Bridge Inspection, Maintenance, and Management Strategies in Canada

Sami Moufti[1], Iason Gkountis[2], Ahmad Jabri[3], Ahmad Shami[4], Kien Dinh[5], and Tarek Zayed[6]

ABSTRACT

The crumbling state of bridge Infrastructure in the developed countries, such as the United States and Canada, has been recently making news headline stories, and drawing both public and official attention to the matter's criticality. Given the limited budget at hand, the state/provincial and federal transportation agencies are facing a steep challenge to upkeep their bridge inventories at safe conditions and/or acceptable service levels. This has created auxiliary needs for more efficient allocation of bridge maintenance funds, which urged transportation agencies to sponsor the development of Bridge Management Systems (BMS) since the early 1990's. Since then, the practice has gone through ample evolution, and had to benefit from incidents and accumulated experience. In an effort to form an understanding and update the knowledge about the contemporary state of the practice, this paper presents a survey of the current trends in bridge inspection, maintenance and management across Canada. Although most of the findings show similarities in the applied data collection and information management methods, differences were recorded in data interpretation, and intervention/ maintenance strategies. The paper provides insights of the latest trends in bridge management and preservation, which is ultimately believed to form a basis for educated future bridge management decisions.

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The crumbling state of bridge Infrastructure in the developed countries, such as the United States and Canada, has been recently making news headline stories, and drawing both public and official attention to the matter's criticality. Given the limited budget at hand, the state/provincial and federal transportation agencies are facing a steep challenge to upkeep their bridge inventories at safe conditions and/or acceptable service levels. This has created auxiliary needs for more efficient allocation of bridge maintenance funds, which urged transportation agencies to sponsor the development of Bridge Management Systems (BMS) since the early 1990's. Since then, the practice has gone through ample evolution, and had to benefit from incidents and accumulated experience. In an effort to form an understanding and update the knowledge about the contemporary state of the practice, this paper presents a survey of the current trends in bridge inspection, maintenance and management across Canada. Although most of the findings show similarities in the applied data collection and information management methods, differences were recorded in data interpretation, and intervention/ maintenance strategies. The paper provides insights of the latest trends in bridge management and preservation, which is ultimately believed to form a basis for educated future bridge management decisions.

Introduction

Bridges, roadways, and transit networks are vital constituents of a country's civil infrastructure; all of which contribute to its social and economic welfare, and compose a substantial portion of its national economy. In Canada, the total value of infrastructure

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in 2012 was estimated to be around $ 538 billion; according to the Canadian infrastructure report card [1]. However, approximately one third of the Canadian infrastructure is in a fair or worse condition as stated by the same report. Past and forecasted figures indicate that “transportation” forms the largest portion of the Canadian infrastructure industry value, with “roads and bridges” comprising its most significant worth share as per latest estimates by the Business Monitors International report on Canadian Infrastructure [2]. However, most of the nation’s bridges were built during the boom period of infrastructure construction in the 60’s and 70’s of the past century [3]. With many of the nation’s bridges approaching or exceeding their 50-year design life, the aging problem of the bridge infrastructure imposes great bridge preservation challenges on provincial and municipal ministries of transportation in Canada. Bridge aging concerns are similar in the United States. According to America’s 2013 Infrastructure Report Card, the average age of the nation’s 607,380 bridges is currently 42 years [4]. Statistics by the Federal Highway Administration’s report further indicate that one in nine of the nation’s bridges are rated as “structurally deficient” [5].

The growing problem of bridge aging and deterioration has created needs for a further detailed bridge element inspection system that is able to sufficiently provide in-depth inputs for maintenance decision making and budget allocation. In order to assist informative decisions, bridge managers have been advocating the use of an updated, performance based insight of the bridge breakdown that would emphasize the detailed geometric and functional characteristics of bridges [6]. Within this context, the first edition of the “Guide Manual for Bridge Element Inspection” was published in 2011 to introduce an improvement on the widely used Commonly Recognized (CoRe) system of bridge elements, and to build on the concept of element-level condition rating [7]. The new guide reconfigures the condition rating scheme to comprehensively capture bridge elements’ distress indicators; providing in-depth assessment of bridges, and promoting detailed data reporting to fully support agency decision making and inventory management.

As a result, the FHWA has recently started works on updating the widely used 1995 National Bridge Inventory (NBI) coding guide to accurately reflect the condition and performance of highway bridges, and to integrate the newly developed guide for detailed bridge inspection data acquisition [8]. Accordingly, there has been a parallel trend among transportation agencies towards the adoption and implementation of element level inspection. This is due to the fact that a further in-depth inspection provides more details for later analysis and implementation in effective deterioration curves and performance models [9]. Newly established or updated guidelines, as well as the recent state of the practice, suggest increased incorporation of bridge element condition data to achieve more insightful assessments. As an integral part of this research, a survey questionnaire was conducted in an effort to investigate the most current practices among transportation departments/agencies in Canada and the United States. The research team sent the survey questionnaire to more than fifty bridge engineers, inspectors and managers. Responses were successfully collected from the Canadian provinces of Quebec, Ontario, Alberta, British Colombia, Nova Scotia, and Saskatchewan. The survey included 38 technical questions allocated to the following 3 sections:

- Bridge Inspection Practices,
- Bridge Maintenance, Repair, and, Rehabilitation Practices,
- Decision Making and Bridge Management System (BMS)

Fig. 1 captures the average age distribution of bridges falling under the agencies represented by the surveyed bridge experts. In order to form an understanding and update the global knowledge about the contemporary state of the practice, obtained responses are thoroughly analyzed and discussed in detail to extract a general sense of the current bridge inspection and maintenance/rehabilitation practices, and provide insights of the latest trends in bridge management and preservation.

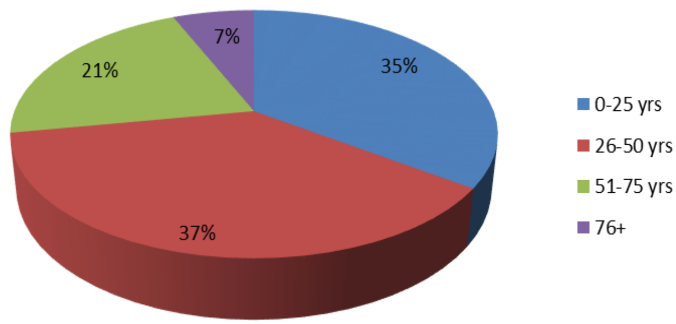

Figure 1. Average age distribution of bridges under the surveyed agencies

Bridge Inspection

Bridge inspection aims at recording observations of the state of all bridge elements by well-trained and experienced personnel, as part of what should be a progressive reporting system that forms the basis of any logical deductions and conclusions on the state of the inspected bridge [10]. The earliest forms of bridge inspection standards were incorporated in the "AASHTO Manual for Maintenance Inspection of Bridges", which was released in 1970 and received several updates since then. Another major manual that helped establishing a common federal condition reporting code is the FHWA "Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges", which was also under continues development since it's early publication in 1972 [11]. The accumulated experiences over the years, in addition to learned lessons and advisories from state bridge experts, have always urged FHWA and AASHTO to accommodate upgrades in newly adapted inspection guidelines. In Canada, most provinces have their own inspection standards/manuals; such as the Ontario structures inspection manual (OSIM), and the Quebec manual of structures inspection (MIS).

Although visual inspection is still largely accepted as the most prevalent bridge inspection practice, many NDE techniques have been developed and widely adapted to objectify the evaluation process and make it more detailed and reliable. Such methods include Half-Cell Potential test, Impact Echo test, acoustic methods (hammer sounding, chain drag), and Ground Penetrating Radar (GPR), etc. Upon providing their inputs on the employed concrete bridge deck assessment methods; all respondents indicated the use of visual inspection, making it the most prevalent evaluation approach (Fig. 2).

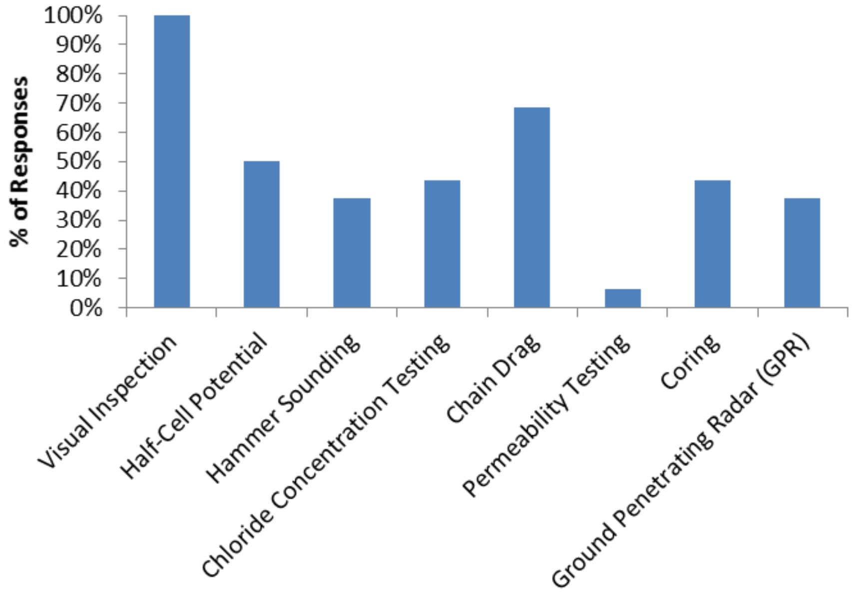

Figure 2. Commonly employed assessment methods for bridge decks

Chain drag is the second most popular technique; since agencies largely depend on this method for the detection of delamination areas. Approximately 50% of the respondents indicated the use of half-cell potential and coring. Ground Penetrating Radar (GPR) received a relatively low share, although it has long been considered a highly promising technique. From a generic list of possible defects that develop in concrete, respondents were asked to choose defects that are most commonly encountered on bridge decks according to their experience and judgments. The list included: Scaling, Corrosion of reinforcement, Pop-outs, Longitudinal cracks, Transverse cracks, Diagonal cracks, Map cracks, Alkali-aggregate reaction, Delamination, Honeycombing, Spalling, and Surface defects (stratification, segregation, cold joints, abrasion, slippery surfaces, deposits).

As can be noticed from Fig. 3, the highest majority of respondents indicated that delamination and spalling are the major distress indicators on bridge decks (75%). It is evident that corrosion of reinforcement is the major causing factor of a set of many defects including spalling and delamination, yet the subsequent surface manifestations may be more easily detected by visual inspection. Corrosion of reinforcement was selected by 69% of respondents. Diagonal cracking was the least common defect with only 6%. Similarly, the subsequent Figs. 4 and 5 show the most prevalent defects for concrete bridge beams and substructures (piers/abutments), respectively.

Bridge Maintenance, Repair and Rehabilitation

Bridges deteriorate over time; slowly in the beginning after construction or renovation and with a higher rate later on. By drawing an intervention plan and performing scheduled actions, the life of a bridge can be extended and the costs of maintenance are kept low.

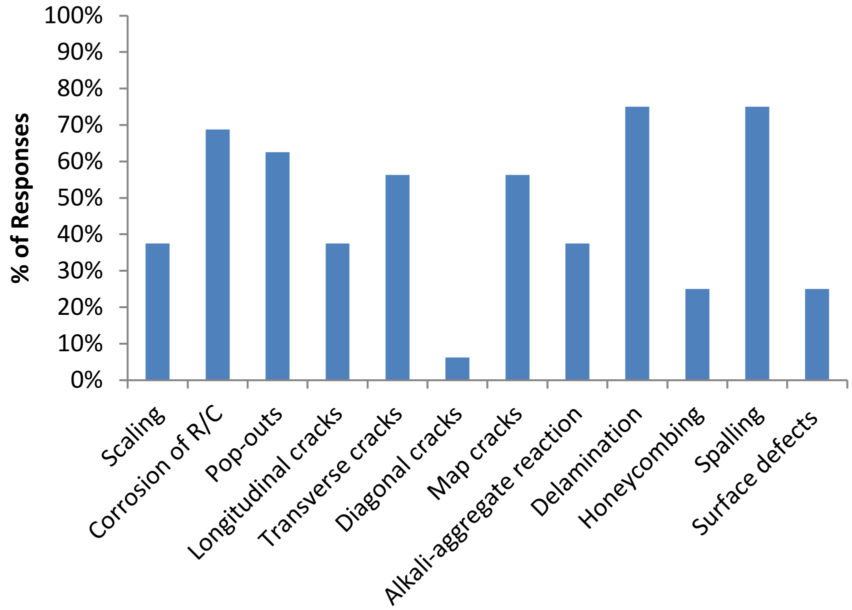

Figure 3. Common defects of concrete bridge decks

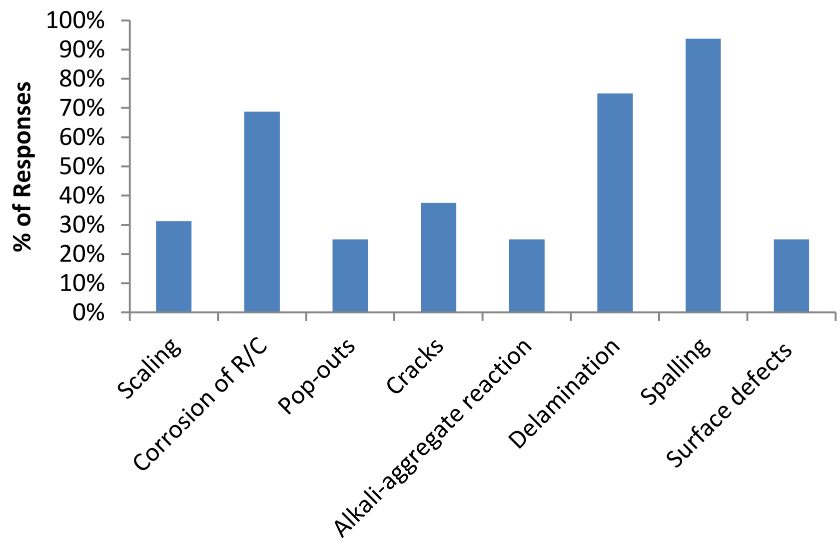

Figure 4. Common defects of Concrete bridge beams

As the general rule applies, the cost of maintenance and repair is considerably higher when the condition of a bridge is severely deteriorated. Lastly, there is a minimum accepted level of a bridge condition below which it is considered unsafe and incapable of fulfilling its scope and immediate action should be taken or the bridge should be closed to traffic. Appropriate guidelines and intervention strategies can be generally found in bridge maintenance/ rehabilitation manuals issued by local transportation agencies.

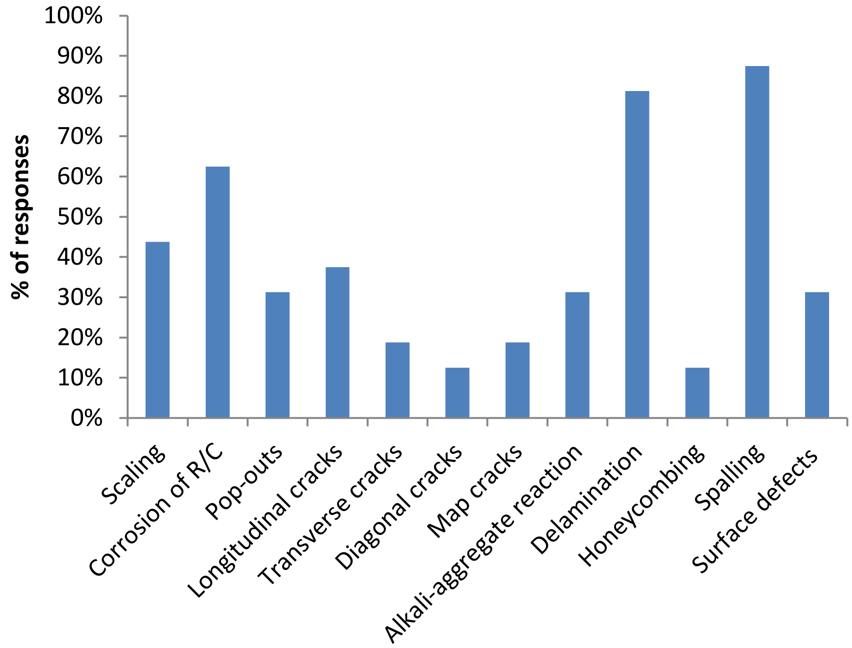

Figure 5. Common defects of concrete bridge piers & abutments

For instance, the Ministry of transportation of Quebec (MTQ) has issued the "Bridge Maintenance Manual" [12], based on which the appropriate intervention strategies are selected for curing a bridge. In this official booklet, the whole approach of the MTQ related to maintenance, repair and rehabilitation of bridge infrastructure is described. Accordingly, Ontario Ministry of Transportation follows the guidelines of the "Structural Rehabilitation Manual" [13]. As is the case in many Canadian DOTs, there are some clear intervention types that can be implemented on a bridge. The general idea is to attempt to control the deterioration mechanisms and even counteract them.

Table 1. Main Intervention Categories, and sample linked activities [12]

Intervention Categories	**Sample Activities**
Preventive maintenance	• Waterproofing concrete surfaces • Removal of vegetation • Removal of concrete fragments
Routine maintenance	• Replacement of bolts / rivets • Fixing a steel member of deck joint • Repair / replacement of signs
Repair	• Rehabilitation of asphalt • Repair with shotcrete • Filling cracks by injection
Upgrading	• Strengthening • Adding traffic lanes

There are numerous intervention actions that are applied to maintain or improve the condition of a bridge. All these actions can be grouped under a major intervention strategy or type. The best suited intervention type can be selected, depending on a) the special needs and attributes of a bridge, b) the short-term and long-term scope of the project, c) the desire of the authority and d) the condition of the bridge itself. Table 1 presents prime bridge intervention categories that are defined by MTQ, along with a sample of relevant activities. In general, different provinces adjust the previous guidelines to their specific needs, but the philosophy remains untouched. Table 2 summarizes the most commonly employed bridge deck intervention types, and the suggested application frequency; according to the surveyed panel of experts. It can be clearly concluded that different types of intervention commonly take place when they are accordingly needed, or when the range of deterioration is very considerable.

Table 2. Commonly employed bridge deck intervention actions

Types of Intervention	**Suggested Actions**	**Suggested Frequency**
Preventive Maintenance	Applying waterproofing membrane	If not done so
	Girders painting	
Routine Maintenance	Bridge washing	Once a year
	Washing and debris removal	Every year for major bridges / Every 3 years for other
	Deck sealing	Every 4 years
Repair	Repairing areas of high corrosion potential and/or delamination; Shotcreting soffit	Based on inspection
	Crack sealing	
	Concrete repairs	
	Joint repairs	
Replacement	Asphalt replacement	15 Years
	A polymer modified asphalt membrane/wearing surface replacement	18 Years
	Deck replacement	50 Years
	Replace the expansion joints	When needed
Upgrading	Shotcreting soffit; use FRP to increase strength	When needed
	Widening	
	Sidewalk additions/widening	
	Realignment	
	Barrier upgrades	

Bridge Management & Decision Making

In an effort to globally manage bridge inventories and retain a detailed review of each bridge in the system, DOTs in the U.S and Canada have developed or adapted Bridge Management Systems (BMS). In the US, PONTIS as part of AASHTOware package is the most widely implemented BMS. While in Canada, different provinces have their own BMS packages, such as the OBMS in Ontario, and the GSQ in Quebec. Those systems are designed to keep track of individual bridge details and inspection records, develop deterioration forecasts, and prioritize maintenance actions. Ref. [14] defines BMS as a rational and systematic approach to organizing and carrying out all activities related to maintaining a network of bridges. The main goal of a BMS is to advise bridge managers in making consistent and justifiable decisions regarding maintenance, rehabilitation, and replacement (MR&R) of bridges and in identifying future funding needs. These management decisions include both decisions made for an individual bridge and decisions made for the entire network of bridges. At the network level, a BMS tries to establish optimal investment funding levels and performance goals for an inventory of bridges, while at the bridge level it has to identify the appropriate combinations of treatment scope and timing for each individual bridge over its life cycle [15].

In practice, the appropriate action/intervention plan is decided by going through a bridge management decision process, or an immediate engineering judgment from bridge experts. Answers from the surveyed professionals reveal that experience has the upper hand when it comes to taking actions and deciding on appropriate intervention techniques.

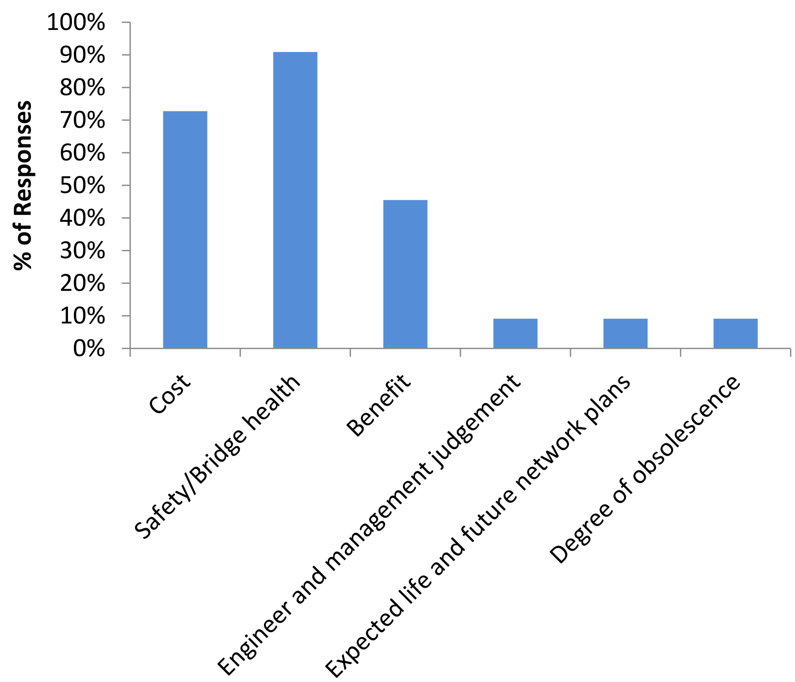

Figure 6. Criteria for maintenance decision making

As for the decision making criteria, illustrated in Fig. 6, it is noted from the responses that the public safety, reflected by the Safety/Bridge health in the survey, can be considered the most important factor in decision making. As anticipated, the first priority of any infrastructural facility is to provide safe services for the public. As to the optimization model/technique used to suggest maintenance priorities, Fig. 7 displays the prioritization factors leading to maintenance, rehabilitation or full replacement decisions. Commonly, life cycle costing and benefit over cost ratio (B/C) are used as optimization techniques for BMS.

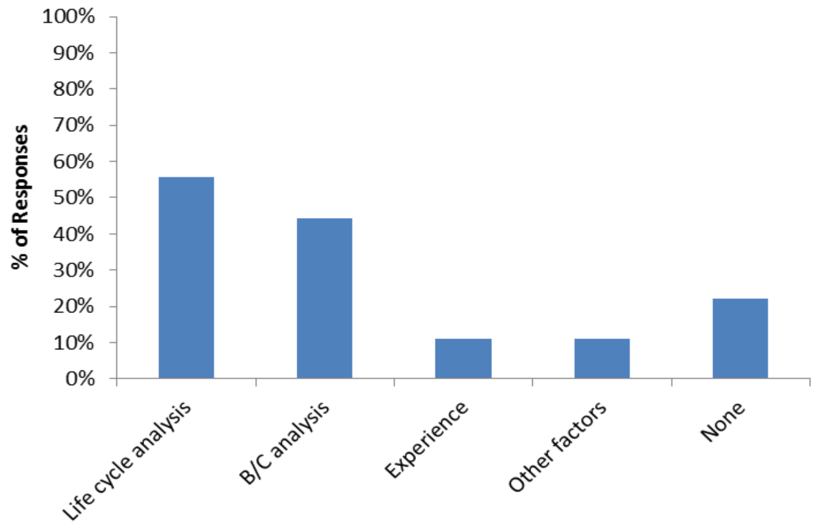

Figure 7. Optimization techniques for bridge MR&R

Conclusion

Transportation agencies are challenged with the task of preserving their existing bridge infrastructures and keeping them within acceptable levels of service. Since maintenance funds are often limited in such economic times, strategic investments in new technologies for precise bridge inspection, such are the Ground Penetrating Radar (GPR), are highly recommended. This, along with effective maintenance prioritization and management, should assist in achieving better results and advance the state of the practice.

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