TOWARDS A LIFE CYCLE FRAMEWORK FOR BRIDGE MANAGEMENT SYSTEMS IN THE UK: INSIGHTS FROM A CRITICAL REVIEW OF INTERNATIONAL APPROACHES AND MODELS

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Effective Bridge Management Systems (BMS) are of paramount importance to bridge owners and bridge managers. BMS in the UK encompass an inventory of existing bridge stock, schedule of inspections, condition rating of structures, budget planning, deterioration modelling, bid for maintenance funds, and maintenance repair and rehabilitation, but fail to consider sustainability and long-term options. A Life Cycle Assessment (LCA) approach is currently being proposed to address this problem, which can be incorporated into a BMS. In order to achieve this, a critical analysis was performed on international literatures in the area of BMS study. This presents insights of previous approaches and models towards improving existing BMS functionalities, while responding to generic requirements. Findings revealed that the incremental improvement of BMS does not consider sustainability options to enable sustainable decisions to be made regarding bridge management activities. Therefore, systems should start considering sustainability optimization criteria which can be delivered through a life cycle approach.

Keywords: asset management, bridge management system, life cycle assessment, sustainability.

INTRODUCTION

Bridges play a vital role in economic development. Bridges provide a means of transporting goods and services from place to another (Wilmer, 2012). Managing bridge networks across the country is a major challenge to governments and bridge-owners (Flaig and Lark, 2000; BOF, 2004; Duffy, 2004; Gattuli and Chiaramonte, 2005). Challenges faced by bridge-owners are; bridge deterioration due to ageing, increased traffic and environmental conditions (BOF, 2004). The need for urgent attention towards the ever increasing deterioration problems paved the way for the emergence of bridge management.

Bridge management provides guidelines for effective decisions for the maintenance, strengthening, assessment and continuous use of bridges (Gattuli and Chiaramonte, 2005; Hallberge and Racutanu, 2007). In respect to this, bridge-owners have developed tools to meet the objectives of bridge management. A bridge management system (BMS) is a software tool developed by bridge experts to collect and store information, designed to support decision-making regarding resources for operations,

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maintenance, rehabilitation, upgrading and reconstruction of bridges (Austroads, 2002; 2004; 2009).

Important developments have taken place in recent years in UK BMS. However, these developments have not considered sustainability options. Therefore, the purpose of this work is to identify the useful state-of-the-art from international approaches and models of BMS to enable the future development of a framework for BMS in the UK. To achieve this, a literature review was conducted on international model. The understanding from this review allowed a case for in-cooperating a life-cycle assessment in BMS to be presented. To start with, an area that encompasses bridge management and other highway asset is discussed.

ASSET MANAGEMENT

Asset management is a strategic approach that identifies the best allocation of resources for the management, operation and enhancement of the highway infrastructure to meet the current and future needs of the customers (Road Liaison Group, 2005). In addition, asset management is a systematic and coordinated activity which enables organisations to become sustainable by managing their performance, risk and expenditure to achieve organizational strategic plans (IAM, 2008). The integration of asset management principles increases organisational performance, especially in the area of product and service delivery (Road Liaison Group, 2005; IAM, 2008)

Appropriate asset management planning is required to inform key stakeholders of the functional characteristics of these assets, and to ensure they deliver the right services, while meeting sustainability and cost effectiveness criteria (Austrods, 2009). Transportation network embodies the most expensive infrastructural assets (Elbehairy, 2007). Network includes roads, bridges, railways, waterways and air ports. Yet bridges are one asset with distinct features, which requires specific management strategies; hence, asset management for bridges (Figure 1) is developed as a separate and critical category within wider asset management planning (Austroads, 2004; IAM, 2008; Austroads, 2009; HMEP, 2013).

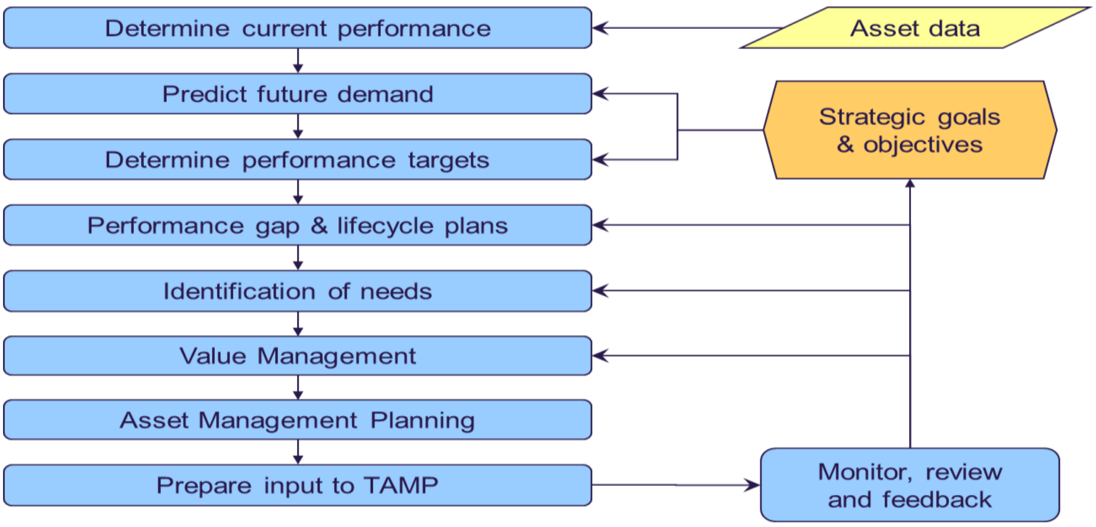

Figure 1. Asset Management for Bridges (Adapted from: Brown, 2013)

The components of asset management for bridges are indicated in Figure 1. A holistic determination of performance target and ability to predict future demands is the strategic goal and objectives of asset management for bridges.

BRIDGE MANAGEMENT FRAMEWORK

Bridge management is an aspect of the road network asset, focused on bridges (Austroads, 2009). It is the means by which a bridge network is catered for from conception to disposal (Ryall, 2001). Bridge management is the process by which agencies monitor, maintain, and repair deteriorating systems of the bridge using available resources (Elbehairy, 2007). It involves a systematic approach of carrying out work activities related to planning, design, construction, maintenance, rehabilitation and replacement of bridges (Deshmukh and Bernert, 2000).

Bridge management within the UK evolved rapidly after the completion of a 15-year national programme of assessment and strengthening, which started in 1987 and ended in 2002 (Flaig and lark, 2000; BOF, 2004). The assessment was initiated as a response to a government initiative to increase the load carrying capacity of bridges from 30tons to 40tons (Duffy, 2004; Cole, 2008). This paved the way for various guidance and design codes to emerge, which includes the Design Manual for Roads and Bridges (DMRB) developed by UK highway Agency.

BMS in the UK

Evolution of BMS in the UK started with the first generation of BMS, which used an electronic inventory as an advancement of earlier inventory sheets (Flaig and Lark, 2000; Kim, 2001). The second generation of BMS was designed to help manage bridge maintenance task, with inventory, assessment, inspection, maintenance and repair data (Fiaig and Lark, 2000 and Kim, 2001). The third generation of BMS has attributes of making decision and proposing repair and strengthening options (Kim, 2001). This stage of BMS, therefore calls for a closer look at investigating a system with attributes of aiding decision making, while considering environmental and cost implications. This is a noteworthy point, as the UK construction industry is tending towards achieving a sustainable future (Steel *et al*., 2003; Cole, 2008)

The first electronic based UK BMS was the National Structure Database (NAT) (Flaig and Lark, 2000; Gordart and Vassie, 2001; Duffy, 2004) that was introduced to replace the traditional manual system. The system was sensitive enough to store and process inventory and inspections. Systems from other countries could not be integrated into the UK NAT because they were designed to attend to the needs of the country they originated from (Flaig and Lark, 2000). Austroads (2004) mentioned that most countries have adopted the American Association Society of Highway Officers' (AASHO) code, in developing their own BMS. However, the UK is an exception, despite the fact that, Americans are leading in terms of workable BMS (Austroads, 2004; Kirk, 2008).

Another BMS developed in the United Kingdom was Bridgeman, created by Oxfordshire County council and is based on life cycle costing techniques (Cole, 2008). Steele *et al*. (2005) developed a BMS for Surrey County Council called COSMO; this was based on a Life Cycle Assessment (LCA) approach but could not aid decision-making, as it was impossible to generate sufficient data for implementation purposes. However, COSMO requires improvements to meet with the new updated Highway asset management code of practice.

Critical Review of BMS Trends (from 2000 to 2013)

Deshmukh and Bernhardt (2000) investigated the degree of uncertainties in the data collected during inventory analysis. The core of their research was to inform system users of uncertainties in the data collected during inventory stage, and how it can affect the reliability of the decisions made by BMS. Their aim was to examine uncertainties associated with condition assessment, which are quantified using mathematical and statistical principles. They added that most BMS employ a probabilistic deterioration model by using the Markovian model and several techniques to measure data uncertainties.

Deshmukh and Bernhardt (2000) used a deterioration model and reliability model to compare predicted condition with actual conditions of bridges. The result gave a correlative coefficient factor. The correlative coefficient can be used to quantify uncertainties in condition assessment data. In order to test the applicability of the correlative coefficient, they used three case studies (3-bridges) and results indicate that the level of uncertainties was very low from the coefficient of correlation obtained from these bridges. Using this methodology Deshmukh and Bernhardt (2000) demonstrated that uncertainties of data collected for inventory analysis in BMS is negligible. Therefore, most data collected at the inventory stage can be used by a BMS; this may also depend on the experience of the inspector collecting the data.

The approach employed by Deshmukh and Bernhardt (2000) was rich enough to carry out the research purpose, but an area of concern was; though three different parts of the bridges for the case studies was mentioned, there was no record about the defect that occurred at these parts, which is essential in working out uncertainties.

Flaig and Lark (2000) wanted to investigate what the users of BMS expect from the system (BMS). They mentioned that most bridge owners were not satisfied with the performance of their BMS as it is not able to meet their desired requirements. Flaig and Lark (2000) mentioned that the increase in the load-carrying capacity of a bridge from 38-ton vehicle to a 40-ton vehicle as mandated the highway authorities to engage in the use of BMS, in order to cope with the challenge. However, users of the system are not satisfied with the fundamental attributes of these systems. In order to investigate this issue - user satisfaction- surveys were sent to users to find out their views, on how the system should be improved to meet their demands. The questionnaire was designed to ask questions concerning current practice, attitudes towards BMS, preference, inspection and experience with existing systems.

Flaig and Lark (2000) were able to identify from their survey that more information is required from BMS to increase decision making potential. They revealed that BMS at this time operated on a theoretical basis rather than being practical to meet with the demands of a bridge manager; this resulted in their dissatisfaction. While Flaig and Lark (2000) were able to achieve their aims, it is possible to argue that a more accurate response could have been derived using a qualitative approach, here a semi structured interviews would be used to investigate the phenomena. This will mirror the true state of what the users actually require of their system rather than ticking boxes.

Duffy (2004) presented an idea to develop a centralized BMS. This stemmed from the increasing challenge posed to bridge managers when a bridge stock is increased and needs to be managed. Duffy (2004) mentioned that the National Roads Authority (NRA) in Ireland, are bestowed with the responsibility of maintaining all national roads. Therefore, they require a BMS to coordinate inspection and repair activities in order to manage their bridge stock. However, Duffy (2004) observed that having a BMS does not guarantee a well-managed bridge stock, as individual local authorities needed to develop their own BMS, which resulted in poor value for money and increased rate of deterioration. Duffy (2004) therefore suggested that there was a need to develop a centralize system to manage bridge stock efficiently.

In this vein, the Eisrpan – a BMS – was now developed in Ireland, which functioned on the bases of Denbro (Germany's BMS) and as a centralized system. Duffy's methodology was to identify the user problem, which was lack of a centralized system. However, Duffy did not give a background methodological approach to how the problem *"lack of centralized system"* became a cause for poor value for money and increase rate of deterioration. How this was produced (either through an interview or questionnaire survey) we are not informed. Nevertheless, Duffy's paper was able to encapsulate the need for a centralized BMS in order to improve management strategies.

Hanji and Tateishi (2007) reported on a government initiative to increase the performance of structures. This was born out of the desire to generate positive decisions about maintaining and preserving highway structures. Hanji and Tateishi (2007) mentioned that most US bridges are over 40 years old, and 40% of them are structurally incapacitated and need attention in the form of repairs, rehabilitation and replacement. To achieve these objectives the Federal Highway authorities arranged a programme called Long-Term Bridge Performance (LTBP) which was similar to Bridge Management in Europe (BRIME) (Godart and Vassie, 2001), conducted to advance the performance of structure for long-term use. Duffy pointed out that it was necessary to implement BMS if the initiative objectives were to be met.

Therefore, for both LTBP and BRIME, the aim was to introduce a BMS that serves as a catalyst for achieving the aims and objectives (enhancing decision-making regarding maintenance and preservation of bridge structure). This is, however, to emphasise the increasing need of a BMS in order to enhance bridge management performance. The question is;- should we focus on continuous development of new BMS or focus on evolving the existing BMS to improve performance of structure.

Hallberg and Racutanu (2007) reported on how the Swedish Road Administration (SRA) has developed their own BMS called Based Bridge and Tunnel Management System (BaTMan), used for operational, tactical and strategic management. They mentioned that, unlike other BMS, BaTMan falls short of Maintenance, Repair and Rehabilitation (MR&R) options within its operation resulting into capital loss. They claimed that existing systems are not predictive in terms of identifying environmental dilapidation of structural elements and materials.

However, a system that operates on predictive bases has now been developed called Life Cycle Management System (LMS). The LMS is partly based on Life Cycle assessment (LCA), Life Cycle Cost, Ecology etc. The idea of integrating a LCA to evaluate environmental options was innovative; however, questions regarding implementation became another concern for experts in this field. Similar to Duffy (2004), Hallberg and Racutanu (2007) also identified the need to have a BMS, but their focus was on its functional characteristics.

Shim and Hearn (2007) wanted to improve the functionality of BMS. This stems from the fact researchers have now started to see the need to improve the existing system functionalities rather developing new ones. Improving the system functionalities can enhance the generation of information. Shim and Hearn hope to improve the output of BMS by proposing a Non-Destructive test (NDE) in the system. They confirmed that the NDE test is a tool for carrying out integrity test which can be categorized into four stages – element protection test, vulnerability test, attack test and damage test – which can be integrated into a BMS. They added that NDE is used for bridge tests and BMS provides information concerning the state of bridges; hence, NDE could be embedded into a BMS.

The argument here is that-; though NDE is known to be a field test arrangement, how will this sit within a BMS framework. Again a clear justification for opting for NDE needs to be informed, as we cannot verify this option based on the categorical principles of NDE alone. We are told that NDE is categorised into four stages, how these stages will be synthesised with BMS was not clearly informed in the methodology. This paves way to questioning the validity of combining NDE test and BMS.

Lee *et al*. (2008) reports on the need for a comprehensive BMS that has the functionality of using historical data to predict future performance. Hitherto, there were no BMS with such attributes. Lee *et al*. (2008) highlighted that predictions for future structural performance could not be effectively determined in the absence of usable data from bridge’s elemental historical condition. Moreover, future structural performance can only be delivered, when access to historical information is available.

Hence, all the future prediction previously made using a deterioration modelling technique is inaccurate. Lee *et al*. (2000) mentioned that there are several prediction techniques already in use (such as regression, Markov models, Bayesian method, fuzzy technique, Genetic Algorithm, Case Based and Artificial Neutral Network [ANN]) but they do not have access to historical bridge condition during analysis. To bridge this short falls, Lee *et al*. proposed ANN-Based Backward Predictions Model (BPM), which improves the accuracy of future condition rating by providing historical bridge condition data. Thus, the functionality of the BMS is now improved.

Tarighat and Miyamoto (2009) proposed a Fuzzy inference system in a BMS. This was conceived to improve the area of uncertainties during data collection. Though Deshmukh and Bernhardt (2000) informed that uncertainties during data collection are negligible; Tarighat and Miyamoto (2009) are of the opinion that uncertainty and impression play a great role during practical bridge inspection. This stems from the fact that, most inspections are visually based hence subjective and uncertain. Therefore in order to bridge this shortfall the fuzzy inference was introduced. According to Tarighat and Maiyamoto (2009), the fuzzy rating system can enhance better decision-making by dealing with imprecise, imperfect and uncertainties of data collected.

The Fuzzy inference is a Non-Destructive Test (NDT) oriented system, which agrees with Shim and Hearn (2007) on the need for BMS to employ NDE characteristics. Tarighat and Miyamoto (2009) and; Deshmukh and Bernhardt (2000) have employed different research strategies to validate their point, although their findings contradicted. A consensus could be reached if a holistic methodology was employed to investigate the type of uncertainties available and if they are quantifiable. This would help evaluate the need to focus on a type of uncertainty.

Akgul (2013) developed a BMS that incorporates a visual and Non –Destructive Test (NDT) based inspection into a BMS. This was conceived as part of the initiative for improving the current state of BMS. Akgul mentioned that, a project was undertaken in Turkey to integrate element condition and condition-rating models into existing BMS, and in order to implement this, it was necessary to merge visual and NDT based inspection characteristics.

The method adopted was to explore a whole range of literature, thereby ensuring a strong theoretical background. Akgul (2013) observed how researchers in this field have improved BMS, and termed their approach 'optimization'. Findings revealed that most BMS comprised prioritisation or ranking capability only, and that there is a need for improvement in the area of optimisation of maintenance and repair actions. This suggests that the quest to improve BMS functionalities is a way of optimizing its outputs in order to increase the level of performance. Akgul's (2013) theoretical approach was clear and convincingly presented.

Hong *et al*. (2013) argued that; BMS should adopt a preventive – proactive – approach rather than examining the rate of deterioration alone. They observed that most BMS operated on the basis of the rate of deterioration; this suggests that structures must deteriorate before a maintenance method is proposed. To bridge this gap, Hong *et al*. (2013) initiated a system that can inform bridge managers of the element that may deteriorate next, which therefore aids proactive decisions to be made regarding the structural element.

Preventative maintenance can be achieved by predicting the deterioration of structural elements and development of a maintenance plan. Hong *et al*. (2013) mentioned that, the rate of deterioration of an element has been extensively examined by researchers in this field. But the ability to take proactive measure is yet to be explored. Hong *et al*. reported that a preventative approach in BMS could be examined using three factors namely; condition assessment, deterioration prediction and intelligence maintenance. Central to Hong *et al*.'s (2013) argument was the need for an improvement in BMS, but this improvement should employ a proactive measure to enhance system efficiency. Although Hong *et al*. (2013) presented an exceptional idea, but an area of concern is that, the system will be forced to accommodate and process several data, which may lead to inaccuracy.

DISCUSSION

The above literature draws attention to the state-of-the-art of BMS, paving way for a conceptual framework to emerge. Three conclusions are derived from the synopsis, which are;

- BMS has evolved and continues to evolve to allow further improvement.
- BMS have strictly concentrated on the maintenance aspect of Bridge Management and Asset Management, in respect to decision making and funding options.
- Specific features of BMS have improved without observing the actual need of users.

The review has flagged users' satisfaction and system functionality as a dominant theme. Now a major concern is user satisfaction of the current attribute of these systems, now that so many functionalities have been integrated. Conversely, the construction industry is at the fore front of achieving sustainability, thereby taking into cognisance every activity within the sector. An approach of making BMS respond to sustainable issues is therefore proposed. Hence, BMS should include mechanism for integrating sustainability, in response to this situation. Moreover, uncertainties over future demand and climate conditions and implications of bridge management on the environment are more important issues to be considered than uncertainties over probabilistic failure mode.

Since BMS helps to prioritize maintenance activities, it is logical to embed a LCA assessment approach into a BMS. LCA provides cradle-to-grave environmental implication of construction activities (Ortiz *et al*., 2009), therefore BMS would have the propensity to provide information on the best possible maintenance techniques with reduced environmental impact.

CONCLUSIONS

The purpose of this study was to explore the state-of-the-art of BMS to enable the future development of a framework for BMS in the UK. Components and attributes of Bridge management and Asset management have been interrogated to pave the way for BMS (a tool for BM and AM) to emerge. Stemming from a critical review, it is concluded that incremental improvements in various BMS models do not consider sustainable options, which will allow effective decisions to be made with regards to bridge management activities. Therefore, systems should start considering sustainability optimization criteria, in order to enhance effective decision making and extend the longevity of infrastructure.

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