VDOT

Virginia Department of Transportation

COMPONENT LEVEL DETERIORATION MODELING FOR BRIDGES IN VIRGINIA

BrM Users Group Meeting 2022

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September 14, 2022

Agenda

- Goal and Objectives
- Background
- Data Preparation
- Methodology
- Results
- Applications
- Recommendations

Goal and Objectives

Goal:

- **Enhance the budget allocation for Infrastructure Investment and Jobs act (IIJA)**

Objectives:

- **Find the best fit distribution for modeling bridge deterioration**
- **Project the condition rating of bridge components over the service life**
    - Deck
    - Superstructure
    - Substructure
    - Culverts

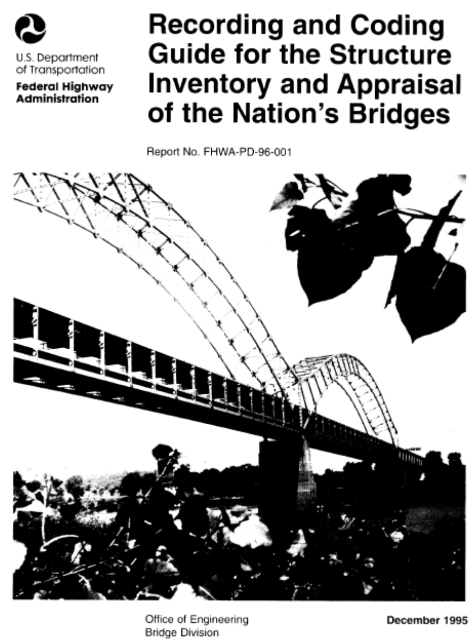
Reasons for Component Level Modeling

- Lack of element data for some bridges
- Lack of historical data for developing accurate element level deterioration models
- Component level models are simpler and faster (deck, superstructure, substructure, culverts vs more than 100 elements)
- Component level based models are more tangible
- No need to convert condition states to condition ratings for checking performance measures

Background

Condition ratings are used to describe the existing, in-place bridge as compared to the as-built condition.

Code	Description
N	NOT APPLICABLE
9	EXCELLENT CONDITION
8	VERY GOOD CONDITION - no problems noted.
7	GOOD CONDITION - some minor problems.
6	SATISFACTORY CONDITION - structural elements show some minor deterioration.
5	FAIR CONDITION - all primary structural elements are sound but may have minor section loss, cracking, spalling or scour.
4	POOR CONDITION - advanced section loss, deterioration, spalling or scour.
3	SERIOUS CONDITION - loss of section, deterioration, spalling or scour have seriously affected primary structural components. Local failures are possible. Fatigue cracks in steel or shear cracks in concrete may be present.
2	CRITICAL CONDITION - advanced deterioration of primary structural elements. Fatigue cracks in steel or shear cracks in concrete may be present or scour may have removed substructure support. Unless closely monitored it may be necessary to close the bridge until corrective action is taken.
1	"IMMINENT" FAILURE CONDITION - major deterioration or section loss present in critical structural components or obvious vertical or horizontal movement affecting structure stability. Bridge is closed to traffic but corrective action may put back in light service.
0	FAILED CONDITION - out of service - beyond corrective action.



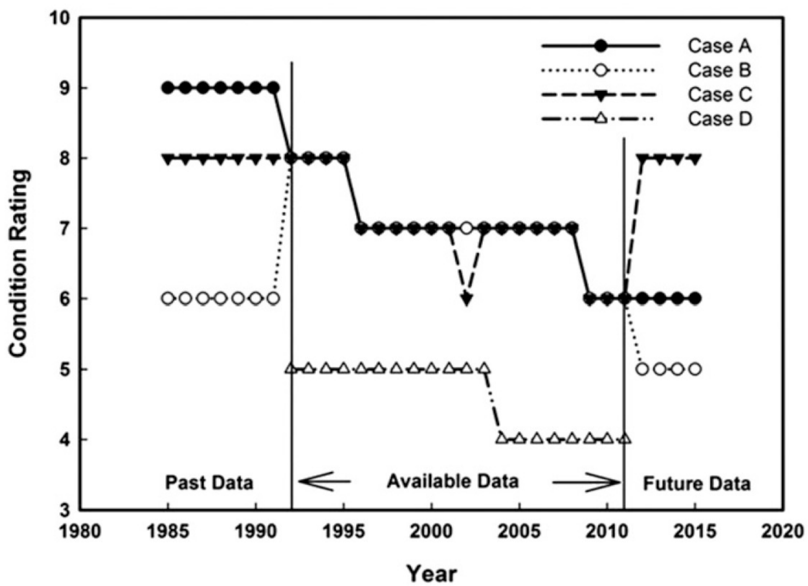
Source: Federal Highway Administration (FHWA). (1995). "Recording and coding guide for the structure inventory and appraisal of the nation's bridges." Rep. No. FHWA-PD-96-001, Washington, DC.

Data Preparation

- Collected NBI data from 1992 to 2018 (27 years)
- Defined a Parameter: Time In Condition Rating (TICR)
- Trimmed Data

Federal ID	Struct Category Acronym	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
3	SGCD	4	4	4	6	6	6	6	7	7	7	7	7	7	7	7	7	7	7	7	6	6	6	6	6	6	6	6
5	SGCD	7	7	6	6	6	6	6	6	6	6	6	6	6	6	5	5	5	5	5	5	5	5	5	5	5	5	5
7	SGCD	8	8	8	8	6	6	6	6	6	6	6	5	5	5	5	5	5	5	5	5	5						
9	SGCD	5	5	5	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	5	5
11	SGCD	6	6	6	6	8	8	7	7	7	7	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
13	SGCD	5	5	5	5	8	8	8	8	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
14	SGCD	7	7	7	7	7	7	7	6	6	6	6	6	6	6	6	5	5	6	6	6	6	6	6	6	6	6	6
15	SGCD	9	9	9	9	7	7	7	7	7	7	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
16	PSCGCD	8	8	7	7	6	6	6	6	6	6	6	6	6	6	6	6	5	5	6	6	5	5	5	5	5	5	4
18	SGCD	7	7	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	5	5	5
19	SGCD	7	7	7	7	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	5	5	5
20	SGCD	6	6	7	7	7	7	7	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6

Data Trimming



General cases	Description of possible cases
For beginning of interval	Case A: Condition rating dropped 1 year before 1992
	Case B: Because of some repairs in 1991, condition rating increased in 1992
	Case C: No change in condition rating
	Case D: One condition rating change in time interval 1992–2011
For end of interval	Case A: No change in condition rating after 2011
	Case B: Condition rating dropped after 2011
	Case C: Condition rating increased because of repair

Source: M Nasrollahi, G Washer - ASCE Journal of Bridge Engineering, 2015

Various Approaches for Deterioration Modeling

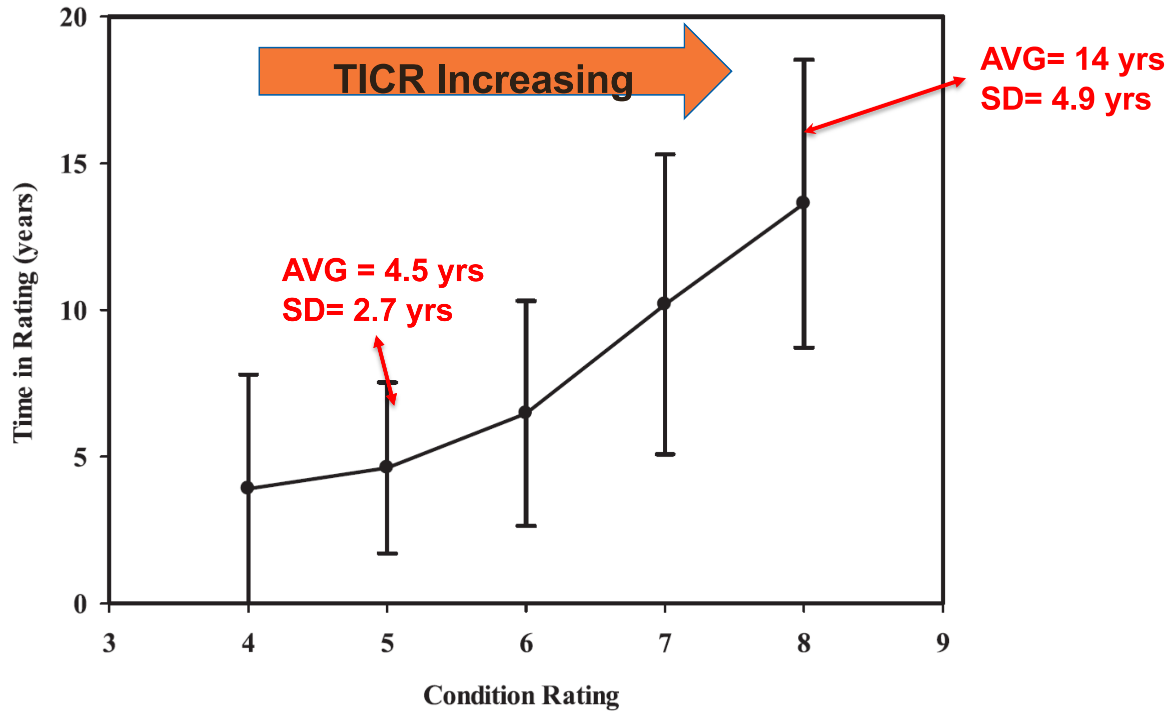
Deterministic Models

- Calculate the means and SDs for Time in Condition Rating (TICR) using standard methods

Stochastic Models

- Considers the random nature of TICR
- TICR may be better described using a probabilistic distribution.

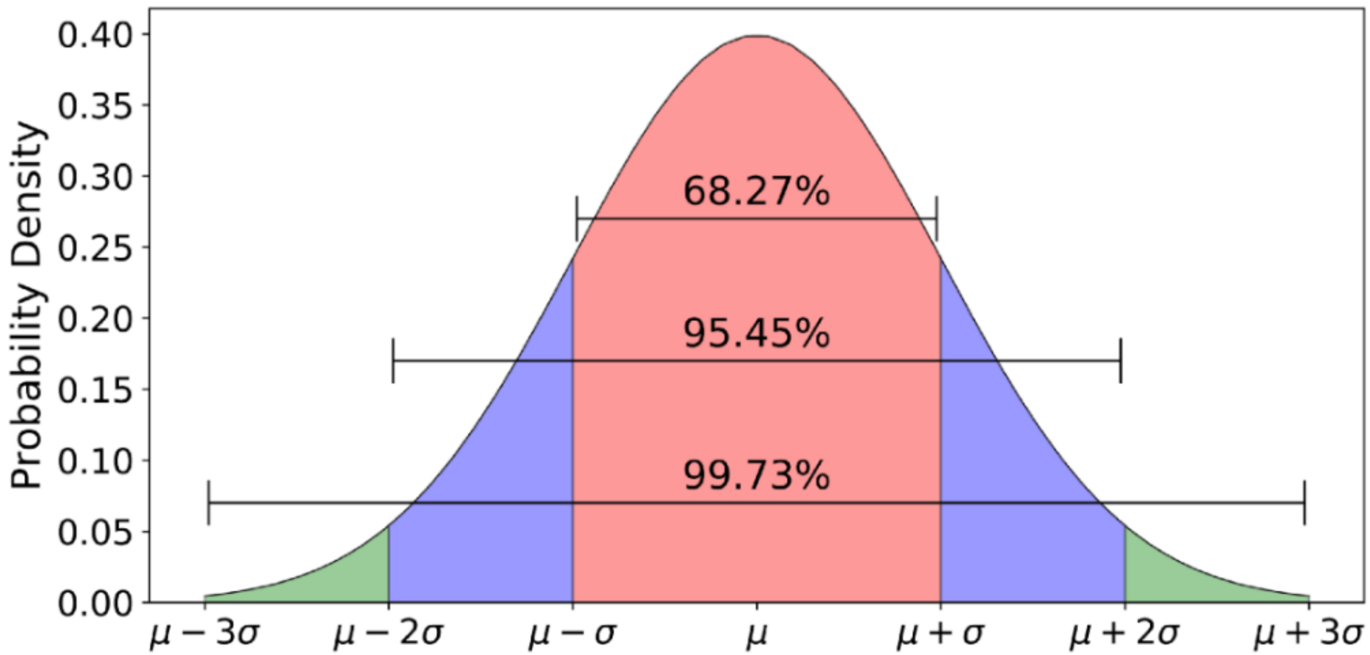
Deterministic Models



Time-in-condition rating for prestressed concrete bridge superstructures based on NBI data for Oregon

Source: M Nasrollahi, G Washer - ASCE Journal of Bridge Engineering, 2015

Normal Distribution Assumption



Source: https://www.isixsigma.com/dictionary/normal-distribution/

Stochastic Models

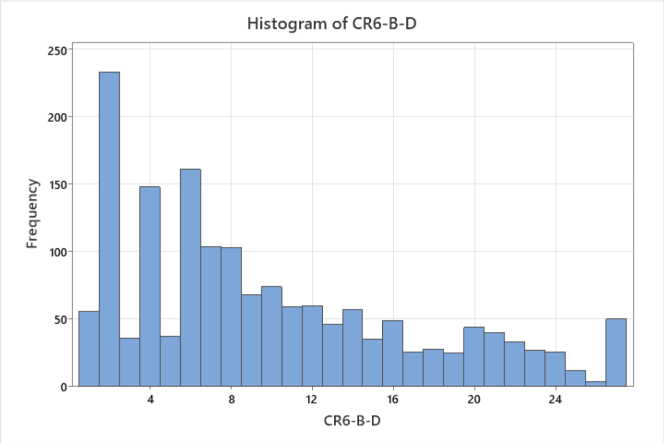
- Normal
- Lognormal
- Exponential
- Weibull
- Gamma

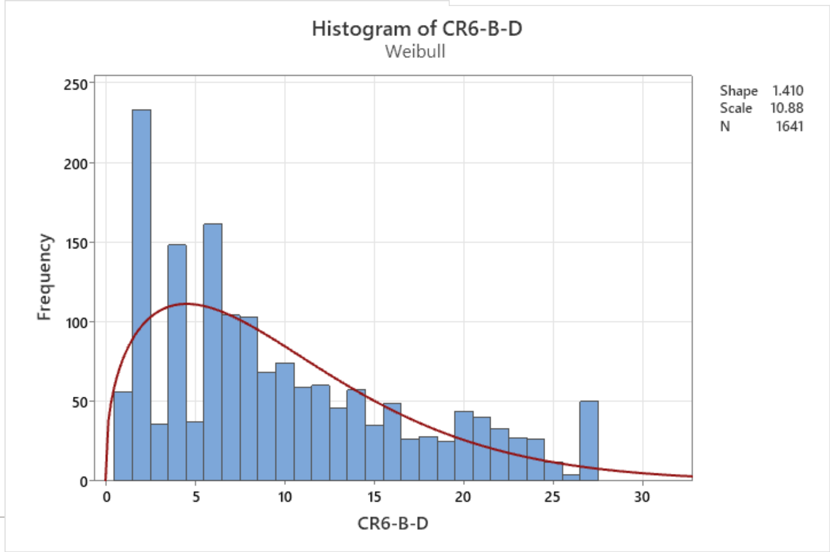
Goodness-of-Fit Test

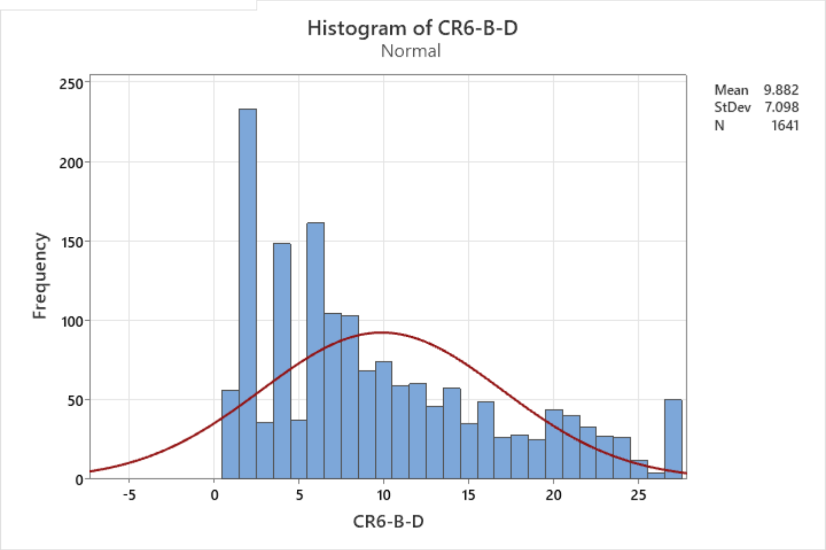
$$W_n^2 = -n - \frac{1}{n}\sum_{j=1}^{n}(2j-1)\left[\ln u_j + \ln\left(1 - u_{n-j+1}\right)\right]$$

	Anderson-Darling statistic				
Condition rating	Normal	Lognormal	Exponential	Weibull	Gamma
4	4.2	2.2	8.5	2.3	2.2
5	14.3	7.7	21.3	7.5	7.7
6	11.2	28.3	70.3	11.2	16.2
7	8.1	23.4	112	5.0	10.0
8	3.0	19	62.7	5.2	10.4

Source: M Nasrollahi, G Washer - ASCE Journal of Bridge Engineering, 2015


Histogram of CR6-B-D
Frequency
CR6-B-D
250
200
150
100
50
0
4
8
12
16
20
24


Histogram of CR6-B-D
Weibull
Shape 1.410
Scale 10.88
N 1641
Frequency
CR6-B-D
250
200
150
100
50
0
0
5
10
15
20
25
30


Histogram of CR6-B-D
Normal
Mean 9.882
StDev 7.098
N 1641
Frequency
CR6-B-D
250
200
150
100
50
0
-5
0
5
10
15
20
25

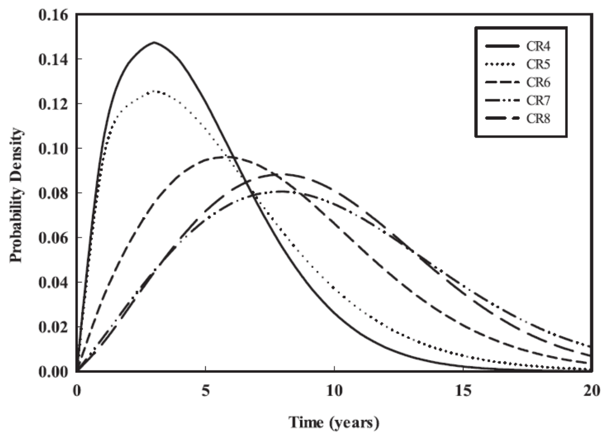
Weibull Distribution

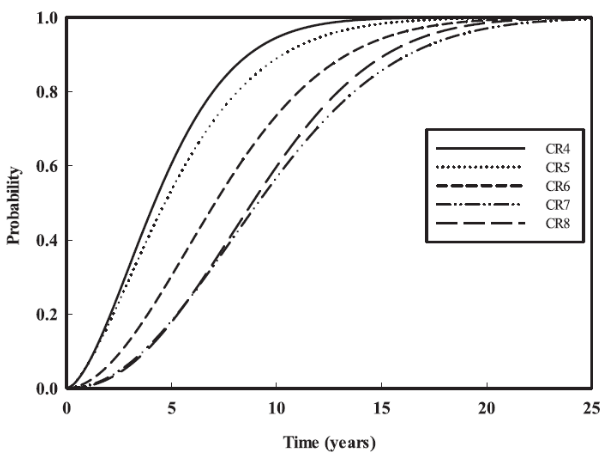
$$f(t) = \frac{\beta(t-\delta)^{\beta-1}}{\theta^{\beta}} \exp\left[-\left(\frac{t-\delta}{\theta}\right)^{\beta}\right] \quad (t > \delta)$$

- t=Time Variable
- β=Shape Parameter
- θ=Scale Parameter
- δ=Location Parameter

Characteristics:

- The scale parameter is known as the characteristic life; this is a point that 63.2 percent of the population fails by the characteristic life point regardless of the value of shape parameter (β)
- When the beta value is between 1 and 3.6, the Weibull distribution approximates the lognormal distribution.
- For wearing out process, the value of beta is greater than 1.
- Location parameter is zero for bridge deterioration models.





	Condition rating				
Parameter	4	5	6	7	8
Shape parameter β	1.64	1.52	1.88	2.07	2.21
Scale parameter θ	5.22	5.95	8.59	10.87	10.40
Mean	4.67	5.37	7.62	9.63	9.21
SD	2.91	3.59	4.21	4.89	4.40
Median	4.18	4.68	7.07	9.10	8.81
β upper bound	1.88	1.65	1.99	2.16	2.37
β lower bound	1.44	1.41	1.78	1.97	2.07
θ upper bound	5.87	5.55	8.94	11.21	10.85
θ lower bound	4.65	6.39	8.25	10.56	10.02
p-Value	0.01	<0.01	<0.01	<0.01	<0.01
Number of samples	117	337	739	1,127	546

Weibull Distribution Characteristics for Concrete Bridges in Oregon

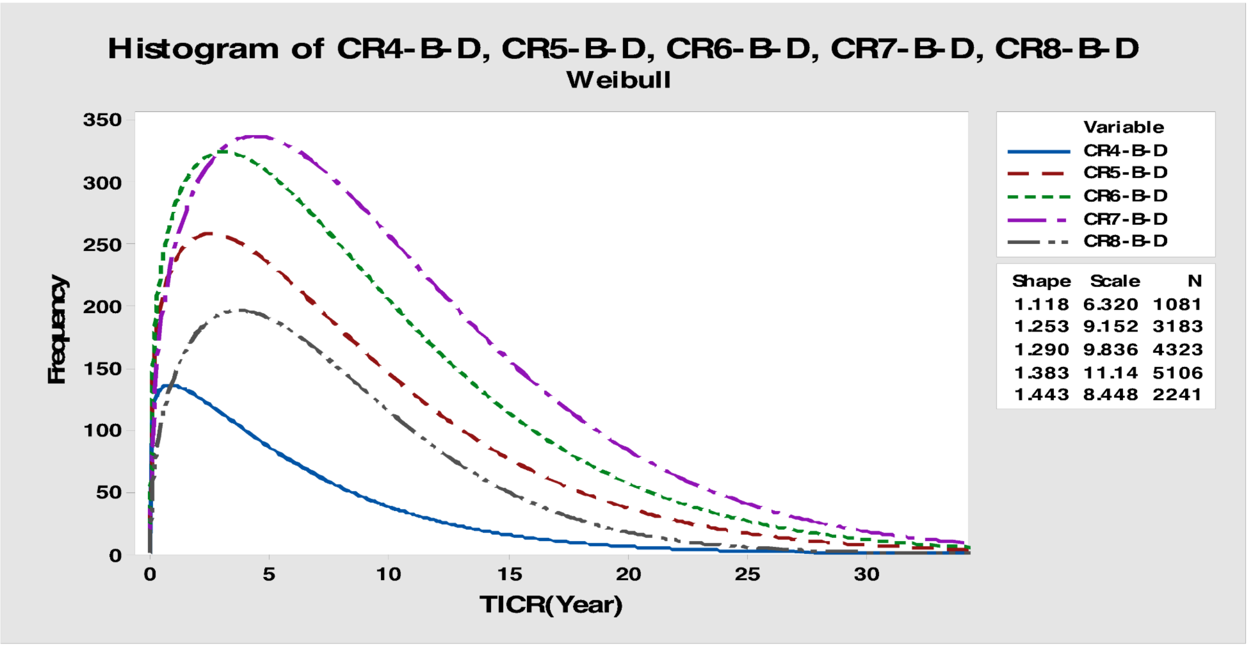
Structure Categories in Virginia

Structure Category	Structure Type Abbreviation
Steel Girders w/ Concrete Deck	SGCD
Steel Girders w/ metal Deck	SGMD
Timber Bridges & Steel Girders w/ Timber Decks	TBSGTD
Timber Bridges w/ Timber Decks	TBTD
Trusses	TR
T-Beams & Concrete Girders	TBCG
Concrete Slabs	CS
Concrete Arches	CA
Prestressed Concrete Girders w/ Concrete Deck	PSCGCD
Prestressed Concrete Boxes	PSCB
Prestressed Concrete Slabs	PSCS
Concrete/Masonry Culverts & Concrete Rigid Frames	CMCCRF
Metal Arches & Metal Culverts	MAMC
Complex Structures	CMPX
Other	Other

Weibull Distribution Parameters

Structure Category	Component	Condition Rating	Helper	Shape	Scale	AD*	F	C	Median
SGCD	Deck	CR4	DeckCR4SGCD	1.23125	7.2762	3.234	281	0	5.40
SGCD	Deck	CR5	DeckCR5SGCD	1.37424	9.7382	7.445	1000	0	7.46
SGCD	Deck	CR6	DeckCR6SGCD	1.4098	10.8763	12.761	1641	0	8.39
SGCD	Deck	CR7	DeckCR7SGCD	1.50679	12.76	19.61	2053	0	10.00
SGCD	Deck	CR8	DeckCR8SGCD	1.37775	6.8641	15.852	809	0	5.26
SGCD	Super	CR4	SuperCR4SGCD	1.29024	7.461	2.998	283	0	5.62
SGCD	Super	CR5	SuperCR5SGCD	1.36385	9.9651	6.032	959	0	7.62
SGCD	Super	CR6	SuperCR6SGCD	1.42986	10.4586	13.253	1619	0	8.09
SGCD	Super	CR7	SuperCR7SGCD	1.44538	11.6023	27.451	2197	0	9.00
SGCD	Super	CR8	SuperCR8SGCD	1.72031	11.5281	6.81	1289	0	9.32
SGCD	Sub	CR4	SubCR4SGCD	1.19786	7.7078	2.443	212	0	5.68
SGCD	Sub	CR5	SubCR5SGCD	1.47937	12.1599	6.879	1045	0	9.49
SGCD	Sub	CR6	SubCR6SGCD	1.50023	12.058	12.873	1573	0	9.44
SGCD	Sub	CR7	SubCR7SGCD	1.55256	13.0699	22.986	2346	0	10.32
SGCD	Sub	CR8	SubCR8SGCD	1.42809	8.2716	14.4	1066	0	6.40

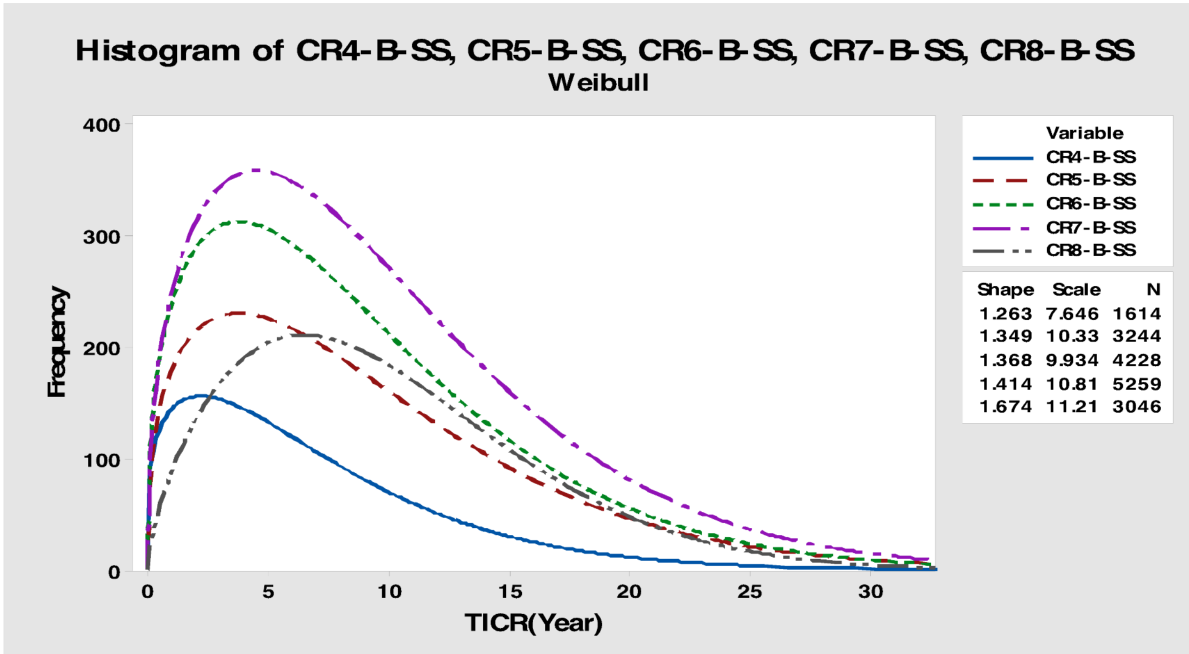
Statistical Analysis - Deck



	Variable	Shape	Scale	N	80% *	90%**	Average
Deck	CR4-B-D	1.118	6.32	1081	9.7	13.3	5.4
	CR5-B-D	1.253	9.152	3183	13.4	17.8	7.9
	CR6-B-D	1.29	9.836	4323	14.2	18.8	8.6
	CR7-B-D	1.383	11.14	5106	15.7	20.4	9.7
	CR8-B-D	1.443	8.448	2241	11.7	15.1	7.1

*Time at which 80% of bridges go to a lower GCR
** Time at which 90% of bridges go to a lower GCR

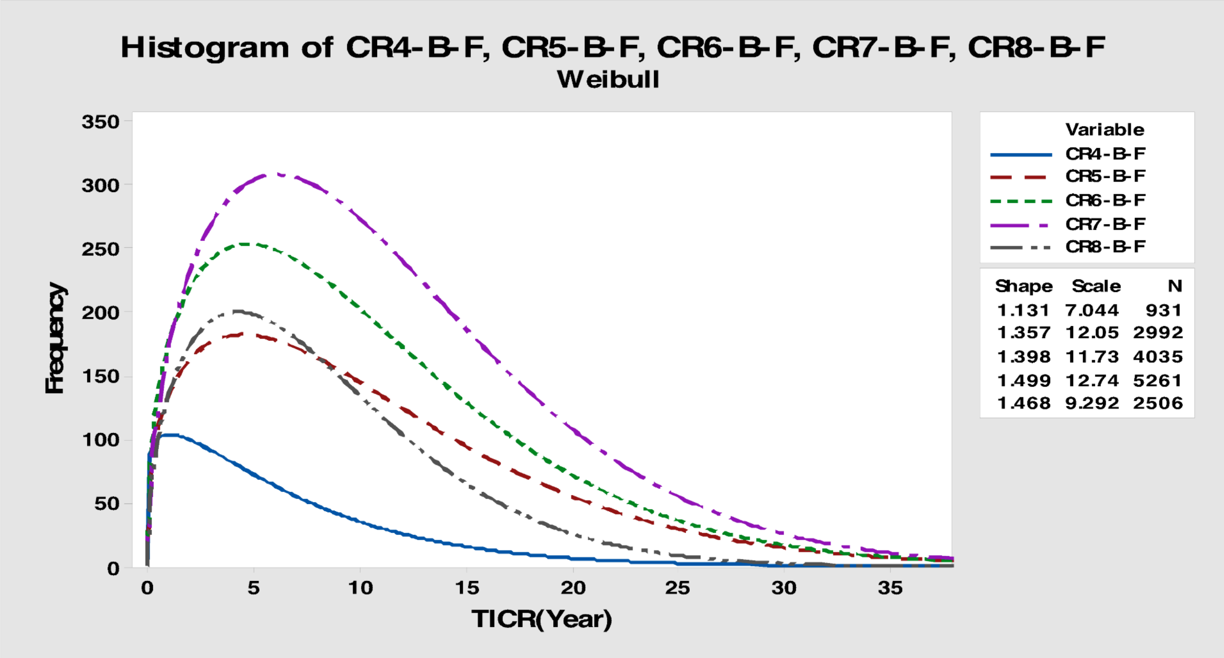
Statistical Analysis - Superstructure



	Variable	Shape	Scale	N	80% *	90%**	Average
Superstructure	CR4-B-SS	1.263	7.646	1614	11.1	14.8	6.5
	CR5-B-SS	1.349	10.33	3244	14.7	19.2	9.0
	CR6-B-SS	1.368	9.934	4228	14.1	18.3	8.6
	CR7-B-SS	1.414	10.81	5259	15.1	19.5	9.4
	CR8-B-SS	1.674	11.21	3046	14.9	18.4	9.6

*Time at which 80% of bridges go to a lower GCR
** Time at which 90% of bridges go to a lower GCR

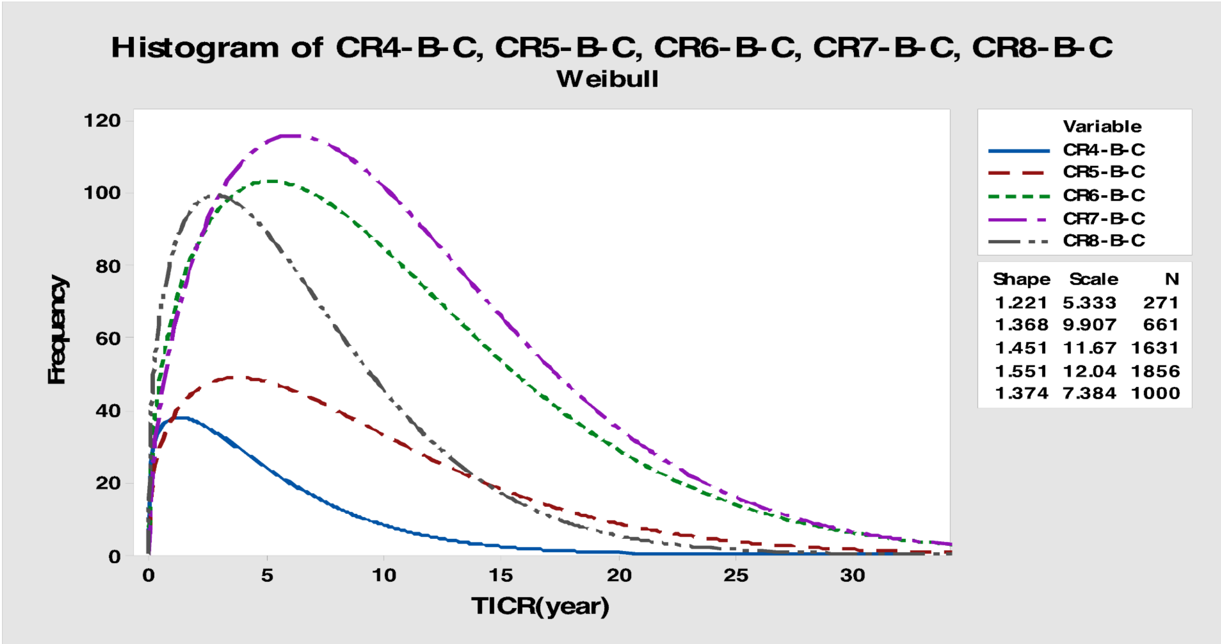
Statistical Analysis- Substructure



	Variable	Shape	Scale	N	80% *	90%**	Average
Substructure	CR4-B-F	1.131	7.044	931	10.7	14.7	6.0
	CR5-B-F	1.357	12.05	2992	17.1	22.3	10.7
	CR6-B-F	1.398	11.73	4035	16.5	21.3	10.3
	CR7-B-F	1.499	12.74	5261	17.5	22.2	11.2
	CR8-B-F	1.468	9.292	2506	12.8	16.4	7.9

*Time at which 80% of bridges go to a lower GCR
** Time at which 90% of bridges go to a lower GCR

Statistical Analysis- Culverts



	Variable	Shape	Scale	N	80% *	90%**	Average
Culverts	CR4-B-C	1.221	5.333	271	7.9	10.6	4.4
	CR5-B-C	1.368	9.907	661	14.0	18.2	8.5
	CR6-B-C	1.451	11.67	1631	16.2	20.7	10.2
	CR7-B-C	1.551	12.04	1856	16.4	20.6	10.4
	CR8-B-C	1.374	7.384	1000	10.4	13.5	6.2

*Time at which 80% of bridges go to a lower GCR

** Time at which 90% of bridges go to a lower GCR

Transition Probability

$$P(A_{9\ to\ 8} \cap A_{8\ to\ 7} \cap A_{7\ to\ 6} \cap A_{6\ to5} \cap A_{5\ to\ 4}) = P(A_{9\ to\ 8}) \times P(A_{8\ to\ 7}) \times P(A_{7\ to\ 6}) \times P(A_{6\ to5}) \times P(A_{5\ to\ 4})$$

$P(A_{x\ to\ y})$= is the transition probability that a component with a general condition rating of "x" goes to general condition rating of "y"

$$P = Max(P_{deck}, P_{superstructure}, P_{substructure})$$

P_{deck} is the probability of transition from the current deck's GCR to CGR of 4;

$P_{superstructure}$ is the probability of transition from the current superstructure's GCR to CGR of 4;

$P_{substructure}$ is the probability of transition from the current substructure's GCR to CGR of 4.

	Deck							9 to 8	8 to 7	7 to 6	6 to 5	5 to 4		Last GCR to GCR=4	Super					
Fed ID	Last GCR	STR_CAT	TICR	Helper	Shape	Scale	Probability of Transition to a lower GCR in the next T years	9	8	7	6	5	**Probability of Transition From Last GCR to 6**	**Probability of Transition From Last GCR to 4**	Last GCR	STR_CAT	TICR	Helper	Shape	Scale
13	6	SGCD	12	DeckCR6SGCD	1.41	10.88	0.83	1.00	1.00	1.00	0.83	0.29	1.00	0.24	7	SGCD	12	SuperCR7SGCD	1.45	11.60
35	5	CS	6	DeckCR5CS	1.40	12.88	0.53	1.00	1.00	1.00	1.00	0.53	1.00	0.53	5	CS	6	SuperCR5CS	1.45	13.28
61	6	PSCB	1	DeckCR6PSCB	1.24	10.56	0.36	1.00	1.00	1.00	0.36	0.26	1.00	0.09	5	PSCB	11	SuperCR5PSCB	1.37	13.16
73	7	SGCD	12	DeckCR7SGCD	1.51	12.76	0.77	1.00	1.00	0.77	0.25	0.29	0.77	0.06	7	SGCD	12	SuperCR7SGCD	1.45	11.60
110	7	SGCD	12	DeckCR7SGCD	1.51	12.76	0.77	1.00	1.00	0.77	0.25	0.29	0.77	0.06	6	SGCD	12	SuperCR6SGCD	1.43	10.46
112	7	SGCD	12	DeckCR7SGCD	1.51	12.76	0.77	1.00	1.00	0.77	0.25	0.29	0.77	0.06	6	SGCD	7	SuperCR6SGCD	1.43	10.46
114	6	SGCD	9	DeckCR6SGCD	1.41	10.88	0.74	1.00	1.00	1.00	0.74	0.29	1.00	0.22	7	SGCD	10	SuperCR7SGCD	1.45	11.60
117	6	SGCD	3	DeckCR6SGCD	1.41	10.88	0.45	1.00	1.00	1.00	0.45	0.29	1.00	0.13	7	SGCD	12	SuperCR7SGCD	1.45	11.60

Results

The study evaluated the 295 bridges originally proposed for inclusion in the IIJA program.

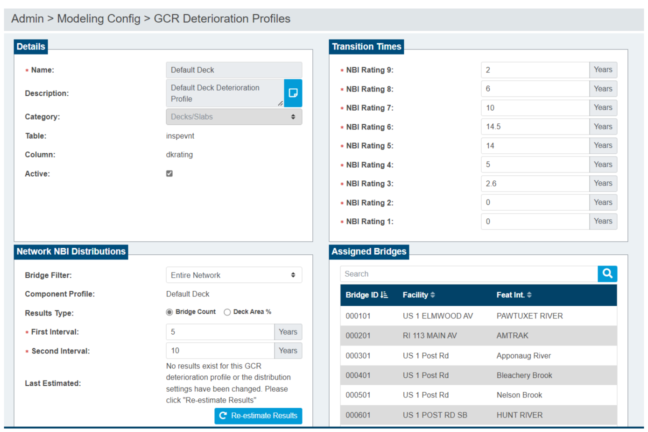
Number of Bridges	Probability of transition to poor condition (Deck Area) in the next four years	Probability of transition to poor condition (Deck Area) in the next four years	Comments
156 out of 295 have a min GCR=5	68%	72%	approximately 7 out of 10 bridges which currently have a min GCR of 5 are predicted to be in poor condition in the next four years.
115 out of 295 have a min GCR=6	17%	18%	approximately 1 out of 5 bridges which currently have a min GCR of 6 will be in poor condition in the next four years.

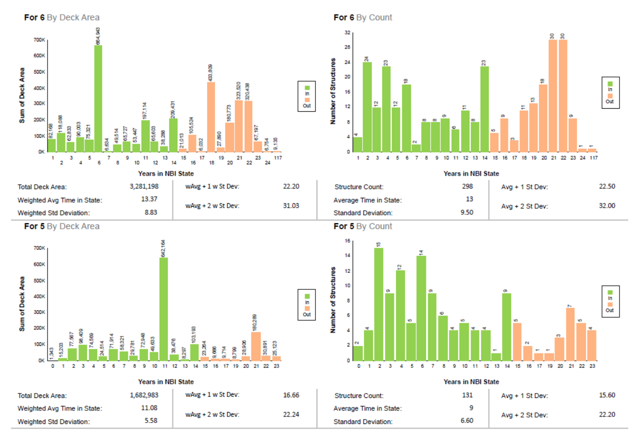
Applications

- Bridge Management Systems
- Deterioration Models
- Establishing Performance Measures
- Calibration of Element Level BMS

Recommendations

- Consider using Weibull distribution in for BrM component level analysis
- Include Weibull distribution in BrM for the Reliability Based Inspection interval introduced in the SNBI





Questions?

Thank you!

Email: massoud.nasrollahi@vdot.virginia.gov