DVANAESTO MEĐUNARODNO NAUČNO – STRUČNO SAVETOVANJE

OCENA STANJA, ODRŽAVANJE I SANACIJA GRAĐEVINSKIH OBJEKATA

Pregledni rad

Radomir Folić[1], Boris Folić[2] i Miloš Čokić[3]

WHY THE MAJORITY OF COUNTRIES USE BRIDGE MANAGEMENT SYSTEMS?

Summary: *The Bridge Management System (BMS) includes a systematic approach to the organized monitoring of the condition of bridges, especially the registration of defects and damage, and the performance of all activities related to maintenance and rehabilitation during the operation of bridges. In doing so, the owner of the bridges is provided with documentation to make adequate decisions on focusing the budget on individual bridges or the network of bridges according to priority. This paper analyzes some management systems abroad with a brief historical background. Until the 80's of the previous century there was an active work on the introduction of BMS in Serbia, however since 2010 there has been a pause in the development and implementation of BMS. This situation should be overcome as soon as possible because of the general benefits of well-established and implemented BMSs for the road network and traffic improvement.*

Key words: *Bridge management systems, concrete bridges, bridge inspection, condition assessment, guidelines, bridge rating, service life*

ZAŠTO VEĆINA DRŽAVA KORISTI SISTEM UPRAVLJANJA MOSTOVIMA?

Rezime: *Sistem za upravljanje mostovima (BMS) obuhvata sistematizovan pristup organizovanog praćenja stanja mostova, naročito registracija defekata i oštećenja, i obavljanja svih aktivnosti vezanih za održavanje i rehabilitacije tokom eksploatacije mostova. Pri tome se vlasniku mostova obezbeđuje dokumentacija da donosi adekvatne odluke o usmeravanju budžeta na pojedine mostove ili mrežu mostova prema prioritetu. U ovom radu su analizirani neki sistemi upravljanja u inostranstvu uz sažet prikaz istorijata. U Srbiji je i pored aktivnog rada na uvođenju BMS-a, sve do osamdesetih godina prošlog stoleća, a od 2010. godine nastao je zastoj u razvoju i primeni BMS-a. To stanje bi se moralo što pre prevazići zbog opšte koristi koju dobro postavljen i primenjen BMS donosi putnoj mreži i unapređenju saobraćaja.*

Ključne reči: *Sistem za upravljanje mostovima, betonski mostovi, pregledi mostova, procena stanja, smernice, rejting mosta, životni vek*

[1] Professor Emeritus, University of Novi Sad, Faculty of Technical Sciences, r.folic@gmail.com; folic@uns.ac.rs

[2] PhD, research associate, University of Belgrade, Innovation Centre, Faculty of Mechanical Engineering

[3] PhD, structural engineer, Termoenergo inženjering, Beograd

1. **INTRODUCTION**

On October 18th, 2019, the journal Izgradnja (Construction) organized a scientific-professional conference primarily devoted to the bridge management (hereinafter BMS). The cause for choosing this topic was the collapse of the Morandi Bridge in Italy. Two extensive works by M. Pržulj and [6] were dedicated to the Bridge Management System. Due to the topicality of the BMS problem, an abbreviated and modified version of the mentioned paper was published [7], and the significantly expanded and modified text [8] was published in journals in 2020.

Unfortunately, Serbia has been noticeably passive in this field in recent years although it is among the first countries (initially within the SFRY), and later independently, which actively
worked on the development and implementation of the BMS. Two institutions, Institut za puteve
(the Institute for Roads) from Belgrade and the PE Putevi Srbija ("Roads of Serbia"), previously worked on the development and implementation of the BMS. There was a prominent work, especially until 1997, of a group of experts, led by the late Dragan Bebić, who developed and applied the methodology. After this period there is a lull in the activities. However, in 2009, the Public Company "Roads of Serbia" published a translation of the book, Manual for the Review of Bridges, from Swedish. This valuable publication provides a systematic approach to the organized monitoring of the condition of bridges and the performance of all activities related to maintenance and interventions during operation. This ensures that the bridge owner can make adequate decisions on focusing the budget on individual bridges or the network of bridges. It is important to mention that Sweden was one of the first countries to introduce BMS, back in 1940.

In the book it is emphasized: „The inspection system of the Swedish National Road Administration specifies stringent requirements for the competence of the inspectors, the inspection procedure and the necessary equipment. The aim of this inspection manual is to train inspection personnel and to develop their competence in order that the quality requirements regarding bridge inspections should be satisfied. The manual describes the way inspections should be satisfied. The manual describes the way inspections ads and entity should be performed and provides guidance in this respect."

The opportunity to organize the education of our staff was missed. As an attempt to introduce the foreign experience to the national practice, the mentioned institutions organized a Seminar on 11th April 2010m in the form of a lecture delivered by the French: „ADVITAM"- Regular inspection manual-Setup of a computerized BMS – SER0854-DOC 014 rev B, but there is a pause in activities after that related to BMS.

One of the primary goals of this paper is to encourage the PE "Roads of Serbia"; and the Institute for Roads to continue their work on the development of BMS and its application in practice, which would increase the durability of bridge structures and improve traffic, bringing about techno-economic benefits. It is a relief that there is already a rich material that can facilitate the development of modern BMS in our country.

This paper presents some analyses of the documents related to BMS in Serbia and other countries. The basic components of a BMS are illustrated in Figure 1. The architecture of typical BMS consists of a database, condition and structural assessment modules, a determination prediction module, a lifecycle cost module, and a maintenance optimization module. The database stores inventory and appraisal data. The condition assessment module estimates the future condition of bridge components. The optimization module determines the most cost-effective maintenance strategies. Visual inspection is the default bridge inspectors, primarily qualitative and subjective results [15].

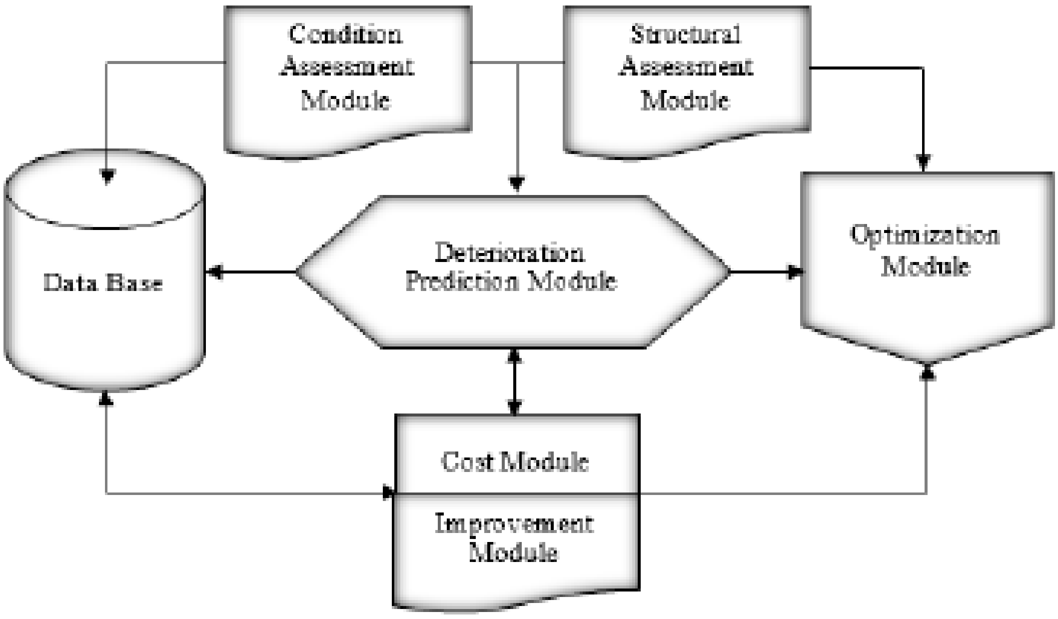

Figure 1. Basic components of a BMS, after [15]

2. HISTORY OF BMS

The development of BMS is related to the reports of catastrophic collapses such as the famous Silver Bridge on December 15th, 1967 with 46 fatalities. This prompted the Federal Agency FHWA to establish the National Bridge Inspection Program in 1970. Sweden has the longest experience with management (since 1940), contributing to reduced allocation for maintenance, as a fraction of the value of construction. A comparative overview of the BMS of several European countries, including Serbia and countries from Regions is presented in Table 1 according to [17]. Review of published paper in Serbia is subject of the paper [15]

Country	Year of BMS starting	Prioritization in BMS	Numb. Of bridge managed in BMS	Used system/software
Bulgaria	From 2004/5	No	1312	Scan print-Freissinet
Croatia	Developed now	Yes	800 on motorways	Oracie 10.G
Czech Republic	2002	Yes	18740	IIS database+MS SQL Server
England	2001	Yes	8600	Oracle
Estonia	2001	Yes	922	Pontis
France	1999	Not yet	9000	Own system
Germany	2000/2001	Yes	38000	SIB-Bauwerke; BMS-Optimisation-tools
Hungary	1996	Yes	6000	Own system
Italy	1986	Yes	3626	Oracle, SQL server
Latvia	2002	Yes	1775	LatBruts
Serbia	1985	Yes	3500	BPM

Table 1 BMS in European country, after [17]

The table contains data on the beginning of the introduction of BMS. This occurred in Serbia in 1985. A system of prioritization was introduced in Serbia until 2009. The number of bridges included in BMS in Serbia is 3500. Although the implementation of BMS started relatively early in Serbia, a unified system has not yet been constituted. The following types of inspections are performed: Control inspections; regular inspections; detailed inspections; special inspections, and extraordinary inspections. In Serbia has been active work on the introduction of BMS, with IT aspects of the database since 2001 (Đ. Uzelac). The Road Information System (ISP) contained a database (BP) on bridges and a BP on traffic. The BMS was created at the Roads Institute, after the model of the bridge management system in the USA and the Organization of Economics Cooperation and Development (OECD) by the late D. Bebić.

3. BRIDGE CONDITION ASSESSMENT

Guidelines for assessment of existing bridges, in many countries, starting with a preliminary evaluation, following by a detailed investigation and advanced assessment [1], [4]. BMS should contain the following [9]: Registration and description structures and their actual condition; Bridge assessment in terms of traffic safety, durability and maintenability; Predict future behaviour (model for deterioration); Strategy for maintenance works or replacement of bridges. According to the real condition of bridges, the budget must be allocated to the various structures. Information management systems (MISs) require periodic upgrades. *Deterioration Models* can be based on statistical (stochastic) or physical (phenomenological) interpretation of the data. Statistical and physical considerations are often combined deterministically. The Markov chain model is chosen as the forecasting tool of BMS packages deterministically [10] and [11]. Fixed values are no longer assigned deterministically to the physical properties but are modelled as probability distributions.

Maintenance is evaluated according to the following three types of standards [20]:

- 1. Quality standards, describing the results to be achieved;
- 2. Quantity standards, identifying the amount of work and resources necessary to meet the quality standard or a predetermined *level of service;*
- 3. Performance standards, describing a general method of performing a task, the resources required, and the rate at which the work should be performed.

The ACI 345 guide [6] provides satisfactory performance and remains in service for many years. Neglecting or delaying bridge maintenance may result in a reduced service life and increased costs due to repair, rehabilitation, or replacement at an early age. Based on the periodical or special inspections, damage is systematized in five classes [11]:

1. Severe damage requiring urgent repairs.
2. Damage requiring repairs in near future.
3. Slight – initial damage which should be registered and monitored.
4. Light damage which does not require monitoring. Similar correlation contents table 2 and 3.

Condition	Description
1. Good	No problems in bridges functions
2. Preventive maintenance	No problems in bridges functions but preventive maintenance required
3. Early action	Possibility of problems in bridges functions, need for early actions
4. Emergency actions	Possibility of problems or existing problems in bridges functions, need for emergency action

Table 2. Bridge soundness (MLIT, 2014) Japan [13]

Rating	**Description**
9	Excellent conditions.
8	Very good conditions. No problems noted.
7	Good conditions problems noted. Some minor problems.
6	Satisfactory conditions. Structural elements show some minor deterioration.
5	Fair foundation. All primary structural elements are sound but may have minor section loss, cracking, spalling, or scour.
4	Critical conditions. Loos of sections loos, deterioration spalling, or scour.
3	Serious conditions. Loos of sections and/or deterioration of primary structural elements. Fatigue cracks in steel or shear cracks in concrete may be present.
2	Critical conditions. Advanced deterioration of primary structural elements. Fatigue cracks in steel shear cracks in concrete may be present or scour may have removed substructure support. Unless monitored, it may be necessary to close the bridge until corrective action is taken.
1	"Imminent" failure Failed conditions. Major deterioration or section loss present in critical structural components or obvious vertical or horizontal movement affecting structural stability. Bridge is closed to traffic but corrective action may put it back in light service.
0	Failed conditions. Out of service and beyond corrective action

Table 3. NBI Condition ratings FHWA [8]

4. MAINTENANCE OF CONCRETE BRIDGES

Maintenance means to ensure that the bridge receives and safely supports a certain traffic load across the obstacle with certainty during the operational period. Maintenance of bridges in terms of repairs, strengthening, or replacement of individual elements in the building, is performed in accordance with the plans and programs.

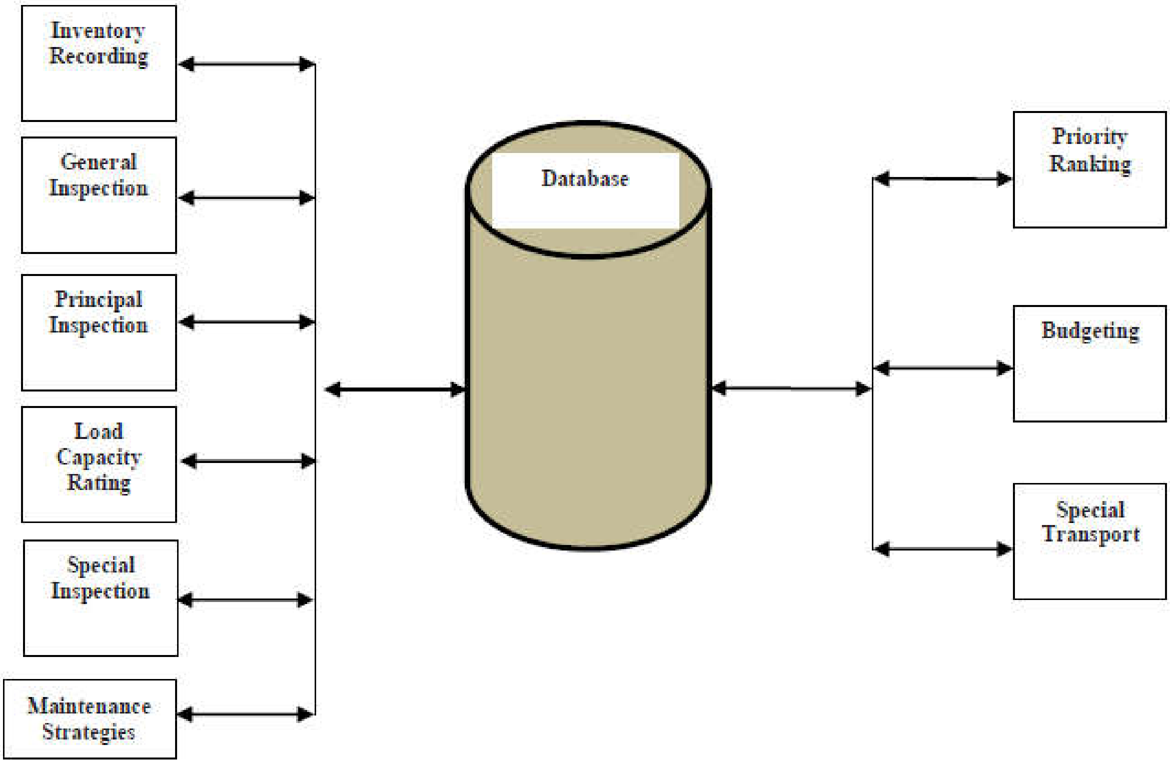

Figure 2. Overview of the COWI-BMS modules, after [7] and [9]

Maintenance Works are carried out at regular intervals as permanent activity and include minor activities such as [4] and [8]:

- Cleaning of the drainage system, expansion joints;
- Repair of impact damage to bridge parapets/safety barriers;
- Sweeping of carriageway and pedestrian pathways;
- Cutting of vegetation growth on Revetments/Embankments adjacent to the bridge and removing driftwood from the upstream side of pillars;
- Repair of concrete surfaces and protective layers of concrete;
- Maintenance of bearings;
- Protection of reinforcement from corrosion.

Capital maintenance requires more resources and includes replacement of degraded parts of the bridge or repair of major damage. This entails utilization of special technical equipment and appropriate preparation for works execution. The following works are executed:

- Replacement of bearings;
- Replacement of expansion joints;
- Replacement of large parts of the railing or entire railing;
- Renovation of the bridge insulation, and Major structural repairs.

Flow chart for process of bridge inspections and planning maintenance give in Fig. 3.

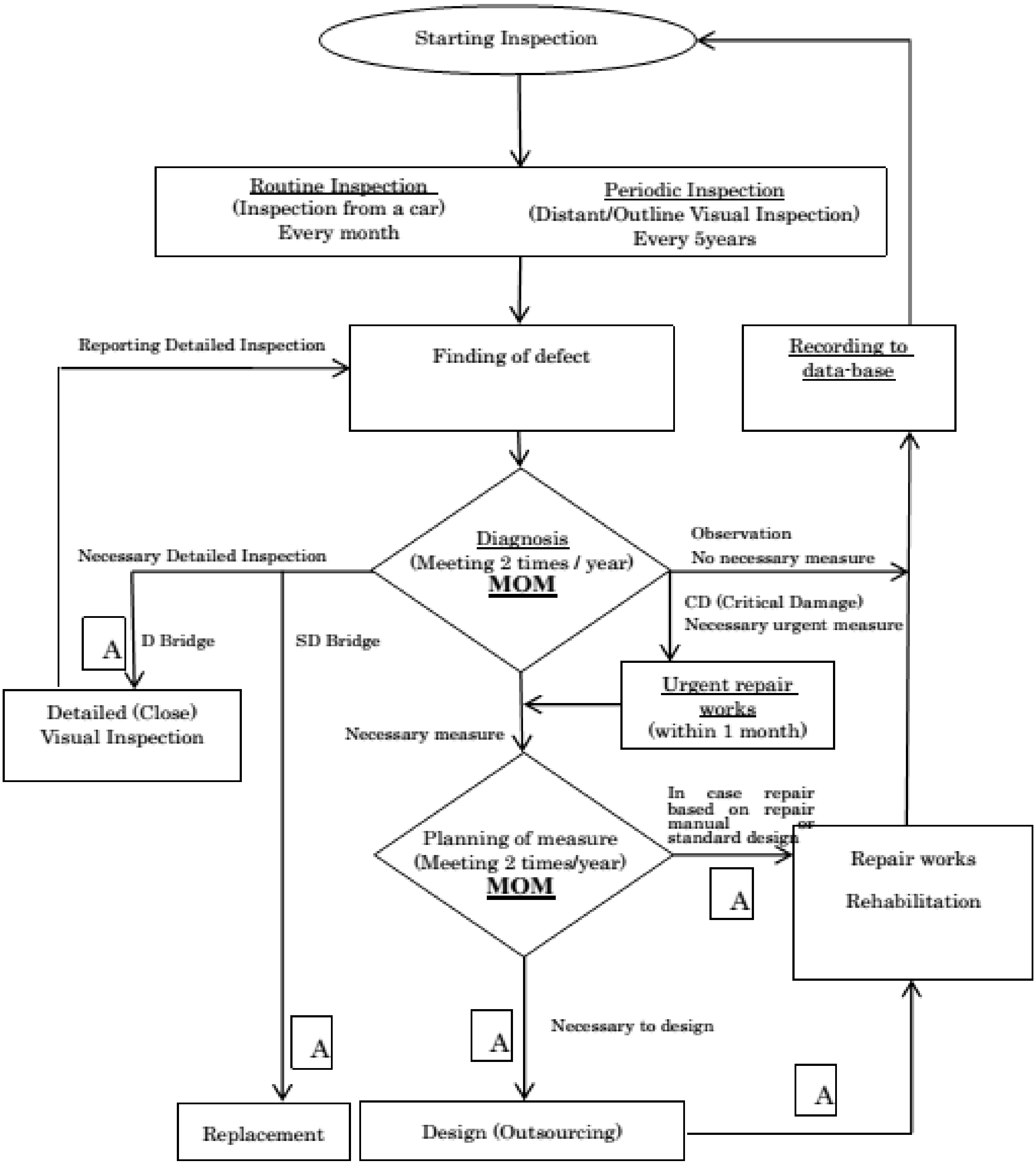

Figure 3. Process of bridge inspections and planning for maintenance, after [11]

It is very important for maintenance, repair, renovation, rehabilitation (In NCHRP Synthesis 327 and AASHTO *Maintenance Manual* definitions can be found) to determinate residual service life (Figure 4).

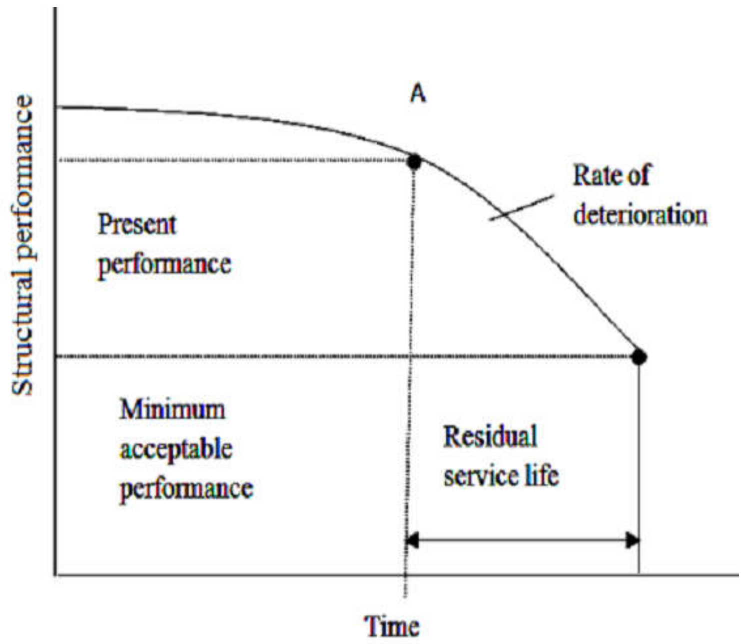

Figure 4. Determination of the remaining service life, according to [Verma] cited in [8] (first columns hither: actual performance – upper, minimum acceptable performance, lower right remaining service life)

Visual inspection is the default bridge inspection methodology. Systematic and regular inspection of bridges is essential to ensure that the demands of road users regarding safety and traffic-ability are satisfied. Action consist of inspection, identification of defect cause, deterioration prediction, performance evaluation, determination of necessary of repair, work implementation and record maintenance to ensure structural performance throughout the required service.

For increasing durability of concrete bridges it is recommended to design and build integral bridges, without expansion joints, and using an integral approach, comprising the complete life cycle.

5. ROLE OF BMS

BMS includes regulations, standards, normative documents and all technical and organizational measures related to the traffic and other aspects of management. In order to implement this approach a user should possess a high quality information system, i.e. computer database on the operation and maintenance of the system, and networks. Real processes, human resources, technology and financing are all important for realization. Computer system - central database:

- Data base on the bridges in the network;
- Organization of work and financing, network and maintenance system management – organization and regulations;
- Technical aspect-financial and organizational aspects;
- Relation Condition-Budget-Interventions. Timeline and dynamics.

Very often, mentioned Guidelines, recommended by AASHTO (Figure 5), are used for illustration contents, and are in active use in many countries, in which modern BMS have been developed. In Figure 5 BMS which contains available data is shown: bridge inventory and "tools" which, the application of adequate models, define the strategy of maintenance, repair and rehabilitation, and determine appropriate financial needs [8].

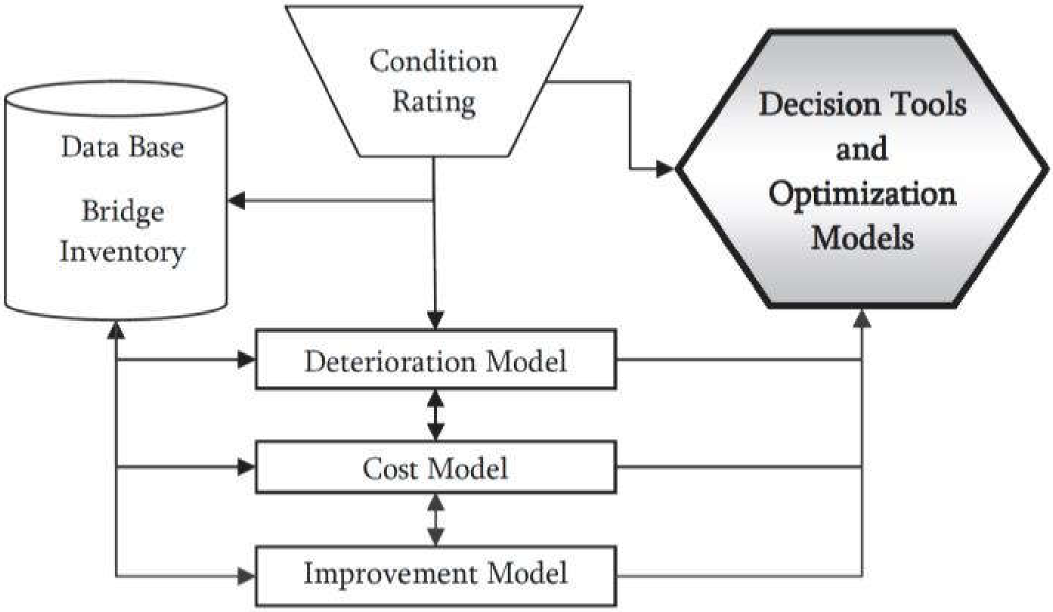

Figure 5. AASHTO Guidelines for Bridge Management System

The structure of BMS is based on condition rating and Bridge Database (BD), Deterioration model (DM), Cost Model for evaluation of costs and Optimization Model for choosing the most rational maintenance strategy. Relationship between bridge condition rating and rate of bridge deterioration with maintenance costs within BMS is very important. Predictions of bridge deterioration based on statistical analysis of large number of data regarding the condition of existing bridges.

Modern BMS have the following modules: 1) Database/Inventory; 2) Inspection; 3) Maintenance; 4) Life Cycle Cost; 5) Prediction model (Deterioration and remain service life for existing bridges). Most difficulties occur while developing deterioration models because transportation agencies have no reliable data about defects and rates of aging and damage. The modern BMS should include life-cycle models, tools for quality management, and cost-benefit optimization models related to bridges, which would help decision-making institutions that manage traffic and bridges. BMS has become easily accessible to inspectors and decision makers thanks to advances in information technology [12],

5. CONCLUSION

The goal of structural management (SM) is to maintain a certain degree of reliability during service life, while optimizing maintenance costs. Determining the load-bearing capacity of bridges is also important for determining priorities (ratings), so this part and here is partially presented using a deterministic approach, following the example of that used in the United States describe in [6].

Assessment of the load bearing capacity and general condition of the structures, as well as assessment of the conditions of use within the changed environmental conditions are of high importance.

The control of crossing of extraordinary, i.e. outsized loads across the bridge and inspection after this case is very important.

However, management is based on economic analysis and ranked by priorities, because it is necessary to use the available funds in the most efficient way, since the budget in all countries is limited. The concept of structural management requires that minimal investments in behaviour monitoring and repair ensure an uninterrupted use of the structure in a certain time interval. When considering maintenance strategies there are two extreme positions: to carry out maintenance as soon as inspections identify the need, and to carry out maintenance only on safety grounds. The first requires more frequent repairs and traffic congestion, and the second requires balancing costs due to the shorter bridge life in order to avoid higher maintenance costs [8].

The existing BMS and following the example of some of the European countries, would contribute to more economical management of bridges. Also, it is recommended to introduce a contemporary method of monitoring the condition of the elements and bridges - Structural Health Monitoring (SHM).

After the analysis in this paper and in previous papers [6], [7] and [8] we can recommend that Serbia, with certain modifications of the existing BMS and following the example of some of the European countries, should contribute to the more economical management of bridges. Also, it is recommended to introduce a contemporary method of monitoring of the condition of the elements and bridges - Structural Health Monitoring (SHM).

It should be borne in mind that:

- Regular monitoring of the condition of bridge components in the BMS enables timely interventions, which ensures greater durability and service-ability of bridges. This is achieved by optimizing maintenance costs;
- The proposed BMS should include life-cycle models, tools for quality management, and cost-benefit optimization models related to bridges, which would help decision-making institutions that manage traffic and bridges. BMS has become easily accessible to inspectors and decision makers thanks to advances in information technology [12],

- Science advances by deterministic and probabilistic reasoning and bridge management should take full advantage of both, in a balance suitable for the specific needs of every location;

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