NBI CONDITION RATINGS FROM BMS DATA

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ABSTRACT

Methods to generate National Bridge Inventory (NBI) condition ratings for deck (NBI Field 58), superstructure (NBI Field 59), substructure (NBI Field 60) and culvert (NBI Field 62) from element-level condition data in a bridge management system (BMS) database have been developed. A translation of data from BMS coding to NBI coding is possible by linking BMS elements to corresponding NBI fields and mapping BMS condition states to the NBI rating scale. Methods for NBI generation are now available and have been calibrated against data gathered by nine state departments of transportation (DOTs) in testing of Pontis BMS in 1992. The performance of NBI generation is good and a uniform generation procedure for all state DOTs is feasible.

INTRODUCTION

The 1991 Intermodal Surface Transportation Efficiency Act (ISTEA) requires that state DOTs implement Bridge Management Systems to support planning of maintenance, repair and rehabilitation activities to promote an efficient use of resources. BMS is a new requirement; it does not supplant bridge condition reporting under the NBI structure.

A key feature needed to complete the implementation of BMS is an ability to serve NBI reporting requirements, specifically an ability to generate NBI rating fields from BMS data on bridge elements and conditions. The generation of NBI ratings from BMS condition reports promotes efficiency in inspections. NBI generation does not qualitatively alter the practice of bridge inspection; conditions are still assessed and reported by human inspectors. However where inspectors use a BMS format for recording conditions, NBI generation eliminates the need to record the same data again in the NBI scale.

One BMS that is being used or considered for use by many state DOTs is the Pontis BMS developed for the Federal Highway Administration (FHWA) (*1*). Pontis BMS operates with a unique format for coding bridge inspection data that differs from the NBI. In particular, Pontis employs new elements to model bridge structures, defines new condition states for elements, and requires a practice of reporting all conditions observed on an element along with the extent of each condition instead of reporting a single average rating value. These features are sources of incompatibility with NBI reporting.

NBI ratings are determined from the observed condition of the components of bridges. A BMS may use elements and condition states that differ from the NBI rating fields and rating scale, but both BMS condition reports and NBI ratings are derived from the same observations. There is a correspondence between the two reporting formats, and therefore it is possible to generate NBI rating fields from condition reports in a BMS database.

Procedures for the generation of NBI rating fields from the database of a BMS were developed in 1992 using data gathered by Colorado DOT in their β test of Pontis BMS. NBI generation procedures operate by combining BMS elements to form groups which contribute to common NBI fields, and by mapping BMS condition reports to the NBI rating scale. NBI generation procedures exist in two parts, a formal process for integrating BMS condition reports and a set of mapping constants that define the correspondence between rating scales. The 1992 study of Colorado data demonstrated the feasibility of the formal process and yielded mapping constants for many Pontis BMS elements.

In 1993, additional work using Pontis β test data from nine DOTs (California, Colorado, Iowa, Kansas, Michigan, Minnesota, Tennessee, Vermont & Washington) completed a general calibration of mapping constants and studied the overall performance of NBI generation procedures. With these data, mapping constants were calibrated for individual DOTs and for the union of all data (simulating a uniform, nationwide NBI generation). Overall performance of the NBI generation is good. Generated NBI rating values are within ±1 of assigned NBI values for 90% of all cases in calibrations for individual DOTs. Using a uniform generation, NBI ratings are within ±1 of assigned values for 88% of cases. Uniform NBI generation introduces only modest shifts in NBI ratings for individual DOTs, and it appears that a uniform NBI generation is feasible.

CONDITION REPORTS IN BRIDGE MANAGEMENT SYSTEMS

In their function as planning tools, Bridge Management Systems require a means of evaluating incidental costs of deferred maintenance and of selecting a workable order of repairs to bridges. BMS must forecast future condition of bridges and of bridge components. The means of forecasting and the data supporting forecasts may be referred to collectively as deterioration models. BMSs rely on deterioration models and actively refine deterioration models through calibration against a database of observed bridge conditions.

Deterioration rates and the impact of deterioration on the cost of repairs can be expected to vary for different bridge components, different structural materials, and different forms of members. It is necessary then to distinguish between deck components, superstructure components and substructure components, to distinguish among components constructed in steel, concrete and timber, and to distinguish among forms such as open sections, closed sections, slabs, columns, etc. Each use, material, and form implies a separate deterioration rate and a separate impact on repair costs. Each requires a separate deterioration model.

Separate deterioration models require separate data to constitute and refine them. Therefore, management systems require coding formats for condition data using many bridge elements. Coding formats are further adapted to the support of deterioration models through new condition states that are responsive to cost-significant changes in bridge elements. The proliferation of bridge elements and the creation of new condition states make BMS data incompatible with the existing NBI record and NBI rating scale.

BMS elements are recognizable bridge components such as steel stringers, steel box beams, prestressed concrete boxes, reinforced concrete abutments and reinforced concrete decks. Elements exist for each material (steel, reinforced concrete, prestressed concrete and timber), for each use (deck, superstructure, substructure, and culvert) and for each form (open stringer, closed box, column, wall, pile cap, slab, deck, etc.). BMS elements include all components that affect NBI rating fields along with other components such as railings that do not affect NBI ratings. In its β version, Pontis BMS included 120 defined elements. Recent work on Commonly Recognized (CoRe) elements has produced a set of 96 elements adapted from β elements (*3*).

The BMS model of a bridge consists of elements and quantities of elements. This is illustrated in Table I which shows the Pontis BMS model for a steel beam bridge. The model presents materials, member types and quantities. The condition report lists the quantities of an element in each condition state. The groupings *Deck, Superstructure, Substructure* and *Other* is the first step in NBI generation; specifically, the identification of contributing and non-contributing elements, and the grouping of contributing elements in specific NBI fields. Note that two BMS elements contribute to *Superstructure* and three contribute to *Substructure*. NBI generation must deliver the average rating for the set of elements grouped in a single NBI field.

NBI GENERATION FROM BMS DATA

BMS data on the condition of bridge elements differs from the NBI format in two ways: BMS uses many elements instead of the four NBI fields; and BMS reports all observed condition states instead of a single rating value. NBI generation therefore involves distinct operations of grouping BMS elements to form NBI fields and of combining BMS condition states. An ensemble of elements and condition states must become a single NBI rating.

BMS can support individual sets of condition states for each of its elements, and each set of condition states requires an individual map for translation to the NBI rating scale. In practice, similar materials and uses employ similar sets of condition states. For example, all painted steel superstructure elements have similar condition state definitions and can be treated with a single map for NBI generation. Prestressed concrete superstructure elements have a different set of condition states and require a different NBI generation map. In all, seventeen maps are needed (Table II).

Two approaches to NBI generation have been studied. The first is a weighted-average computation operating directly on condition state quantities for elements. The second is a table-driven procedure which compares quantities in condition states to requirements on quantities for NBI rating assignment. Weighted-average NBI ratings are generated as

$$NBI = \sum M_i F_i \qquad (1)$$

where:

NBI = NBI condition rating computed from BMS data,

M_i = Mapping Constant for BMS condition state *i*, and

F_i = Fractional quantity of a bridge element reported in condition state *i*.

TABLE I BMS BRIDGE MODEL AND CONDITION REPORT

Element	Quantity	Condition State				
		1	2	3	4	5
Deck						
124 Concrete Deck w/Rigid Overlay	20,600 SF	0	20600	0	0	-
Superstructure						
8 Steel Open Stringer, painted	2,840 LF	2,500	340	0	0	0
33 Steel Floor Beam, painted	936 LF	899	37	0	0	0
Substructure						
41 Concrete Cap, non-integral	6 Ea	4	2	0	0	-
47 Concrete Column	14 Ea	2	10	2	0	-
51 Concrete Expansion Joint	2 Ea	0	1	1	0	-
Other						
94 Open Expansion Joint	58 LF	8	42	8	0	0
96 Moveable Bearing	18 Ea	15	3	0	0	0
102 Metal Bridge Railing	1,422 LF	1,194	200	28	0	0

Weighted-average NBI generation for Pontis BMS can take the form

$$NBI = M_1F_1 + M_2F_2 + M_3F_3 + M_4F_4 + M_5F_5 \quad (2)$$

where the mapping constants and fractional quantities have the same meaning as in Equation (1). Equation (2) is explicitly for an element condition report of five condition states.

For table-driven NBI generation, quantities in condition states are compared to threshold quantities for assignment of an NBI rating. The form of the table is shown in Table III. Percentages of quantities are denoted as P_i. The four requirements for each NBI rating value are simultaneous requirements. The percentages in the BMS condition report must satisfy all four requirements to qualify for assignment of the corresponding NBI rating. The range of possible NBI ratings is determined by the form of the table. In this study, all tables allow ratings from zero to nine (0 to 9).

The mapping constants M_i for weighted average generation and $M_{i,j}$ for table-driven generation are chosen to yield a minimum error in NBI generation. Data from Pontis β test inspections (i.e., the NBI ratings and condition reports) were used as the basis of search procedures to arrive at optimal sets of mapping constants.

DATA IN THE STUDY OF NBI GENERATION

A search for optimal mapping constants M_i and $M_{i,j}$ examines many sets of mapping constants, computes the error in generated NBI ratings, and selects the set that delivers the minimum error. The mapping constants are said to be calibrated to the data used in the search. Data available from DOTs include copies of BMS bridge databases and current NBI condition ratings for bridges in the databases. The data set includes 3,300 bridges

TABLE II MAPS FOR NBI GENERATION

Map	Element Type
1	Unpainted Steel Superstructure
2	Painted Steel Superstructure
3	P/S Concrete Superstructure
4	Reinforced Concrete Superstructure
5	Timber Superstructure
6	Unpainted Steel Substructure
7	Painted Steel Substructure
8	P/S Concrete Substructure
9	Reinforced Concrete Substructure
10	Timber Substructure
11	Reinforced Concrete Deck
12	Steel Deck
13	Timber Deck
14	Reinforced Concrete Slab
15	Steel Culvert
16	Reinforced Concrete Culvert
17	Timber Culvert

TABLE III DECISION TABLE FOR NBI GENERATION

BMS Condition Report	NBI Rating
$P_1 \geq M_{1,9}$ $P_1 + P_2 \geq M_{2,9}$ $P_1 + P_2 + P_3 \geq M_{3,9}$ $P_1 + P_2 + P_3 + P_4 \geq M_{4,9}$	9
$P_1 \geq M_{1,8}$ $P_1 + P_2 \geq M_{2,8}$ $P_1 + P_2 + P_3 \geq M_{3,8}$ $P_1 + P_2 + P_3 + P_4 \geq M_{4,8}$	8

TABLE IV DISTRIBUTION OF BRIDGE CHARACTERISTICS IN THE NBI CALABRATION STUDY

Superstructure Type	Steel	Reinforced Concrete	P/S Concrete	Timber	Mixed	Culvert	Total
	400	1500	400	200	300	500	3,300
Year Built	To 1920	1921-1940	1941-1960	1961-1980	1981-1992		
	50	500	700	1700	350		3,300
Spans	To 100'	101-200'	201-300'	301-400'	> 400'		
	2830	400	30	30	10		3,300
NBI Ratings	0-3	4-6	7-9				
	1%	30%	69%				100%

TABLE V EXAMPLE OF NBI GENERATION

Element	Quantity	Condition State				
		1	2	3	4	5
107 Steel Open Girder, painted	2,840 LF	2,500	340	0	0	0

Weighted Average	Decision Table
NBI = 6.6(0.88) + 6.5(0.12)	P_1 = 88
NBI = 6.6	$P_1 + P_2$ = 100
	NBI = 7

and culverts (Table II). Most of these structures have current NBI rating values of six (6) and above, but there are several hundred occurrences of NBI ratings of three, four or five (3, 4 or 5). There are fewer than 10 occurrences of NBI ratings below three (3).

Mapping constants were calibrated for data from individual DOTs, and for the union of data from all nine DOTs (simulating a single, uniform NBI generation procedure). Constants M_i and $M_{i,j}$ were developed for both weighted-average and table-driven NBI generation. An example of the results is shown in Table V for the generation of NBI ratings for painted steel superstructure.

The two approaches to NBI generation respond differently to changes in a BMS condition report. Table VI shows an example in which four possible condition reports for a painted steel girder are considered. This first case, *a*, is a girder in good condition. Other cases, *b*, *c*, and *d* consider a small quantity of the girder in progressively poorer condition states. The results of both weighted-average generation and table-driven generation are shown. Note that the generated NBI rating decreases more rapidly for the table-driven approach. Generation using tables can be more responsive to poor condition states than a linear weighted-average.

Using mapping constants calibrated individually for DOTs, NBI generation is within ±1 of assigned NBI ratings for 90% of all cases. Using mapping constants calibrated for a unified data set of nine DOTs, NBI generation is within ±1 for 88% of all cases. Results are summarized in Tables VII and VIII.

There is little overall shift in NBI ratings when using a single set of mapping constants for all DOTs. Table VI shows the average differences in generated NBI ratings between the use of a single, uniform set of mapping constants for all DOTs, and mapping constants calibrated for each DOT individually. Positive values indicate that NBI ratings are increased on average using uniform generation; negative values indicate that NBI ratings are decreased. Differences in NBI ratings are often less than ±0.5. It appears that a uniform NBI generation process does not skew NBI ratings.

WORKSHOP ON NBI GENERATION

The data available from β tests have recently been enhanced by the addition of data from a workshop on NBI generation (*4*). Representatives from twenty-two DOTs were invited to review NBI generation procedures and to participate in an exercise of NBI rating and BMS condition reporting for example cases prepared by DOTs. Case histories were developed with real bridges which present specific concerns in NBI generation. There were six deck cases covering concrete, steel and timber decks and addressing concerns in deteriorated joints, deck cracking, spalling, AC overlays, and deck leakage. Seven superstructure cases covered reinforced concrete, P/S concrete, steel and timber bridges addressing concerns in bearing failure, impact damage, severe local loss of section and pack rust. Five substructure cases addressed concerns in substructure settlement, cracking and scour. Three culvert cases cover concrete, steel and timber culverts. These cases allow a

TABLE VI EXAMPLE OF NBI RESPONSE TO POOR CONDITION STATES FOR A STEEL OPEN GIRDER, 2840 LF

Case	Condition Report, LF					Weighted Average NBI	Table Driven NBI
	1	2	3	4	5		
a	2556	284	0	0	0	7(6.6)	7
b	2556	0	284	0	0	7(6.5)	6
c	2556	0	0	284	0	6(6.4)	6
d	2556	0	0	0	284	6(6.2)	4

TABLE VII PERFORMANCE OF NBI GENERATION CALIBRATED FOR INDIVIDUAL DOTs

State	Percentage of Bridges*					
	Weighted-Average Rating			Table-Driven Rating		
	Deck, %	Super, %	Sub, %	Deck, %	Super, %	Sub, %
California	91	85	84	94	88	85
Colorado	97	97	97	97	100	97
Iowa	93	88	98	89	80	99
Kansas	98	94	96	98	94	97
Michigan	88	77	100	94	86	97
Minnesota	94	98	79	94	94	80
Tennessee	82	79	87	83	91	88
Vermont	94	92	80	96	90	95
Washington	77	100	100	100	100	100
Overall	92	86	86	94	89	87

* Within ±1 of assigned NBI Rating

study of the sensitivity of NBI ratings to specific deterioration conditions. The NBI ratings and BMS condition reports obtained from participants are being used in additional calibrations of mapping constants. This calibration from workshop data is in progress. After this calibration is complete, NBI generation software will be made available to transportation departments.

SUMMARY

NBI generation from BMS element data allows inspectors to use BMS reporting formats without a duplication of effort and so aids in the implementation of management systems. Procedures for NBI generation have been calibrated using data from nine states and performance is good. A uniform generation for all

TABLE VIII PERFORMANCE OF NBI GENERATION CALIBRATED FOR ALL DATA

State	Percentage of Bridges*					
	Weighted-Average Rating			Table-Driven Rating		
	Deck, %	Super, %	Sub, %	Deck, %	Super, %	Sub, %
California	90	85	86	94	86	85
Colorado	91	88	85	91	88	79
Iowa	88	74	94	89	77	92
Kansas	97	93	97	98	92	96
Michigan	91	71	88	91	71	74
Minnesota	88	84	73	86	80	72
Tennessee	70	70	68	68	78	64
Vermont	81	89	80	82	89	90
Washington	85	83	85	85	92	100
Overall	90	85	86	93	86	85

* Within ±1 of Assigned NBI Rating

TABLE IX SHIFTS IN NBI RATINGS FOR UNIFORM GENERATION

State	Shift in NBI Ratings					
	Weighted-Average Rating			Table-Driven Rating		
	Deck	Super	Sub	Deck	Super	Sub
California	0.2	0.3	0.0	0.0	0.0	0.0
Colorado	0.2	0.5	0.9	0.2	0.4	0.9
Iowa	0.5	0.7	0.5	0.5	0.5	0.8
Kansas	-0.2	-0.4	-0.3	-0.3	-0.5	-0.1
Michigan	0.0	0.8	0.9	0.0	0.6	0.7
Minnesota	-0.4	-0.2	0.0	-0.4	-0.6	0.2
Tennessee	0.5	0.9	0.8	0.5	0.6	0.9
Vermont	0.4	0.0	0.6	0.3	0.0	0.6
Washington	0.5	0.7	1.2	0.0	0.3	1.0

DOTs is feasible. A recent workshop on NBI rating from BMS will allow a final calibration of NBI generation procedures before release of the software. Validation will continue as DOTs begin to use the NBI generation procedures.

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