Bridge Model Validation at Indiana DOT

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Agenda

- dTIMS BMS Overview
- Predictive models in a BMS
- Implementation benefits
- INDOT deterioration curve validation project
- Conclusions

Bridge Management in dTIMS

Opportunities for Bridge Management in dTIMS:

- **Many different approaches to choose from (structure level, component level, element level)**
- **Requires many parameters to allow users to set up <u>their</u> BMS <u>their</u> way**

Benefits to Bridge Management in dTIMS:

- **Flexible and open system**
- **All treatment options: preservation, repair, rehabilitation, replacement**
- **Unlimited what-if scenarios**
- **Not a "worst-first" system**
- **Slider-based funding needs analysis**
- **Cross Asset Analysis and Optimization functionality**

Bridge Management in dTIMS

State DOTs currently using dTIMS for Bridge Management

- **Arkansas**
- **Colorado**
- **Connecticut**
- **Indiana**
- **Maine**
- **Rhode Island**
- **Utah**
- **Vermont**

Bridge Management in dTIMS

Bridge Management Methodologies

- Component level only
  - Deck, Superstructure, Substructure, Wearing Surface, Culvert, SD, FO, Scour

- Component Level and Element Level (Hybrid)
  - Deck, Superstructure, Substructure, Culvert, SD, FO, Scour
  - Joints, Wearing Surface, Bearings, Girders, Paint System
  - Element level data used to support and/or generate existing or new bridge indexes

- Element Group Level
  - Deck Group (all deck elements group to the deck group, CS1, CS2, CS3, CS4)
  - Superstructure Group (all superstructure elements to the superstructure group, CS1, CS2, CS3, CS4)
  - Substructure Group (all substructure elements to the substructure group, CS1, CS2, CS3, CS4)
  - Joint Group
  - Steel Protective Coatings Superstructure
  - Steel Protective Coatings Substructure
  - Concrete Protective Coatings
  - Beam Ends Paint
  - Wearing Surface Group

Bridge Management in dTIMS

Bridge Data Management Approaches

- **Component level only**
  - **Usually need to track NBI component ratings from most recent inspection**
  - **Can track historical ratings as well which is useful for deterioration modelling**

- **Component Level and Element Level**
  - **Can use element level data to corroborate the component level ratings**
  - **INDOT will be going this way**

- **Element Group Level**
  - **dTIMS is used to store component ratings but also quantities in each condition state for each individual bridge element**
  - **If desired, dTIMS is then used to aggregate element data to component data using element groupings**
  - **Maine is using this approach**

Bridge Management in dTIMS

Structures Element Inspections Table – All Elements

Name	Asset_Code	Asset_Name	Elem_No	Element	Env	Parent_Asset	Parent_Element	State1	State2	State3	State4	Total_Quantity
000105	0149	OLD HAMILTON	107	Steel Open Girder/Beam	2 - Low	Hodgdon		70	0	0	0	70
000106	0149	OLD HAMILTON	113	Steel Stringer	2 - Low	Hodgdon		100	160	20	0	280
000107	0149	OLD HAMILTON	120	Steel Truss	2 - Low	Hodgdon		0	140	0	0	140
000108	0149	OLD HAMILTON	152	Steel Floor Beam	2 - Low	Hodgdon		0	97	0	0	97
000109	0149	OLD HAMILTON	215	Reinforced Concrete Abutment	2 - Low	Hodgdon		0	19	0	19	38
000110	0149	OLD HAMILTON	311	Movable Bearing	2 - Low	Hodgdon		0	2	0	0	2
000111	0149	OLD HAMILTON	313	Fixed Bearing	2 - Low	Hodgdon		0	2	0	0	2
000112	0149	OLD HAMILTON	515	Steel Protective Coating	2 - Low	Hodgdon	Steel Open Girder/Beam	35	35	0	0	70
000113	0149	OLD HAMILTON	515	Steel Protective Coating	2 - Low	Hodgdon	Steel Stringer	0	0	0	280	280
000114	0149	OLD HAMILTON	515	Steel Protective Coating	2 - Low	Hodgdon	Steel Truss	0	0	0	140	140
000115	0149	OLD HAMILTON	515	Steel Protective Coating	2 - Low	Hodgdon	Steel Floor Beam	0	0	0	97	97
000116	0149	OLD HAMILTON	515	Steel Protective Coating	2 - Low	Hodgdon	Movable Bearing	0	0	0	2	2
000117	0149	OLD HAMILTON	515	Steel Protective Coating	2 - Low	Hodgdon	Fixed Bearing	0	0	0	2	2
000118	0149	OLD HAMILTON	820	Reinforced Concrete Wall	2 - Low	Hodgdon		0	0	40	7	47

Trans-
formation

Superstructure Element Component Lookup Table

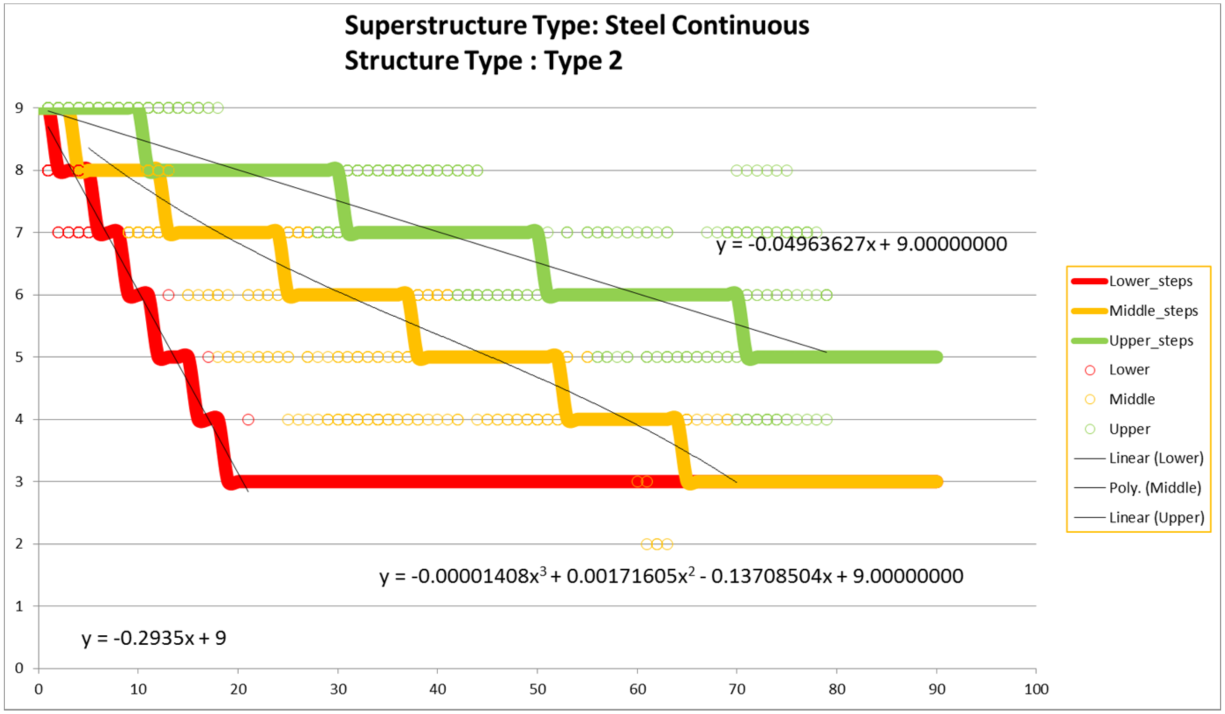
ElemSpr		
Superstructures		
El. No.	Element Name	Units
102	Closed Web/Box Girder, Steel	LENGTH (ft.)
104	Closed Web/Box Girder, Prestressed Concrete	LENGTH (ft.)
105	Closed Web/Box Girder, Reinforced Concrete	LENGTH (ft.)
106	Closed Web/Box Girder, Other	LENGTH (ft.)
107	Girder/Beam, Steel	LENGTH (ft.)
109	Girder/Beam, Prestressed Concrete	LENGTH (ft.)
110	Girder/Beam, Reinforced Concrete	LENGTH (ft.)
111	Girder/Beam, Timber	LENGTH (ft.)
112	Girder/Beam, Other	LENGTH (ft.)
113	Stringer, Steel	LENGTH (ft.)
115	Stringer, Prestressed Concrete	LENGTH (ft.)
116	Stringer, Reinforced Concrete	LENGTH (ft.)
117	Stringer, Timber	LENGTH (ft.)
118	Stringer, Other	LENGTH (ft.)
120	Truss, Steel	LENGTH (ft.)
135	Truss, Timber	LENGTH (ft.)
136	Truss, Other	LENGTH (ft.)
141	Arch, Steel	LENGTH (ft.)
142	Arch, Other	LENGTH (ft.)
143	Arch, Prestressed Concrete	LENGTH (ft.)
144	Arch, Reinforced Concrete	LENGTH (ft.)
145	Arch, Masonry	LENGTH (ft.)
146	Arch, Timber	LENGTH (ft.)
147	Cable - Main, Steel	LENGTH (ft.)
148	Cable - Secondary, Steel	EACH
149	Cable - Secondary, Other	EACH
152	Floor Beam, Steel	LENGTH (ft.)
154	Floor Beam, Prestressed Concrete	LENGTH (ft.)
155	Floor Beam, Reinforced Concrete	LENGTH (ft.)
156	Floor Beam, Timber	LENGTH (ft.)
157	Floor Beam, Other	LENGTH (ft.)
161	Pin, Pin and Hanger Assembly, or both	EACH
162	Gusset Plate	EACH

Structures Table – Superstructure Component Quantities

RoadName	At	At_Description	Name	Asset_Name	ElemSpr_CS1	ElemSpr_CS2	ElemSpr_CS3	ElemSpr_CS4	ElemSpr_Elem_No	ElemSpr_Env	ElemSpr_Qty
ZROAD	0.149000		0149	OLD HAMILTON	170	397	20	0	587	2 - Low	70

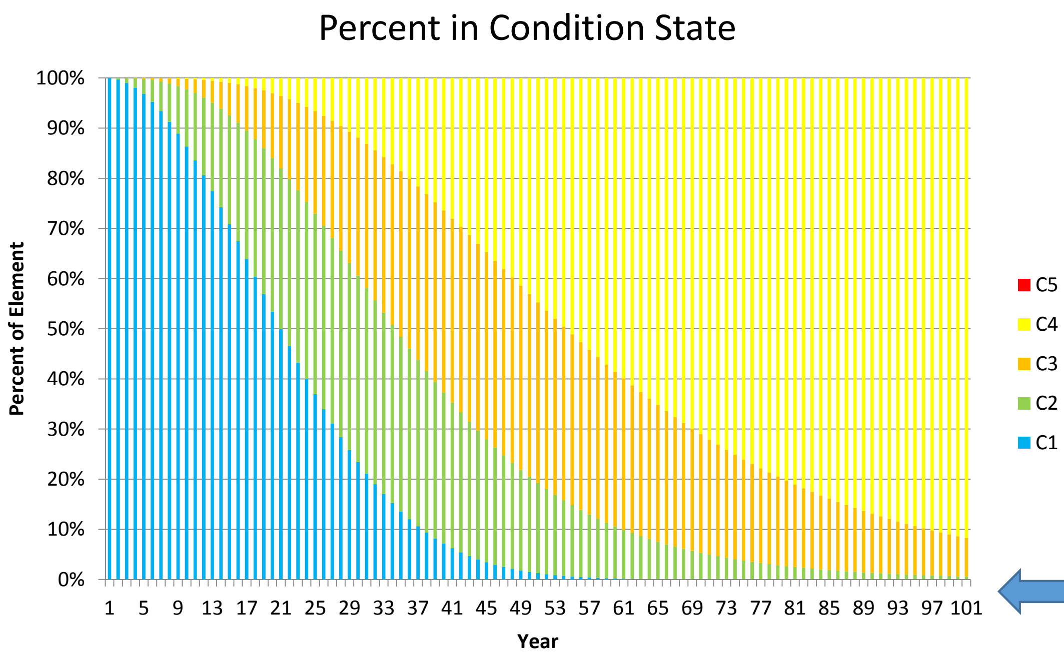
Bridge Management in dTIMS

Component Level Predictive Models



Bridge Management in dTIMS

Element Level Predictive Models



Sample TPMs for Deck

Name	0	1	2	3	Distress Name	Distress State Number	Pavement Family
ENVIRON_1_DECK_CONC_CS1	0.9300	0.0700	0.0000	0.0000	DECK_CONC	0	1
ENVIRON_1_DECK_CONC_CS2	0.0000	0.9800	0.0200	0.0000	DECK_CONC	1	1
ENVIRON_1_DECK_CONC_CS3	0.0000	0.0000	0.9300	0.0700	DECK_CONC	2	1
ENVIRON_1_DECK_CONC_CS4	0.0000	0.0000	0.0000	1.0000	DECK_CONC	3	1
ENVIRON_1_DECK_STEEL_CS1	0.9300	0.0700	0.0000	0.0000	DECK_STEEL	0	1
ENVIRON_1_DECK_STEEL_CS2	0.0000	0.9700	0.0300	0.0000	DECK_STEEL	1	1
ENVIRON_1_DECK_STEEL_CS3	0.0000	0.0000	0.8700	0.1300	DECK_STEEL	2	1
ENVIRON_1_DECK_STEEL_CS4	0.0000	0.0000	0.0000	1.0000	DECK_STEEL	3	1
ENVIRON_1_DECK_WOOD_CS1	0.8700	0.1300	0.0000	0.0000	DECK_WOOD	0	1
ENVIRON_1_DECK_WOOD_CS2	0.0000	0.9300	0.0700	0.0000	DECK_WOOD	1	1
ENVIRON_1_DECK_WOOD_CS3	0.0000	0.0000	0.8700	0.1300	DECK_WOOD	2	1
ENVIRON_1_DECK_WOOD_CS4	0.0000	0.0000	0.0000	1.0000	DECK_WOOD	3	1

Probabilistic models are useful when predicting a **quantity** into the future.

Benefits of Implementation

- **Separates data collection and database management from data analysis**
- **Leverages existing data – analysis can be completed now**
- **Tactical bridge program development – preservation, rehabilitation, replacement**
- **Strategic analysis – funding needs & condition projections based on unlimited "what if" scenarios**
- **Strategic analysis and resource allocation across assets**
  - Slider Based Tools
  - Cross Asset Analysis and Optimization
- **MAP 21 Risk-Based Analysis Compatible**
- **Corridor-based analysis possible with all assets in one platform**
- **Can be used to validate analysis parameters such as curves, triggers, resets**

INDOT Curve Validation Project

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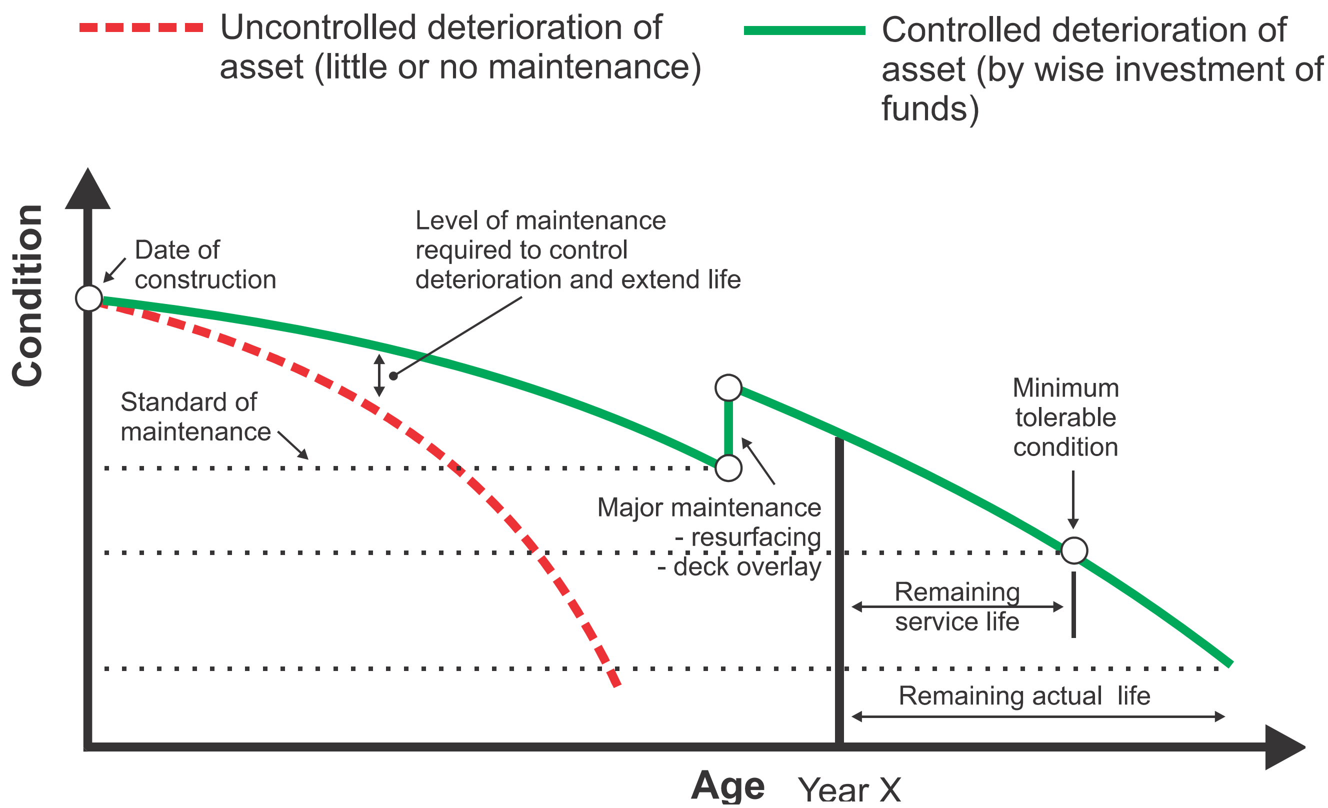
Problem Statement

- **In 2016, INDOT received the results of a research project undertaken by Purdue University.**
- **Purdue developed new deterioration models for the State's bridges for the deck, superstructure, and substructure components.**
  - **Other components already had revised deterioration models**
- **In 2016, INDOT contracted Deighton Associates Limited to develop their next generation BMS.**
- **One aspect of this project was to use INDOT's BMS (dTIMS) to validate the predictive accuracy of the models and quantify any deviation of actual measurements of condition from the predicted baseline.**

Deterioration Models



Research Study and Project Objectives

- **Purdue objectives:**
  - develop a set of bridge condition deterioration curves on the basis of the physical and operational characteristics, climate, and truck traffic, and,
  - identify the factors that influence bridge component deterioration and measure the direction and strength of the influence of each factor
- **Project objectives:**
  - use INDOT's BMS to validate the predictive accuracy of the models and quantify any deviation of actual measurements of condition from the predicted baseline.
  - Establish a procedure that can be used by INDOT to validate deterioration models into the future as required

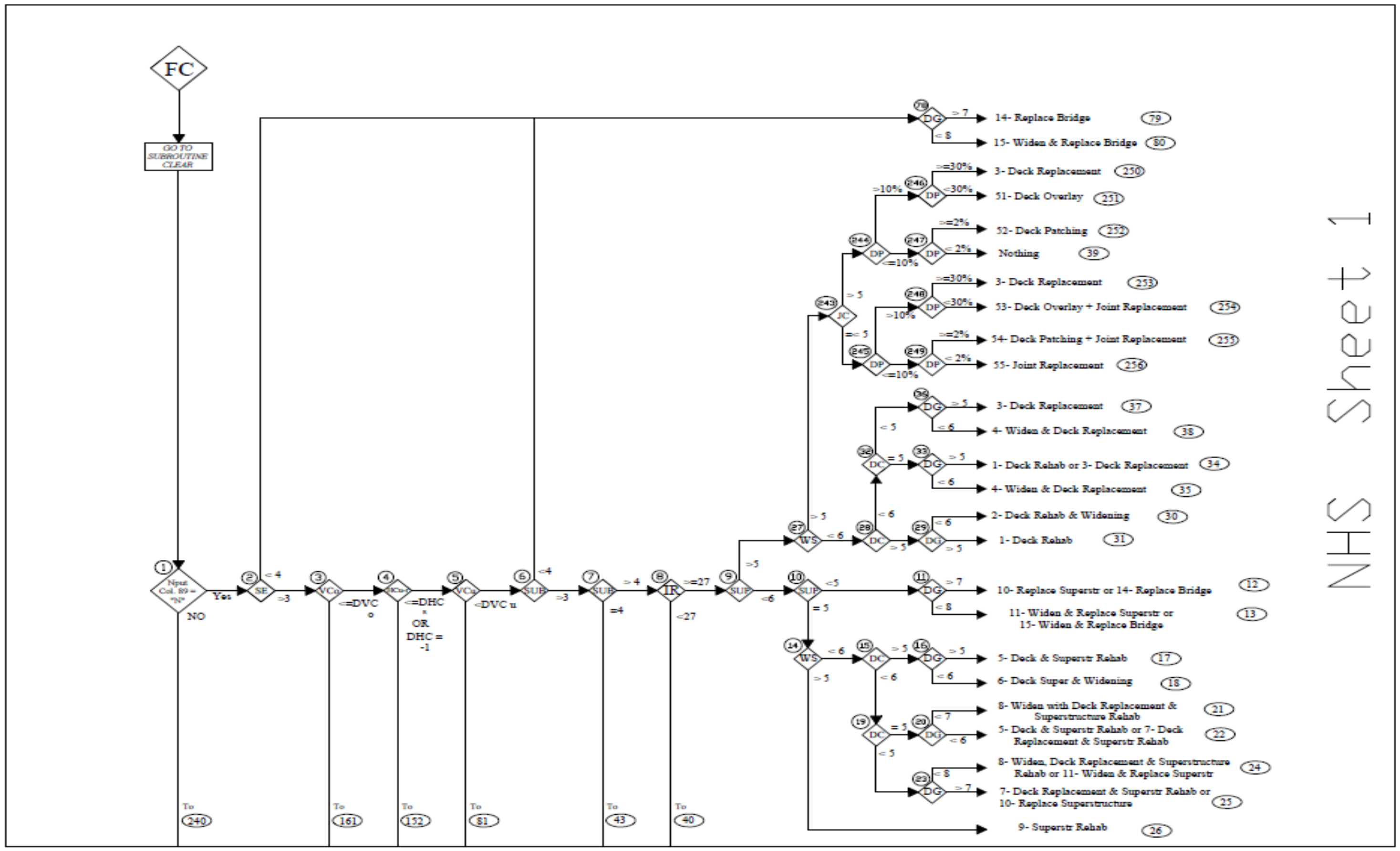
Bridge Management in dTIMS

Treatments – INDOT example uses both primary and combination treatments (moving away from this in 2017 Q2)

ACTION CODE	DESCRIPTION
0	Do Nothing
1	Deck Rehabilitation
2	Deck Rehabilitation and Bridge Widening
3	Deck Replacement
4	Deck Replacement and Bridge Widening
5	Deck and Superstructure Rehabilitation
6	Deck and Superstructure Rehabilitation and Bridge Widening
7	Deck Replacement and Superstructure Rehabilitation
8	Deck Replacement, Superstructure Rehab and Bridge Widening
9	Superstructure Rehabilitation
10	Replace Superstructure
11	Replace Superstructure and Bridge Widening
12	Strengthen Superstructure
13	Strengthen Superstructure and Bridge Widening
14	Bridge Replacement
15	Bridge Replacement and Bridge Widening
16	Substructure Rehabilitation
17	Raise Bridge/Lower Pavement (R/L)
18	Deck Rehabilitation with Full Depth Patching
19	Culvert Replacement
20	For later use
21	Deck & Sub Rehab (1+16)*
22	Deck Replacement & Sub Rehab (3+16)
23	Widen & Replace Deck & Sub Rehab (4+16)
24	Deck & Super & Sub Rehab (5+16)
25	Deck Replacement & Super & Sub Rehab (7+ 16)
26	Widen & Replace Deck & Super & Sub Rehab (8+16)
27	Super Replace and Sub Rehab (10+ 16)
28	Widen Deck & Super Replace & Sub Rehab (11 + 16)
29	Strengthen Super & Sub Rehab (12+16)
30	Widen Deck & Strengthen Super & Sub Rehab (13+16)
31	Deck Rehab & Raise/Lower (1+17)
32	Deck Replace & Raise/Lower (3+ 17)
33	Widen & Replace Deck & Raise/Lower (4+ 17)
34	Deck &Super Rehab & Raise /Lower (5+ 17)
35	Deck Replace & Super Rehab & Raise/Lower (7+ 17)
36	Widen & Replace Deck & Super Rehab & R/L (8+ 17)
37	Super Replacement & Raise/ Lower (10+ 17)
38	Widen Deck & Super Replacement & R/L (11 + 17)
39	Strengthen Super & Raise/Lower (12+ 17)
40	Widen Deck & Strengthen Super & R/L (13+17)
41	Deck & Sub Rehab & Raise/Lower (21+17)
42	Deck Replacement & Sub Rehab & R/L (23 + 17)
43	Widen & Replace Deck & Sub Rehab & R/L (23+ 17)
44	Deck & Super & Sub Rehab & R/L (24+ 17)
45	Deck Replace & Super & Sub Rehab & R/L (25+ 17)
46	Widen & Replace Deck & Sup & Sub Rehab & R/L (26+ 17)
47	Super Replacement & Sub Rehab & R/L (27 + 17)
48	Widen Deck & Super Replace & Sub Rehab & R/L (28+ 17)
49	Strengthen Super & Sub Rehab & R/L (29+ 17)
50	Widen Deck & Strengthen Super & Sub Rehab & R/L (30+ 17)
51	Deck Overlay
52	Deck Patching
53	Deck Overlay + Joint Replacement
54	Deck Patching + Joint Replacement
55	Joint Replacement

Bridge Management in dTIMS

Treatments Trigger Logic – INDOT example using component condition rating and decision tree logic (simplifying this in 2017 Q2)



Research Study Outcomes

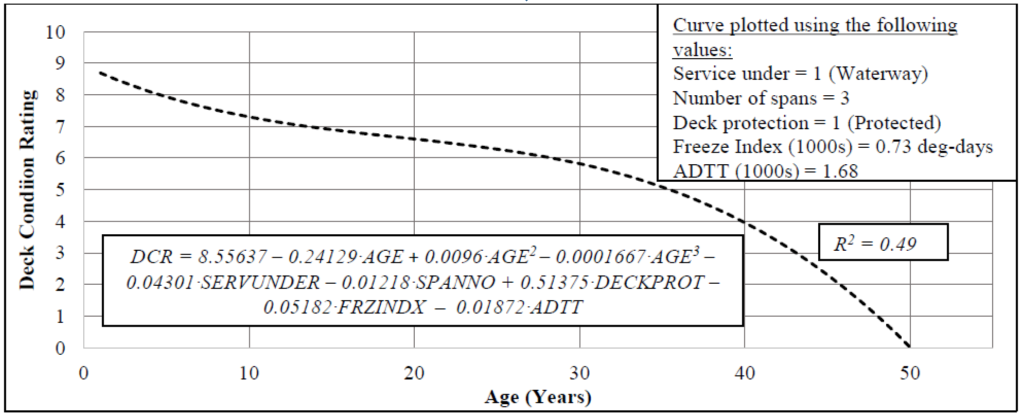
- **Six second and third order polynomial deterioration models were built for bridge decks, six for substructure, and 42 for superstructure.**
- **The influential variables were found to be as follows:**
  - deck age in years (AGE),
  - interstate location (1 if located on Interstate, 0 Otherwise) (INT),
  - angle of skew (SKEW),
  - bridge length (LENGTH),
  - type of service under bridge (SERVUNDER),
  - number of spans in main unit (SPANNO),
  - freeze index in 1,000s of degree-days (FRZINDX),
  - average annual number of freeze-thaw cycles (NRFTC),
  - average annual daily truck traffic in 1000s (ADTT), and,
  - deck protection (1 with protective system, 0 otherwise), (DECKPROT).

Bridge Management in dTIMS

Component Level Predictive Models – INDOT / Purdue Study

Table 5.1 Summary of the Deterministic Models for Bridge Deck Deterioration

BRIDGE COMPONENT	DISTRICTS	FUNCTIONAL CLASS	DETERIORATION MODEL
DECK	NORTHERN	NHS	$DCR = 8.55637 - 0.24129 \cdot AGE + 0.0096 \cdot AGE^2 - 0.0001667 \cdot AGE^3 - 0.04301 \cdot SERVUNDER - 0.01218 \cdot SPANNO + 0.51375 \cdot DECKPROT - 0.05182 \cdot FRZINDX - 0.01872 \cdot ADTT$
		NON-NHS	$DCR = 9.22454 - 0.244998 \cdot AGE + 0.01158 \cdot AGE^2 - 0.00021831 \cdot AGE^3 - 0.00136 \cdot SKEW - 0.01023 \cdot SPANNO + 0.39602 \cdot DECKPROT - 0.03037 \cdot FRZINDX - 0.01397 \cdot NRFTC - 0.08597 \cdot ADTT$
	CENTRAL	NHS	$DCR = 8.1961 - 0.16459 \cdot AGE + 0.0068 \cdot AGE^2 - 0.0001442 \cdot AGE^3 - 0.06213 \cdot INT - 0.04249 \cdot SERVUNDER - 0.0005587 \cdot LENGTH + 0.50755 \cdot DECKPROT - 0.00769 \cdot NRFTC$
		NON-NHS	$DCR = 7.6959 - 0.09989 \cdot AGE + 0.00234 \cdot AGE^2 - 0.00005094 \cdot AGE^3 - 0.06901 \cdot SERVUNDER - 0.00119 \cdot LENGTH + 0.33696 \cdot DECKPROT - 0.03016 \cdot ADTT$
	SOUTHERN	NHS	$DCR = 8.58845 - 0.09752 \cdot AGE + 0.00341 \cdot AGE^2 - 0.0000855 \cdot AGE^3 - 0.00186 \cdot SKEW - 0.00041603 \cdot LENGTH + 0.53671 \cdot DECKPROT - 0.06989 \cdot FRZINDX - 0.04431 \cdot ADTT$
		NON-NHS	$DCR = 8.05846 - 0.14617 \cdot AGE + 0.00663 \cdot AGE^2 - 0.00015219 \cdot AGE^3 - 0.00098333 \cdot LENGTH + 0.43363 \cdot DECKPROT - 0.06043 \cdot FRZINDX - 0.14681 \cdot ADTT$

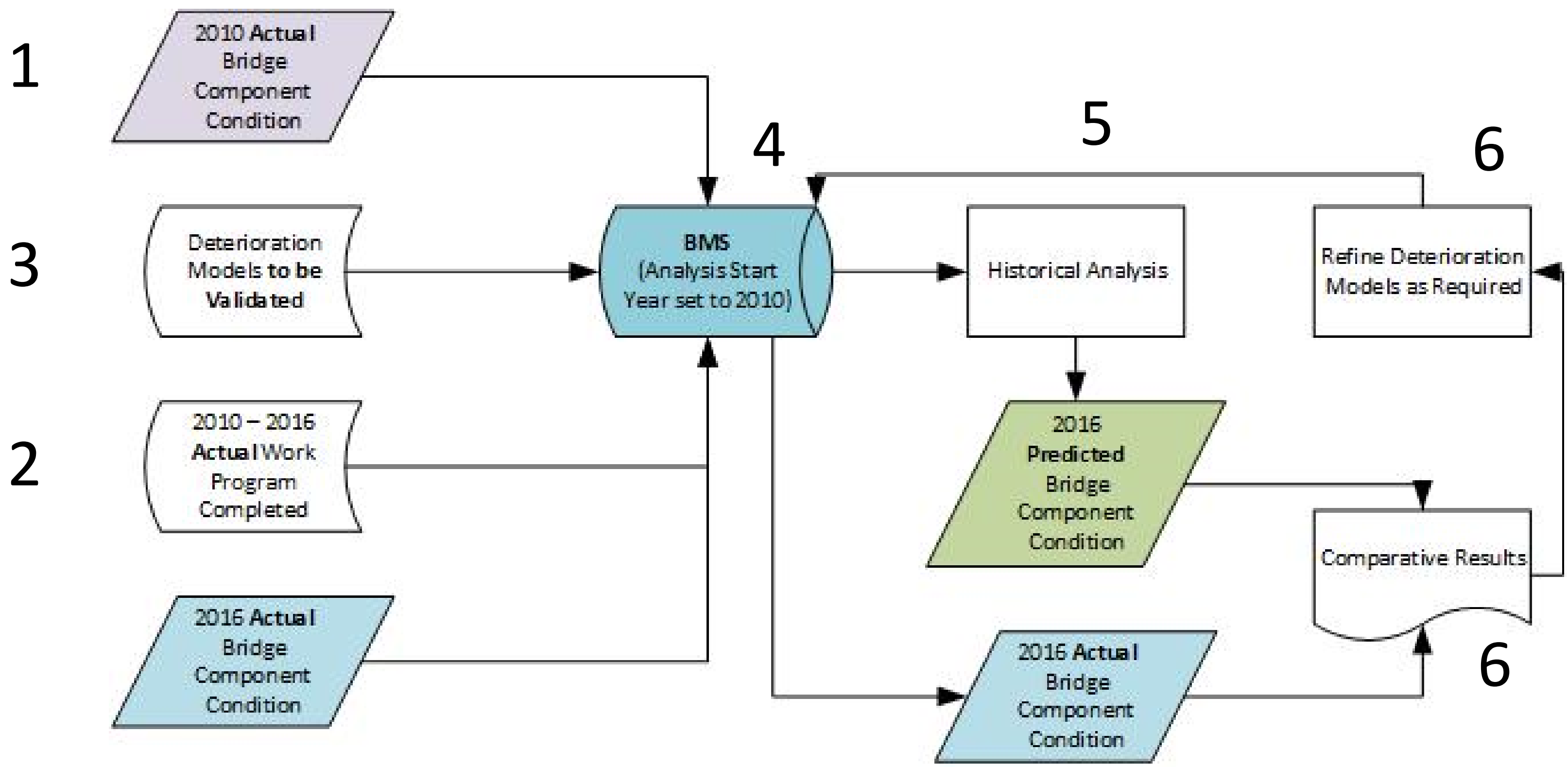


Deterministic curves are useful when predicting a **rating** into the future.

Curve Validation Methodology

1. **Use the BMS to go back in time and capture the condition of the bridge network for a specific point in time,**
2. **Capture the actual work done by INDOT in the BMS from that historical point in time to current time,**
3. **Define the deterioration models that are to be validated in the BMS,**
4. **Run an analysis using the BMS from that historical point it time to current time,**
5. **Review the results of the historical analysis and compare to the actual, current bridge condition, and,**
6. **Quantify any variances between predicted and actual. Refine the deterioration models as required and re-define the models in the BMS.**

Curve Validation Methodology



Turning Back the Clock

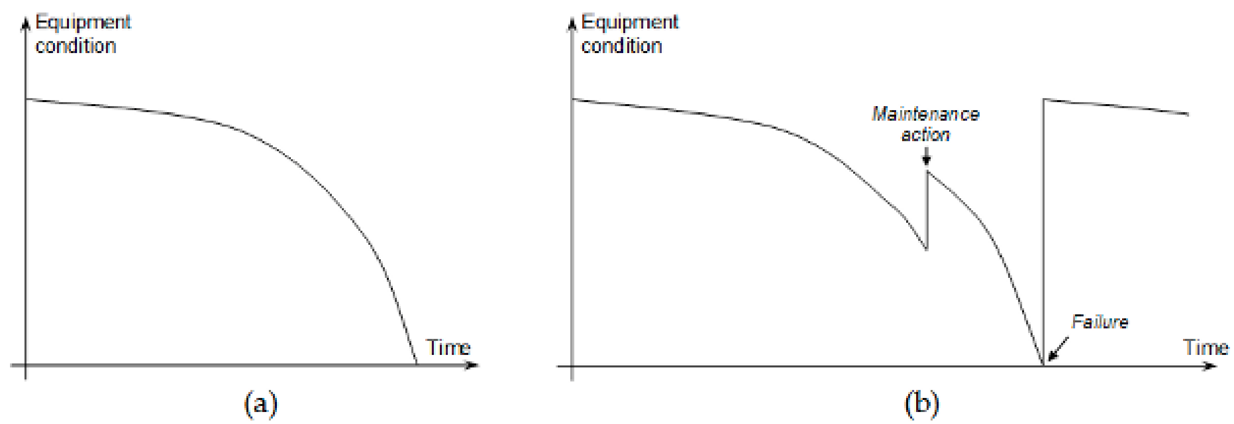
- **Choose a historical point to allow for sufficient deterioration**
- **In essence, you "turn back the clock" in the BMS to 2010.**
- **2010 bridge conditions for deck, superstructure, substructure, and wearing surface *as they were* in 2010 were loaded into the BMS.**

Capturing Actual Historical Work Done

- **Next, the *actual* bridge projects that INDOT performed between 2010 and 2016 were loaded into the BMS.**

Define Deterioration Models in dTIMS

- **The deterioration models that *are to be validated* are defined in the BMS for each of the components.**
- **In this way, the condition projections made by the BMS will be based on the deterioration models that *are to be validated*.**

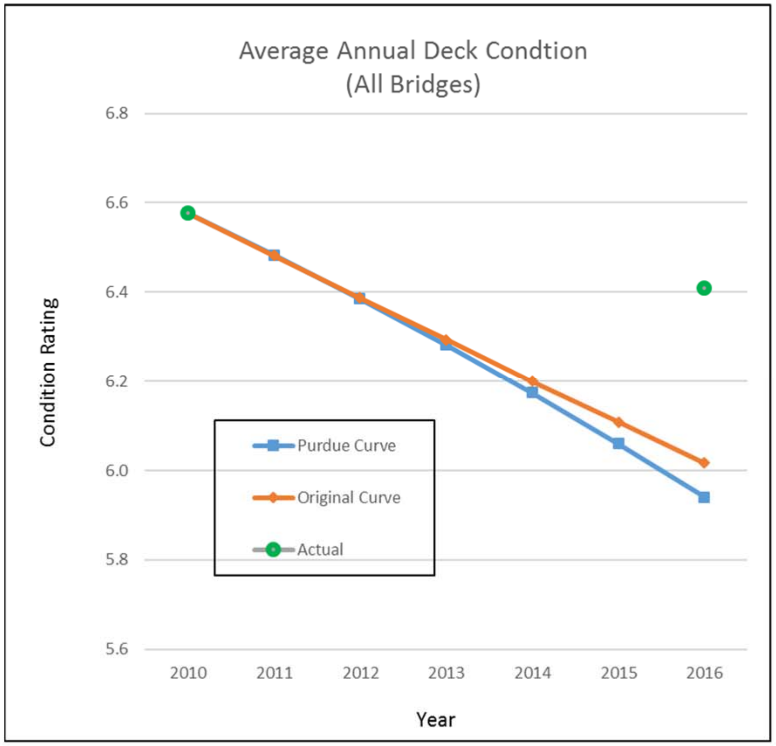


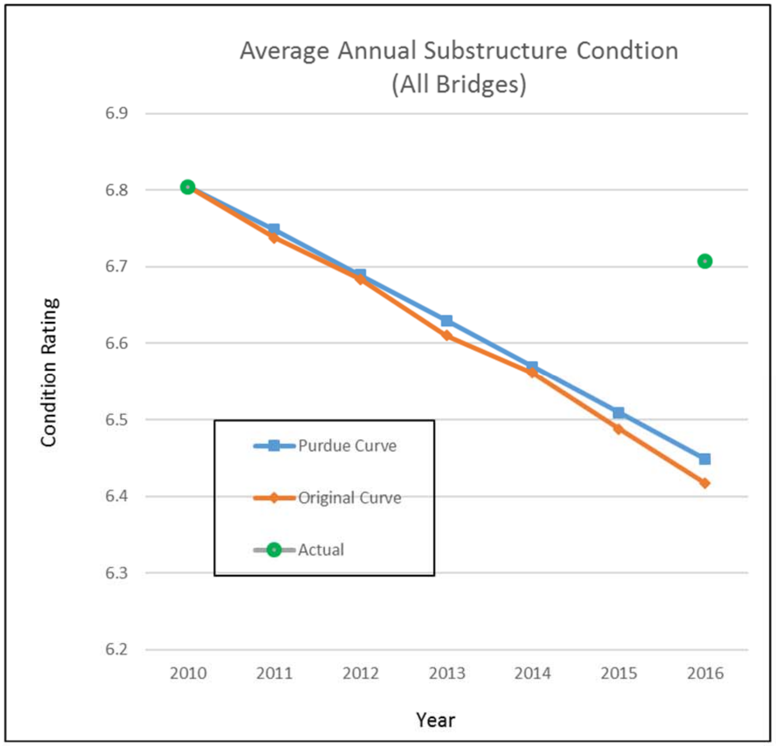
A Historical Analysis

- Run the analysis in the BMS
- The projections will follow the "to be validated" deterioration curves and the bridge projects that are selected are the actual projects performed by INDOT.
- The premise of this analysis is that for every bridge in the network, its predicted condition in the BMS in 2016 is based on the "to be validated" deterioration models, and the *actual* work that has been performed from 2010 to 2016.
  - This condition is one of the two important parameters required to validate the deterioration models.
- The 2016 actual bridge condition data is loaded into the BMS.
  - This is actual condition since it is based on the actual bridge inspections that have taken place.
  - The second parameter is the actual bridge component condition.
- Comparisons can now take place.

Review the Results

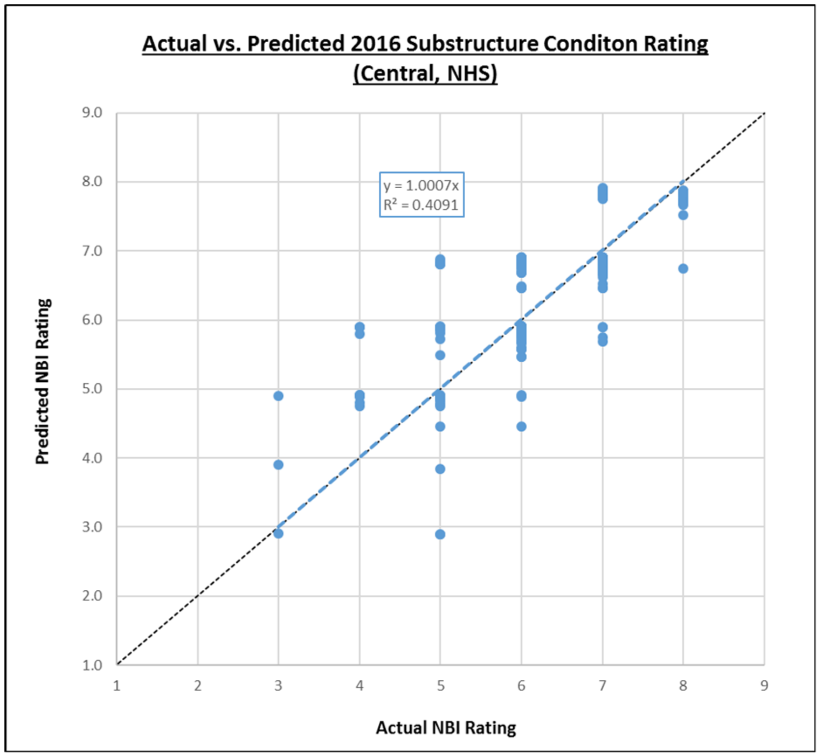
- **Predicted Deck and Substructure Deterioration versus Actual Inspections**

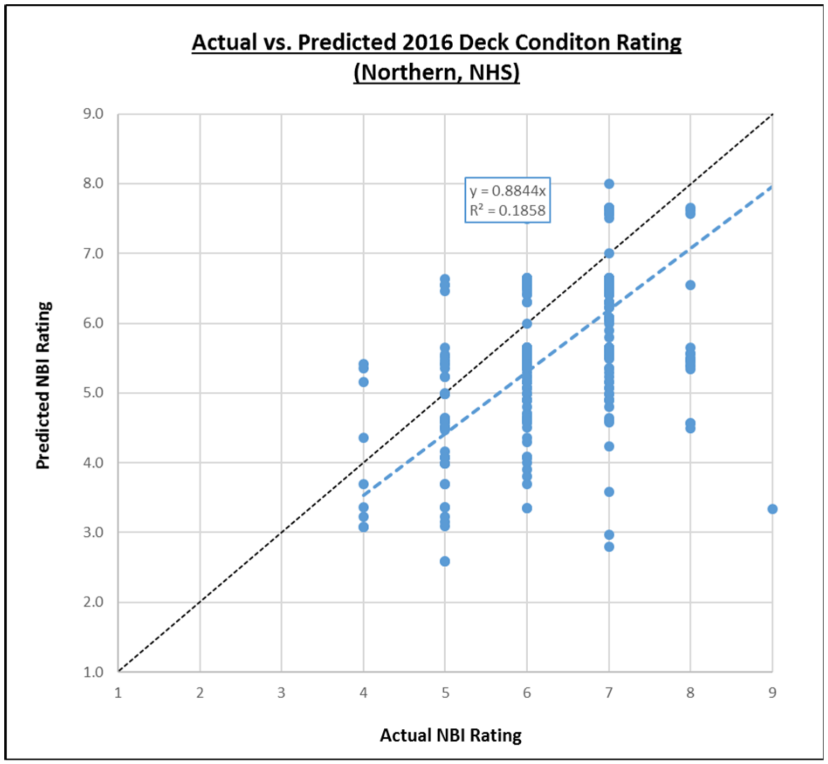




Review the Results

- **Predicted Deterioration versus Actual Inspections for Sub and Deck**





Conclusions

- **A framework and methodology that was used at INDOT to validate bridge deterioration models was presented.**
- **The Deighton project was not to comment on the *accuracy* of the bridge models that were developed for INDOT, but rather that bridge deterioration models must be validated so that the results from the BMS can be validated and hence provide the consumers of the results with a higher degree of confidence.**
- **This framework can be adopted by other agencies that have a BMS or any asset management system so they can validate their own asset deterioration models.**
  - **The process presented is repeatable and defendable and hence can withstand a high degree of scrutiny.**

Conclusions

- **Any agency that is using an asset management system and has not put their own deterioration models through a similar validation exercise runs the risk of not being able to defend the results of the management system with a high degree of confidence, and hence may be in danger of tarnishing their credibility along with the credibility of the asset management system.**

Thank you

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For follow-up questions, contact:

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