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REVIEW PAPER

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BRIDGE MANAGEMENT SYSTEMS: AN OVERVIEW AND COMPARISON

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ABSTRACT

Bridges are one of the key elements of the transportation infrastructure of each country, and the reliability of the entire transportation network depends on their functioning. Maintaining bridges in proper technical condition is the main task of bridge management, for which more and more countries use bridge management systems (BMS). This study is devoted to comparing different BMS, reviewing the main functions and modules and determining the perspectives of development and implementation of the latest technologies in BMS. The analysed bridge management systems were compared by functions such as storage of bridge passport data, initial information on the bridge condition, assessment of the bridge condition, forecasting of the bridge condition and consideration of different maintenance strategies. Some systems are distinguished by the fact that they can predict future bridge condition, offer optimal maintenance strategies and take into account losses not only for the operation of structures, but also for transportation. Prospects for the development of BMS were also identified: the use of neural networks, the introduction of building information modelling (BIM) and the Internet of Things (IoT).

Keywords: bridge management systems, management, bridge, comparison

INTRODUCTION

Bridges are recognised as one of the key elements of road and rail infrastructure, and the efficiency of the entire transportation network system depends on their technical condition. The dynamics of increasing the number of bridges per year by about 1% of the total number of existing bridges indicates constant growth in the need for their maintenance and diagnostics (Bień & Salamak, 2022).

Bridge management systems (BMS) are used in many countries to ensure the operational readiness of bridges. A BMS includes a register of all bridges and is a database formed based on information collected during regular inspections and maintenance. Such a toolkit allows stakeholders to obtain complete information on the condition of bridge facilities under their control and make informed decisions on maintenance and operation (Ryall, 2010).

Bridge management covers all stages of the bridge life cycle – from design to reconstruction – and is focused on ensuring safe and efficient operation.

Developed countries such as the United States, Switzerland, Sweden, Norway, Finland (Mirzaei, Adey, Klatter & Thompson, 2014), China (Wan et al., 2019) and others have successfully used bridge management

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systems for many decades. While developing countries have primarily focused on the construction of new bridges, the use of BMS in them has only been introduced in the last decade (Bodnar, Panibratets, Zavhorodniy & Borysenko, 2018; Joshi, 2023).

BACKGROUND

Ryall (2010) defines six stages of the bridge life cycle, divided into two main groups: preventive management and regular maintenance and repair. Figure 1 shows the distribution of bridge life cycle stages.

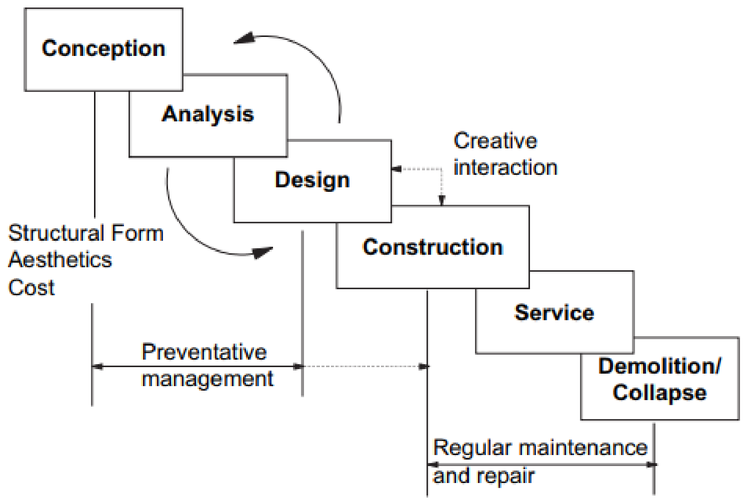

Fig. 1. Stages of the bridge life cycle

Source: Ryall (2010).

Most bridge management activities begin after a bridge is put into operation. The first stage involves collecting data about the bridge after the construction process is completed. The next stage adds information from regular inspections, maintenance and repairs. Parameters such as bridge materials, current and previous conditions, rate of deterioration, traffic volume location and conditions of the structure are used to estimate the projected real-life service life and load capacity, as well as prioritise financial resources for maintenance and repair.

Every year, the cost of maintaining the operational condition of each bridge and the entire bridge complex increases. Given the limited budgetary resources, the responsible services must prioritise bridge maintenance and inspection. For this purpose, bridge management systems are used, which provide a complete set of information on each facility and, in some cases, allow for the prioritisation and forecasting of bridge conditions in the short and long term.

It is important to note that the objective of a bridge management system is not to keep bridges in the best possible condition, but to prevent significant deterioration – which can lead to high maintenance costs. In the long term, it is best to maintain bridges in "average" condition from year to year at the lowest cost (Söderqvist & Veijola, 1998).

RESULTS

Implementation of bridge management systems in the world

Bridge management systems are key in ensuring that bridges are effectively maintained and scheduled for necessary maintenance and inspections. However, for a long period, the implementation of such systems was limited, relying instead on paper-based data and, in most cases, the absence of any accounting and management system. Maintenance was performed only after significant damage or destruction of the structure.

The first bridge management system was developed in the United States. In 1968, the Federal Highway Administration created the National Bridge Inspection Group, which developed a prototype bridge management system – the National Bridge NBI (Wan et al., 2019). Other countries later created their own BMS based on these existing developments.

Sweden has the most experience in bridge management, having started a comprehensive approach to bridge maintenance in 1944. Many of the surveys conducted in Sweden are stored in various archives (Racutanu, 1999). However, the actual implementation of bridge management systems in the modern sense started later.

In many cases, the creation of bridge management systems was triggered by the destruction of one or more bridges to avoid sudden and unpredictable accidents on these structures in the future. A series of bridge failures in the 1960s in the United States drew public attention to the problem of bridge conditions and prompted the Federal Government to develop a unified bridge inspection procedure that eventually evolved into the PONTIS bridge management system (Thompson, Small, Johnson & Marshall, 1998).

Another important reason for the introduction of bridge management systems is the accumulation of many bridges with limited information about their condition, which has led to the fact that maintaining existing bridges has become more expensive than building new ones (Miyamoto, Kawamura & Nakamura, 2000).

Many countries began implementing bridge management systems in the late 20th century, and this process continues to this day. Every year, the number of countries developing their own systems or using the experience of other countries increases. Figure 2 shows the launch years of the first and current versions of bridge management systems. It can be concluded that every year, more and more countries or individual administrations implement bridge management systems that are being improved and expanded.

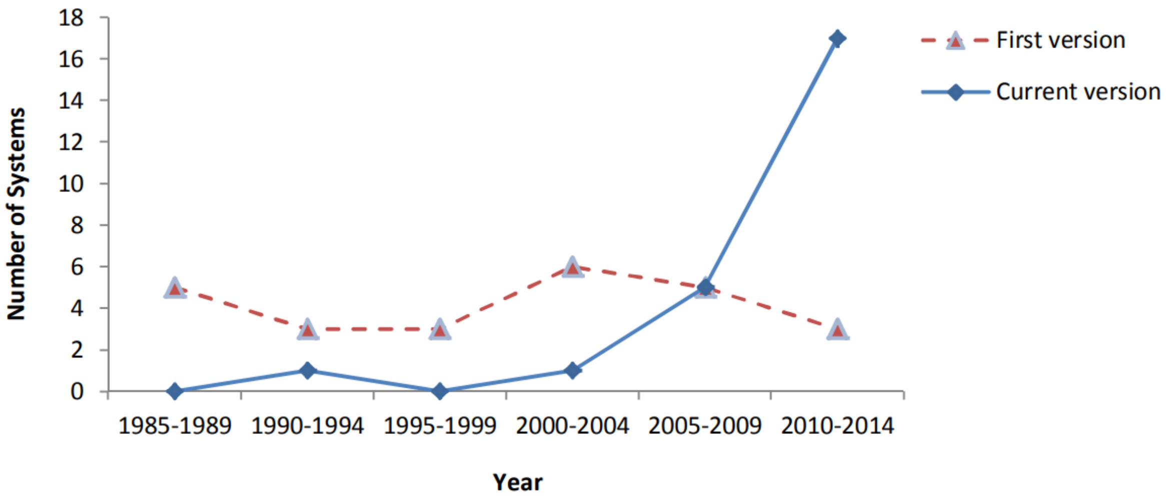

Fig. 2. Years of first and current versions

Source: Mirzaei et al. (2014).

At the same time, there are countries, such as Iran (Gholami, Sam & Yatim, 2013) and Serbia (Folić & Partov, 2020b), that are only now actively trying to implement bridge management systems to keep their bridge assets in good condition.

Structure of a modern bridge management system

The structure of modern bridge management systems is similar in most cases. Most are modular, allowing each system to include or exclude certain modules depending on specific needs. However, in all of these systems, the main module is the inventory module, based on which other modules function (Powers, Frangopol, Al-Mahaidi & Caprani, 2018).

According to Woodward et al. (2001), an effective bridge management system should include at least the following modules:

- inventory of the stock;
- knowledge of bridge and element conditions and their variation with age;
- evaluation of the risks incurred by users (including assessment of load-carrying capacity);
- management of operational restrictions and the routing of exceptional convoys;
- evaluation of the costs of the various maintenance strategies;
- forecast the deterioration of conditions and the costs of various maintenance strategies;
- socio-economic importance of the bridge (evaluation of indirect costs);
- optimisation under budgetary constraints;
- establishment of maintenance priorities;
- budgetary monitoring on a short- and long-term basis.

At the same time, according to a study by Ryall (2010), an effective bridge management system (Fig. 3) requires modules that include:

- inventory;
- inspection;
- maintenance;
- costs;
- bridge condition.

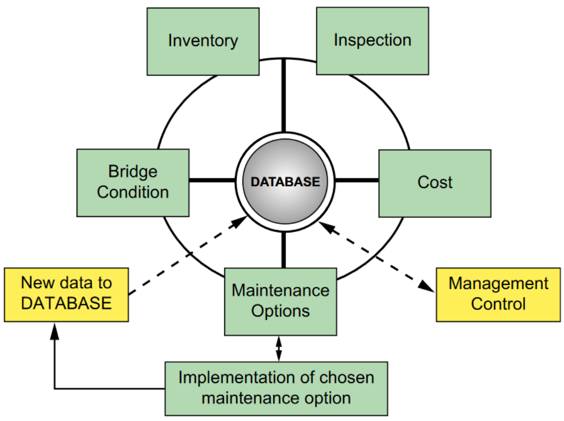

Fig. 3. A basic bridge management system

Source: Ryall (2010).

In general, bridge management systems can be categorised into three types depending on which modules they include (Dullah, Ghazali & Jausus, 2014). Type 1 is the simplest, while Type 3 is the most comprehensive representative of bridge management systems (Table 1).

Table 1. Groups of bridge management system components

Type 1	database/inventory inspection
Type 2	database/inventory inspection maintenance life-cycle cost
Type 3	database/inventory inspection maintenance life-cycle cost prediction model

Source: Dullah et al. (2014).

Comparison of modern bridge management systems

Subsequently, the bridge management systems of different countries, including the United States, Canada, China, Japan, Vietnam, Ukraine, Korea, Australia, Italy, Poland and others, were analysed (Söderqvist & Veijola, 1998; Thompson et al., 1998; Miyamoto et al., 2000; Woodward et al., 2001; Bjerrum & Jensen, 2006; Hallberg & Racutanu, 2007; Ryall, 2010; Dullah et al., 2014; Mirzaei et al., 2014; Chuang & Yau, 2017; Liao et al., 2017; Bodnar et al., 2018; Wan et al., 2019; Folić & Partov, 2020b, 2020a; Bello, Popescu, Blanksvärd & Täljsten, 2021; Joshi, 2023). In total, 34 bridge management systems were reviewed, analysed (Table 2) and compared by the following functions:
- bridge passport;
- survey data;
- inspection history;
- bridge condition assessment;
- cost of maintenance;
- transportation costs;
- forecasting the future condition of the bridge;
- maintenance planning.

Bridge condition assessment includes assessments performed directly in the bridge management system and by inspectors. Maintenance planning considers both short-term and long-term planning.

Most bridge management systems have similar functionality, and only a few systems exhibit exceptional features by not storing survey data and providing limited information about previous surveys. This can be considered an exception to the rule rather than a general standard. One of the "rarest" features is the ability to calculate transportation costs. This means that the system can calculate additional costs for road users in case of a bridge's improper condition or destruction.

The prospects for the development of bridge management systems are broad. One of the development areas is using neural networks to predict the condition of bridges, assess their condition and identify factors that affect their deterioration (Trach et al., 2022, 2023). The introduction of building information modelling

Table 2. Comparison of bridge management systems

Country	Name	Passport of the bridge	Inspection data	History of inspections	Bridge condition assessment	Maintenance costs	Transportation costs	Bridge condition forecasting		Maintenance planning
								Deterioration	Shortening	
Australia	MRWA	+	+	+	+	+	-	+	+	+
Australia	NSW	+	+	+	+	+	-	+	-	n/a
Canada	GNWT	+	+	+	+	+	+	+	+	+
Canada	OBMS	+	+	+	+	+	+	+	+	+
Canada	QBMS	n/a	+	+	+	+	+	+	+	+
Canada	eBMS	+	+	+	+	+	+	+	+	+
Canada	PEI BMS	+	+	+	+	+	+	+	+	+
China	CMBS	+	+	+	+	n/a	n/a	n/a	n/a	n/a
Denmark	DANBRO/DANBRO+	+	+	+	+	+	-	+	+	+
Finland	FBMS	+	+	+	+	+	-	+	+	+
France	OA-MeGA	+	-	-	+	-	-	+	n/a	+
Germany	GBMS	+	+	+	+	+	+	+	+	+
Germany	SIB-Bauerwerke	+	+	+	-	-	-	+	n/a	+
India	IBMS/UBMS	+	+	+	+	n/a	-	+	n/a	+
Ireland	Eirspan	+	+	+	+	+	-	-	-	+
Italy	APTBMS	+	+	+	+	+	-	+	+	+
Japan	RPIBMS	+	+	+	-	+	+	+	+	+
Korea	KRMBS	+	+	+	+	+	-	+	+	n/a
Latvia	Lat Brutus	+	+	+	+	+	-	+	+	n/a
Malaysia	JKR BMS	+	+	n/a	-	-	-	-	-	-
Netherlands	DISK	+	+	–	+	+	+	-	-	+
Norway	BRUTUS	+	+	+	+	+	+	+	+	+
Poland	SZOK	+	+	–	+	-	-	+	-	+
Poland	SMOK	+	+	+	+	+	-	+	+	+
Spain	SGP	+	+	+	+	+	+	-	-	n/a
Sweden	BaTMan	+	+	+	+	+	+	+	+	+
Sweden	Safebrow	+	-	-	+	+	+	+	n/a	+
Switzerland	KUBA	+	+	+	+	+	-	+	+	+
Taiwan	TBMS	+	+	+	+	-	-	n/a	n/a	+
Ukraine	AEBMS	+	+	n/a	+	+	-	+	-	+
UK	NATS	+	+	+	+	n/a	-	-	-	+
USA	ABIMS	+	+	+	+	+	-	-	-	+
USA	PONTIS/AASHTOWare	+	+	+	+	+	-	+	+	n/a
Vietnam	Bridgeman	n/a	+	+	+	+	-	-	-	n/a

Source: own work.

(BIM) can also improve bridge management by allowing analysis of not only the description of damage and its assessment, but also tracking its development over time and a better understanding of the cause and effect of its occurrence. However, the implementation of BIM requires significant amounts of server space due to the large size of the models and a large amount of work to digitise and model existing bridges (Wan et al., 2019).

The prospects for the development of bridge management systems are broad. One of the development areas is using neural networks to predict the condition of bridges, assess their condition, and identify factors that affect their deterioration (Trach et al., 2022, 2023). The introduction of building information modelling (BIM) can also improve bridge management by allowing analysis of not only the description of damage and its assessment, but also tracking its development over time and a better understanding of the cause and effect of its occurrence. However, the implementation of BIM requires significant amounts of server space due to the large size of the models and a large amount of work to digitise and model existing bridges (Wan et al., 2019).

Another promising direction is the use of IoT technologies, which can provide an opportunity to obtain more data on the condition of bridges in real-time while also contributing to the efficiency of bridge management systems.

CONCLUSIONS

This study examined modern bridge management systems that are used to ensure bridge safety and improve the efficiency of their maintenance. The basic functionality typical for each system was analysed, and the features of some systems that can predict future states of structures, take into account traffic losses and offer optimal maintenance strategies were highlighted. The use of such systems can improve traffic safety and reduce bridge maintenance costs. However, it should be noted that the development and implementation of such systems require significant financial and technical resources.

Potential areas of development include the integration of the latest technologies, the development of forecasting and decision-making systems using neural networks, the introduction of BIM and the use of the IoT. In general, developing and implementing new capabilities in bridge management can further improve the safety and efficiency of transport infrastructure.

Authors' contributions

Conceptualisation: R.T. and V.T.; methodology: T.W.; validation: T.W. and R.T.; formal analysis: V.T. and R.T.; investigation: V.T.; resources: V.T.; data curation: V.T.; writing – original draft preparation: V.T.; writing – review and editing: R.T. and T.W.; visualisation: V.T.; supervision: T.W. and R.T.; project administration: V.T.; funding acquisition: V.T. and T.W.

All authors have read and agreed to the published version of the manuscript.

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SYSTEMY ZARZĄDZANIA MOSTAMI: PRZEGLĄD I PORÓWNANIE

STRESZCZENIE

Mosty są jednym z kluczowych elementów infrastruktury transportowej każdego kraju i od ich funkcjonowania zależy niezawodność całej sieci transportowej. Utrzymanie mostów w należytym stanie technicznym to główne zadanie zarządzania mostami, do którego realizacji coraz więcej krajów korzysta z systemu zarządzania mostami (BMS). Niniejsze opracowanie poświęcone jest porównaniu różnych systemów BMS, przeglądowi głównych funkcji i modułów oraz określeniu perspektyw rozwoju i wdrożenia najnowszych technologii w BMS. Analizowane systemy zarządzania mostem porównano pod kątem takich funkcji, jak: przechowywanie danych paszportowych mostu, wstępna informacja o stanie mostu, ocena stanu mostu, prognozowanie stanu mostu oraz uwzględnienie różnych strategii utrzymania. Niektóre systemy wyróżniają się tym, że potrafią przewidzieć przyszły stan mostu, oferują optymalne strategie konserwacji i uwzględniają straty w eksploatacji konstrukcji. Zidentyfikowano także perspektywy rozwoju BMS: wykorzystanie sieci neuronowych, wprowadzenie modelowania informacji o budowaniu (BIM) oraz internetu rzeczy (IoT).

Słowa kluczowe: systemy zarządzania mostem, zarządzanie, most, porównanie