Bridge Repair Priority Ranking System

Nasser Yari

Department of Civil Engineering, Wentworth Institute of Technology, Boston, Massachusetts

E-mail: yarin@wit.edu

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Abstract

DOTs, cities, and towns in the United States have limited or constrained funding to maintain their bridges and improve the transportation infrastructure as desired by the public. Bridge Repair Priority Ranking System (BRPRS) prepares a network bridge project management strategy within management specified budget limits. The objective is to refine the decision-making process to attain the maximum network service life, at the lowest possible cost to sustain a bridge network at the highest possible network condition index. Subsequently, the BRPRS provides data to network managers for presentation to respective government budget approval process as well as the voting public. Bridge prioritization is based on ranking all the available bridges in a network, with an overall score developed using the pre-defined set of criteria pertinent to individual bridge site conditions selected by a network manager. Bridge network managers face the challenge of having many bridges in the same relative condition with limited funding sufficient to rehabilitate one or two bridges per fiscal year. BRPRS will justify bridge management decisions which result in improved budget decision making while improving the network bridge condition index. Bridge engineers or bridge owners using BRPRS can specify the selection and prioritize repair schedules based on factors such as condition, criticality, risk, functionality, type, size, and age. Priority ranking techniques are based on calculating a value for each bridge and then sorting all bridges in descending order of their parameters.

Keywords: BMS, Bridge Management, Priority Ranking

1. Introduction

Traditionally, maintenance, rehabilitation, and replacement (MR&R) projects are selected on a “worst first” approach. This method is acceptable if an unlimited budget is available to provide sufficient funding to sustain the bridge network at a high level of performance (Rashidi et al, 2016). This is typically not the case--municipalities and state transportation agencies have a limited resource to manage their infrastructure. Consequently, there is a need for prioritization to utilize available funds to assure the highest network level of performance as evaluated by bridge infrastructure managers’ specified parameters. The bridge owners are confronted with major challenges to improve and maintain the aging bridge infrastructure (Allah Bukhsh et al, 2018).

Figure 1 illustrates the age distribution of New Hampshire Department of Transportation (NHDOT) bridges. About 95% of NHDOT bridges require some type of maintenance or rehabilitation. New bridges could use some type of proper preventive maintenance to extend their service life.

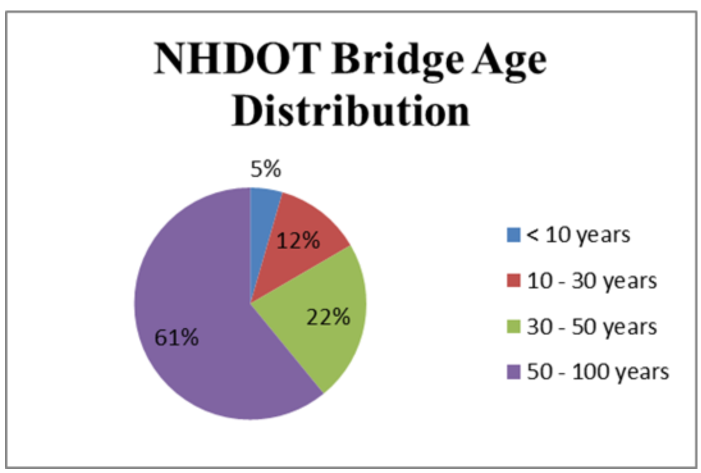

Figure 1. NHDOT bridge age distribution.

The goal for BRPRS is to extend the useful life of bridges in the most cost-effective manner by evaluating financial plans to identify funding levels required to sustain bridge networks at selected service levels. Bridge Repair Priority Ranking System (BRPRS) prepares a network bridge project management strategy within management specified budget limits. The objective is to refine the decision-making process to attain the maximum network service life, at the lowest possible cost to sustain a bridge network at the highest possible network condition index. Subsequently, the priority ranking system provides data to network managers for presentation to respective government budget approval process, as well as the voting public. The BRPRS presents the site-specific bridge parameters, weighting factors, and cost comparative factors to provide a bridge network priority ranking system that includes preservation, general maintenance, rehabilitation, and replacement projects.

2. Background

Project priority ranking systems have been used by several state departments of transportations to evaluate and select bridge projects for their preservation, rehabilitation, capital improvement programs, and replacement projects in preparing long and short term budget plans. (Kulkarni et al, 2004). Most BMS programs provide some type of ranking system on a network level. BrM (Pontis) provides bridge ranking based on benefit-to-cost ratio, the average health index, or the sufficiency rating for each project (Cambridge, 2005).

The sufficiency-rating (SR) approach is still used by some state DOTs for ranking bridges. Sufficiency rating (SR) was developed by the Federal Highway Administration (FHWA, 1995) to rate and rank bridge inventories. The SR is used by FHWA as of priority-ranking technique to determine the eligibility of bridges for MR&R activities and overall assessment of a bridge's condition. A SR calculation scale is expressed as a percentage from 0 to 100, with 0 representing a completely deficient bridge and 100 a new or rehabilitated bridge. SR categorizes bridges into three groups for MR&R recommendation. (1) bridges with SR ratings between 80 and 100 should receive preservation treatments and no additional maintenance, (2) bridges with SR between 50 and 80 are eligible for rehabilitation and (3) bridges with SR between 0 and 50 are eligible for replacement. Bridge deficiencies are described in one of two categories: structurally deficient or functionality obsolete (Xanthakos, 1996).

The drawbacks of the SR method are (Sianipar et al, 1997): (1) overlooks the Average Daily Traffic (ADT), (2) SR is determined on the basis of a single standard, and (3) the method provides no room for optimization. Based on the SR method, narrow bridges that have a low capacity are subjected to low sufficiency ratings, although these bridges may be in good or better condition. (Elbehairy et al, 2006). The SR is not capable of providing MR&R strategy for each bridge.

Benefit-to-Cost Ratio: The benefit-to-cost ratio (B/C) considers all the benefits and costs associated with a project. Agency benefits are defined as “the present worth of future cost savings to the agency bridge expenditures” (FHWA, 1989b). Benefit/cost ratios are used to compare the use of fundings between projects. Numerous projects on the network level may be prioritized by evaluating the B/C ratio for each project. In comparing all the projects, those projects with the highest B/C ratio would be ranked as the most efficient (Sallman et al, 2012). Farid et al (1993) reported that the B/C ratio is difficult to use for assessing user costs and forecasting future conditions. The B/C ratio assumes the benefits gained from improvement projects are constant. However, this is not always correct; this assumption does not take into account project timelines within the limits of the analysis period.

Health Index: The Bridge Health Index was developed by the California Department of Transportation (CALTRANS). The purpose was to create a unified condition index that would solely reflect the structural condition of the bridge (Roberts et al, 2000). The Heath Index determines the remaining bridge asset value and compares it to its replacement value or to its best possible condition versus the current condition.

The National Bridge Inventory (NBI) is the aggregation of structure inventory and appraisal data which was initially developed in 1971 to observe bridge operations and safety. The NBI inventory data consisting of 116 items provides information for each bridge. These items are specified in the Recording and Coding Guide for the structure inventory and appraisal of the Nation’s Bridges (FHWA-PD-96-001). The National Bridge Inspection Standards (NBIS) were established in 1971 to require that all bridge inspection processes, frequency of inspections, qualification of the bridge inspectors, bridge inspection reports and the maintenance of bridge inventories meet the National Bridge Inspection Standards (Rossow, 2012). All bridges longer than 20 feet (6.1 meters) must be inspected per (NBIS; 23 CFR 650 subpart C) and reported by the states and federal agencies to the Federal Highway Administration.

3. Bridge Repair Priority Ranking System

The bridge prioritization process is based on a set of criteria for performance measures which will be used to prioritize projects in the ranking system. These criteria are based on fundamental values and concepts in the following categories:

1. Condition
2. Criticality
3. Risk
4. Functionality
5. Type
6. Age
7. Size

The rating scoring system includes user specified site conditions pertaining to a respective individual bridge in a network. The priority ranking index is from 0 (least candidate for rehabilitation and replacement) to 100 (most preferred candidate for rehabilitation and replacement).

The priority ranking points for rehabilitation are calculated as:

$$PRPR = \alpha C + \beta CT + +\gamma R + \delta F + \varepsilon BT + \theta A + \mu S \quad (1)$$

where

PRPR - priority ranking points for rehabilitation (ranging from 0 to 100)

C - condition rating points based on NBI rating system

CT - criticality based on traffic volume, road class, detour length, border bridge, utility, and impact

R - risk based on scour critical, flood, ice, fracture critical member, and bridge rail type

F - functionality based on load limit, vertical clearance, lane width, shoulder width, waterway adequacy, and mobility

BT - bridge type: girder, movable, culvert, timber, truss

S - size

A - age

The weighting variables (α, β, γ, δ, ε, θ, μ) are a percentage of each criterion in the rating equation and are agency specified. It is recommended that the rating score total 100 points to denote the highest priority. Bridge managers can adjust the weighting factors of each category and their respective parameters based on their highway network. Table 1 shows the recommended range of category weighting factors. The sum of the weighting factors must not exceed 1.

Table 1. Ranking Criteria Weighting Factors

Criteria	Weighting Variable	Recommended Range	Default Value
Condition	α	0.40 – 0.60	0.40
Criticality	β	0.10 – 0.30	0.18
Risk	δ	0.10 – 0.30	0.15
Functionality	γ	0.10 – 0.20	0.12
Type	ε	0.0 – 0.10	0.05
Age	θ	0.05 – 0.15	0.05
Size	μ	0.05 – 0.10	0.05
Total			1.00

3.1 Condition:

The bridge condition criteria are worth 40% to 60% of the total PRPR. A bridge condition assessment is normally divided into three sections or components: (1) Deck, (2) Superstructure, and (3) Substructure. In this study, the default condition weighting factor is 40% (α = 40%) in which the Deck Condition score accounts for 20% of the rating, while the Superstructure and Substructure Condition score account for 40% each. NBI condtion rating shown in Table 2.

C = 0.2 k(Deck)+0.4 k(Superstructure)+0.4 k(Substructure)

Where

k = (9-N)/(100/9) (3)

N = NBI condition rating of bridge component

Table 2 NBI condition rating

NBI Condition Rating	
9	Excellent Condition
8	Very Good Condition
7	Good Condition
6	Satisfactory Condition
5	Fair Condition
4	Poor Condition
3	Serious Condition
2	Critical Condition
1	Imminent Failure Condition
0	Failed Condition

The NBI condition rating for Bridge #216/112 Spaulding Turnpike over NH 75 based on NHDOT's inspection report is:

Deck: 6 Satisfactory
Superstructure: 8 Very Good
Substructure: 7 Good

From equation 3 the scoring numerical value for each bridge component can be calculate as:

k(deck)=(9-6)(100/9)=33.3
k(superstructure)=(9-8)(100/9)=11
k(substructure)=(9-7)(100/9)=22

From equation 2 the condition score is

C=0.2(33.3)+0.4(11)+0.4(22)=20

The condition of this bridge is worth 20 out of 100. The maximum points in this category (bridge condition) will not exceed 100 points (i.e. the worst condition).

3.2 Criticality

Criticality is based on a set of criteria that is important to the public. These criteria include traffic volume (T), road classification (RC), detour length when bridge is closed to traffic (D), border bridge (if a bridge is connecting two states) (B), utilities on the bridge (U), and the economic, environmental, societal impact caused by a bridge closure (I). Table 3 describes the percentage of each section of criticality. Criticality recommended weighting factor is 10% to 30% of PRPR (β=10% to 30%)

$$CT = 0.3T+0.2RC+0.15D+0.05B+0.1U+0.2I \quad (4)$$

Table 3. Criticality Recommended Scoring

Annual Average Daily Traffic	Points
> 50,000	100
25,000 – 49,999	75
10,000 – 24,999	50
1,000 – 9,999	25
0 to 999	12.5
Road Class	**Score**
Interstates & Turnpikes	100
Other Freeways & Expressways	75
Collector	50
Local	25
Detour Length (miles)	**Score**
>20	100
10 – 20	75
5 – 10	50
0 – 5	25
Utilities	**Score**
Contains utilities	100
No utilities	0
Criticality	**Score**
Economic	25
Environmental	25
Societal	25
School Bus Route	25

Table 4 shows the scoring of criticality for Bridge #216/112 Spaulding Turnpike over NH 75.

Table 4. Criticality Scoring of Bridge 216/112 on Spaulding Turnpike

Parameter	Criteria	Value
Traffic Volume	35,000	22.5
Road Class	Turnpikes	20
Detour Length	9 miles	11
Border Bridge	No	0
Utilities	No	0
Impact		
Economic	Yes	5
Environmental	No	0
Societal	Yes	5
School Bus Route	Yes	5
		68.5

From equation 4 the traffic volume is 30% of criticality. In this bridge example the traffic volume of 35000 AADT based on table 3 will result with the total score of 75 points. Applying the weighting factor of 0.3 will result in the value of 22.5 as shown in table 4.

3.3 Risk

The bridge risk criteria are factors that may cause bridge failure. In the United States, bridge scour has been the number one cause of bridge failures. The risk criteria for this study are scour critical (SC), flood (FL), ice (IC), fracture critical member (FC), bridge rail types (BR), and impact damage (I). A fracture critical bridge is defined by the FHWA as a steel member in tension, or with a tension element, whose failure would probably cause a portion of or the entire bridge to collapse.

$$R = 0.3\,SC + 0.1\,FL + 0.2\,BR + 0.3\,FC + 0.1\,IC$$

Table 5. Risk Recommended Scoring

Scour Critical	**Score**
Yes	100
No	0
Flood	
Yes	100
No	0
Bridge Rail	
Does not meet standard	100
Meets standard	0
Fracture Critical Member	
Yes	100
No	0
Ice	
Yes	100
No	0

Table 6 shows the risk value scoring of Bridge 216/112 on Spaulding Turnpike. total risk value is 20 points since this bridge is not over water and bridge rail does not meet the current standard.

Table 6. Risk Value Scoring of Bridge 216/112 on Spaulding Turnpike

Parameter	Value	Score
Scour Critical	No	0
Flood	No	0
Bridge Rail / Barrier	Does not meet standard	20
Fracture Critical Member	No	0
Ice	No	0
Total		20

3.4 Functionality

Functionally obsolete bridges are those that do not have adequate vertical clearances, lane widths, shoulder widths, or those that may be occasionally flooded or fail to meet current traffic demand or current geometric standards. The Federal Highway Administration defines functionality obsolete as, does not meet current design standards (for criteria such as lane width), either because the volume of traffic carried by the bridge exceeds the level anticipated when the bridge was constructed and/or the relevant design standards have been revised.

In this study, the functionality criteria is based on load limit (LL), vertical clearance (VC), lane width (LW), shoulder width (SW), waterway adequacy (WA), and mobility (MB). The scoring detail is shown in Table 7.

The recommended weighting factor is 10% to 20% of PRPR (γ=10% to 20%) with default setting of 12%.

$$F = 0.2\,LL + 0.2\,VC + 0.1\,LW + 0.1\,SW + 0.2\,MB + 0.2\,WA$$

Table 7. Functionality Recommended Scoring

Load Limit	Score
< 3 tons	100
3 – 10 tons	70
< HS-20	50
HS 20	0
Lane Width (ft)	**Score**
< 12	100
≥12	0
Mobility (vehicles/hour)	**Score**
>1400	100
1100-1400	75
900 – 1100	50
700-900	25
<700	0
Vertical Clearance (ft)	**Score**
<14	100
14 – 16	50
>16	100
Shoulder Width (ft)	**Score**
<4	100
4 – 10	50
≥10	0
Waterway Adequacy	**Score**
Flood Overtopping	100
Clearance < 12 ft	50

Table 8 shows the scoring of functionality for Bridge 216/112 Spaulding Turnpike over NH 75.

Table 8. Functionality Value Scoring of Bridge 216/112 on Spaulding Turnpike

Parameter	Value	Points
Load Limit	HS-20	0
Lane Width	12 ft	0
Mobility	1400	20
Vertical Clearance	16.8 ft	0
Shoulder Width	10	0
Waterway Adequacy	N/A	0
Total		20

3.5 Bridge Type, Size and Age

The recommended weighting factors for bridge type, size, and age are 5% each as described in Table 9

Table 9. Bridge Type, Size, and Age Recommended Scoring

Type	Score
Girder	80
Movable	100
Culvert	20
Timber	50
Truss	100
Cable Supported	100
Arch	75
Size (deck area sq-ft)	**Score**
>30,000	100
20,000 – 30,000	80
10,000 – 19,999	60
5,000 – 9,999	40
< 5000	20
Age (years)	**Score**
> 50	100
40 – 50	80
30 – 39	60
20 – 30	40
< 20	20

Table 10 shows the scoring of bridge type, size, and age for Bridge #216/112 Spaulding Turnpike over NH 75.

Table 10. Bridge Type, Size, and Age Scoring of Bridge 216/112 on Spaulding Turnpike

Parameter	Value	Points
Type	Girder	80
Size	6,500 ft^2	40
Age	42 years	80

The total PRPR score for Bridge 216/112 on the Spaulding Turnpike may be calculated using the default weighting variable values from Table 1 and the individual category scores from Tables 4, 6, 8, and 10. These results are shown in Table 11.

Table 11. Composite Score Calculation of Bridge 216/112 on Spaulding Turnpike

Category	Score	Weight	Weighted Score
Condition	20	0.4	8.0
Criticality	68.5	0.18	12.3
Risk	20	0.15	3.0
Functionality	20	0.12	2.4
Type	80	0.05	4.0
Size	40	0.05	2.0
Age	80	0.05	4.0
Total			35.7

4. Case Study

A sample network consisting of 170 New Hampshire Turnpikes bridges has been chosen to demonstrate the application of the developed priority ranking method. Table 12 shows some of the calculated BRPR scores. In order for BRPRS (Bridge Repair Priority Ranking System) to be effective, there needs to be a fine balance between the condition of the bridge and the other criteria that affect the traveling public. The BRPRS, in altering the distribution rate outside of the recommended range, should not compromise the condition of the bridge, nor should it be solely based on the condition.

The current method of bridge management is insufficient to meet the demands of the traveling public; the "worst first" routine is no longer being viewed as the best option. The BRPRS is most effective when the condition range is between 40% and 60% which allows other user factors to be considered. The criteria such as traffic volume, detour length, bridge rail, fracture critical member, lane width, and mobility that interrupt the nation's economy, lifestyle, and the safety of motorists should be a significant part in decision making.

The two other criteria that should remain constant are toll plaza bridges and emergency vehicle route bridges. These two criteria should receive an additional 5 to 10 points in the priority rating. The detour bypass around toll plazas can be costly due to revenue loss. Emergency vehicle route bridge closure can have a significant impact on the community and can be costly to the bridge owner in providing a safe reliable detour.

Table 12. NH Turnpike BRPR Scores

Town	Description	BRPR Score
Portsmouth	I-95 over Piscataqua River Road	63
Dover / Newington	SB Spaulding Turnpike over Little Bay	60
Dover / Newington	NB Sp. Turnpike over Little Bay	58
Hampton	I-95 over Taylor River	51
Manchester	F.E. Everett Turnpike NB over Black Brook	47
Nashua / Hudson	WB Connector over B&M RR and Merrimack River Sagamore Bridge	45
Dover	Sp. Turnpike NB over Cocheco River	44
Dover	Sp. Turnpike SB over Cocheco River	434
Manchester	F.E. Everett Turnpike SB over Black Brook	43
Merrimack	Baboosk Road over F.E. Everett Turnpike	43
Merrimack	F.E. Everett Turnpike SB over Pennichuck Brook	41
Merrimack	F.E. Everett Turnpike NB over Pennichuck Brook	41
Concord	F.E. Everett Turnpike SB over Hall Street	40
Milton	Spaulding Turnpike over Route 75	36
Nashua	F.E. Everett Turnpike NB over Nashua River	34
Concord	F.E. Everett Turnpike NB over B&M Railroad	34
Portsmouth	I-95 over Hodgson Brook	33
Nashua	F.E. Everett Turnpike SB over Canal Road	29
Nashua	F.E. Everett Turnpike NB over Canal Road	27
Bow	F.E. Everett Turnpike over Dow Road	26
Hooksett	I-93 over Ramp A and B	25

5. Summary

The prioritization is based on multi-criteria type of analysis, a priority ranking is computed for each bridge, the ranking index is expressed as a number from 0 (least candidate for rehabilitation and replacement) to 100 (most preferred candidate for rehabilitation and replacement) which enables project managers and decision-makers to understand and compare the overall health of a various bridges in the network. This ranking system has been tested through case study and experienced professional engineers and asset managers from municipalities and NHDOT. The advantage of this system is that it provides flexibility to the bridge owners to adjust the weighing factor based on their own interest. However, the adjustment must be within recommended weighing factor and the changes must be on the network level. This priority ranking system is designed to integrate with the proposed GIS Based Bridge Management System. The drawback of this system is the weighing factor is based on engineering experience and judgment which can be bias.

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