1- Pile jacket w/o cathodic protection

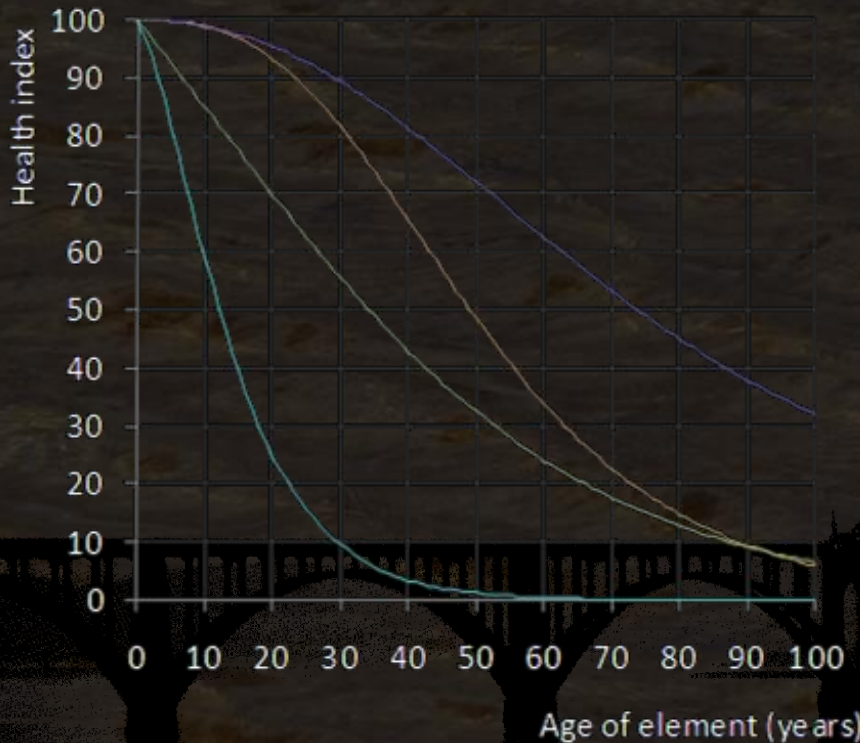




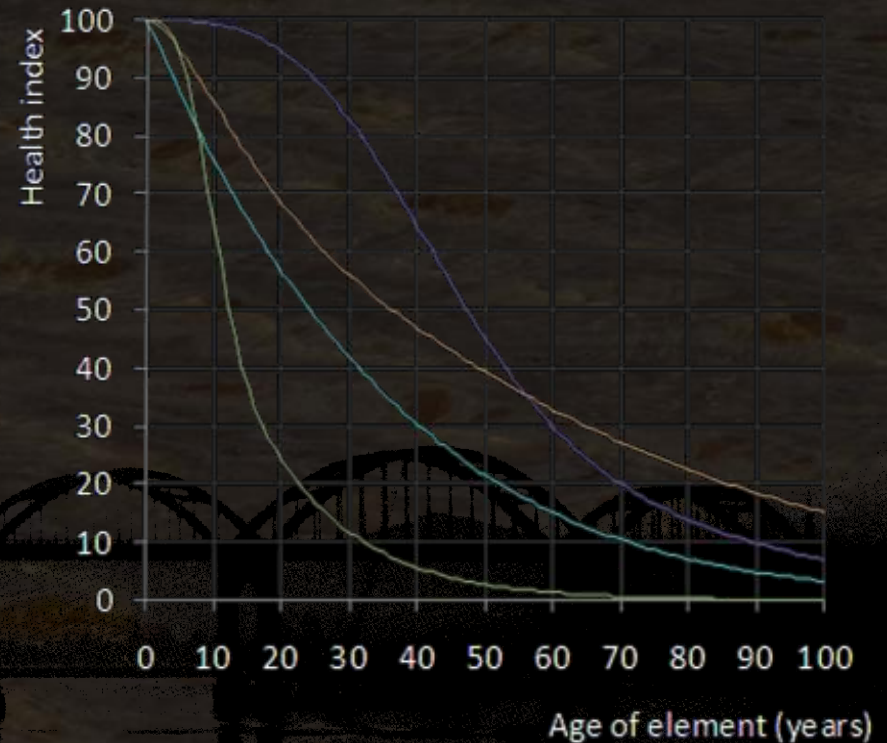


# New deterioration models

- I6-Other (incl asphalt) slope protection
- I7-Drainage system
- J2-Reinforced concrete wall
- K1-Sign structures/hi-mast light poles



- L1-Moveable bridge mechanical
- L4-Moveable bridge hydraulic power
- M1-Moveable bridge electronics
- M4-Moveable bridge navigational lights





Bridge deterioration models

# RISK FROM ADVANCED DETERIORATION



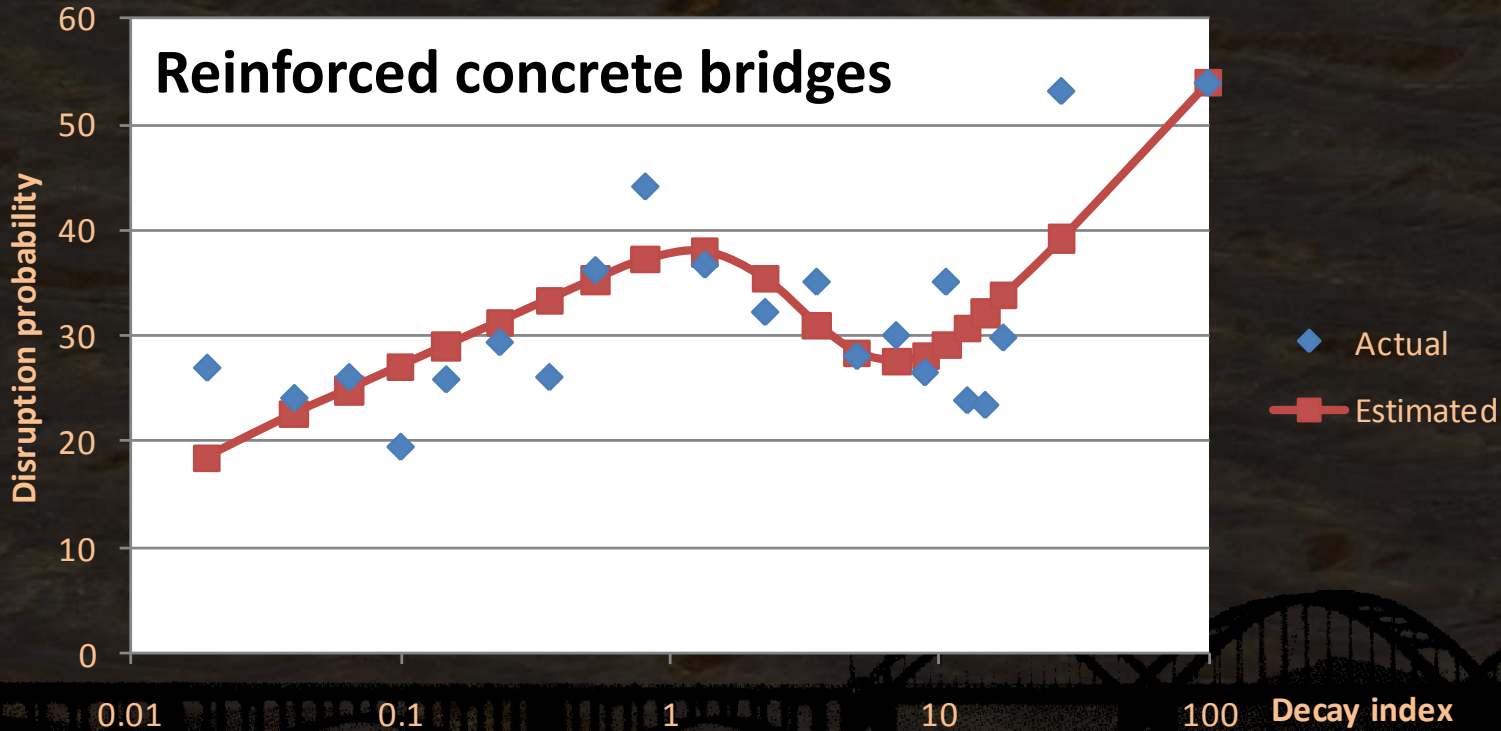
# Lognormal risk model

- Appropriate when explanatory variable is built up by multiplication
- Based on log of weighted percent in worst and 2<sup>nd</sup>- 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 2<sup>nd</sup>-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.*

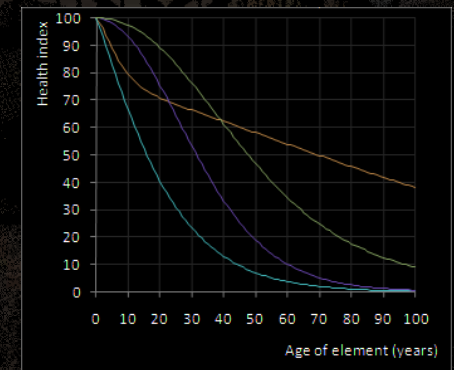




# Other conclusions

- 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

Microsoft Excel - Florida PLAT Beta1

File Edit View Insert Format Tools Data Window Help Acrobat

Florida PLAT Dashboard Screening Details Options 170013

J4 1.63414030670475

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
1	D01				Polk			<b>Candidates</b>																	
2	Menu	160013						Benefit/Cost	2004	2005	2006	2007	2008	2009	2010	2011	2012								
3								Do nothing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0								
4								Auto MRR&I	1.6	0.8	0.6	0.3	0.1	-0.2	-0.4	-0.6	-0.8								
5	US-17 OVER SR-60&CSX RR							Auto replace	5.1	4.1	3.6	3.2	2.8	2.3	1.9	1.5	1.1								
6	Steel: Stringer/Girder				1937/1954			Custom 4	--	--	--	--	--	--	--	--	--								
7	US- 00017 (mp 18.158)							Custom 5	--	--	--	--	--	--	--	--	--								
8	Urban Other Princ				35852 (+2.54%/yr)			Custom 6	--	--	--	--	--	--	--	--	--								
10	Health	68			Benefit	2.1		Forecasting																	
11	Index				+Cost			Timing																	
14	Suff:	72.5			FO			<b>Auto MRR&amp;I if done in 2004</b>																	
15	Flags:	DkCrak						Agency life cycle costs \$k																	
16	Appraisal:	Rwidth						Direct cost:	579																
17	Safety:	BrRail						Indirect cost:	95																
18								Near-term risk:	265																
19								Long-term cost:	316																
20								Agency LCC:	1255																
21								User life cycle costs \$k																	
22								Accident cost:	797																
23								Delay cost:	0																
24								Work zone user cost:	0																
25								Long-term cost:	329																
26								User LCC:	1125																
27								Adj. benefit/cost summary \$k																	
28								Initial agency cost:	674																
29								Agency benefit:	-153																
30								User benefit:	1254																
31								Benefit/cost ratio:	1.6																
32								Total life cycle cost:	2380																
33																									
34																									
35																									
36																									
37																									
38																									
39																									
40																									
41																									

DEFICIENT ROADWAY WIDTH and APPROACH ALIGNMENT  
Approach roadway alignment: 5

ROADWAY ON STRUCTURE  
Bridge roadway width, curb to curb: 23.95 ft.  
(LOS std= 28.22 ft; Design std= 40.03 ft)  
Excess accident risk: 1.72 accidents per year  
Approach roadway width: 23.95 ft.  
Lanes on roadway: 2  
Total horizontal clearance: 23.95 ft.

Condition	Action	Qty	Cost (\$000)	Benefit (\$000)	B/C
107/3 - Paint Sl' Opn Girder (LF)					
205/3 - R/Conc Column (EA)					
215/3 - R/Conc Abutment (LF)	Maint	85.31	3	-3	-0.97
234/3 - R/Conc Cap (LF)					
302/3 - Compressn Joint Seal (LF)	Replace	206.70	31	31	0.98
311/3 - Moveable Bearing (EA)					
313/3 - Fixed Bearing (EA)					
321/3 - R/Conc Approach Slab (EA)					
331/3 - Conc Bridge Railing (LF)	Replace	518.40	26	-25	-0.96
Roadway widening			367	3312	9.02

Forecast needs Jan 1, 2004  
12/3 - Bare Concrete Deck

State	Qty	Action
1	0.00	Misc
2	0.00	DN
3	0.00	DN
4	0.00	DN
5	8214	Replace
Total	8214	(SF)

Effect of Auto MRR&I in 2004  
101 - Replace deck

Condition over 10 years

Cell C16 commented by Paul D. Thompson

NUM



# Thank you!

Paul D. Thompson

[www.pdth.com](http://www.pdth.com)



*Paul D. Thompson*