engineering proceedings

MDPI

Proceeding Paper

Comparative Analysis of the Approach of Different Countries to the Standards of the Bridge Structures' Condition Management System †

Anzhelika Stakhova *,‡ and Adrián Bekö ‡

Department of Structural Mechanics, Faculty of Civil Engineering, Slovak University of Technology in Bratislava, Radlinského 11, SK-810 05 Bratislava, Slovakia
* Correspondence: anzhelika.stakhova@stuba.sk
† Presented at the 4th International Electronic Conference on Applied Sciences, 27 October–10 November 2023; Available online: https://asec2023.sciforum.net/.
‡ These authors contributed equally to this work.

Abstract: The work examines the control systems of bridge structures, which are used to assess the condition, forecast repair works, and optimize costs. Bridge management is a key element of infrastructure systems in many countries, as it ensures safety, efficiency, and economic development. Examples of such systems as Pontis, Bridgit, Danbro, etc., are presented, which are used in different countries to assess the condition of bridges and plan repair works. The importance of safety and optimal operation of bridge structures is highlighted. It is highlighted that bridge management systems are necessary tools for countries with different operation and maintenance strategies. The importance of rational management of bridges to ensure safety and sustainable development of transport networks is brought to the fore.

Keywords: bridge management systems; bridge condition assessment; maintenance optimization; infrastructure safety

check for updates

Citation: Stakhova, A.; Bekö, A. Comparative Analysis of the Approach of Different Countries to the Standards of the Bridge Structures' Condition Management System. *Eng. Proc.* **2023**, *56*, 265. https://doi.org/10.3390/ASEC2023-15884

Academic Editor: Simeone Chianese

Published: 7 November 2023

1. Introduction

With the increase in traffic and the importance of ensuring the safety and efficiency of the existing transport infrastructure, bridge management systems are becoming a key element in ensuring the optimal functioning and maintenance of bridge structures. Bridge management includes a comprehensive system of condition assessment, maintenance and repair planning, risk analysis, and decision making to ensure the reliability and duration of their operation [1].

This issue has repeatedly become the object of research and development in various countries [1–3]. Each country has its own unique requirements, standards, and regulations affecting bridge control systems. However, there is active interaction and exchange of experience between countries, which allows us to improve and harmonize bridge management methodologies.

In this paper, we will consider some of the most important bridge management systems used in different countries. Emphasis will be placed on their features, condition assessment methods, operation, and maintenance strategies, as well as the use of subjective assessments and forecasting for work planning.

Understanding different bridge management systems and sharing experiences between countries is an important step in improving the safety, reliability, and durability of bridge structures. Thanks to this, it is possible to develop optimal management strategies that will take into account the specifics of each bridge structure and ensure the effective use of resources for their maintenance and repair. Already developed bridge management systems will be considered, and approaches and methods used for effective management of bridge structures will be described.

2. Materials and Methods

Due to the devastating consequences of the Ohio bridge disaster, which killed 46 people, the United States of America became the first country to establish a bridge health management system [4]. During the development of this system, standards were established that determined the technical conditions for conducting an inventory of all bridges on public roads, as well as the conditions for their inspection. The frequency of inspections should be coordinated with the periodicity of current and capital repairs. The received information was transmitted to the Federal Government for the adoption of funding priorities.

Already in 1980, the approach to the bridge management system in the USA underwent fundamental changes [4]. The system was no longer limited to recording the condition of bridges, but had a clear goal that the country's road industry had to achieve. The goal formulated during the implementation of the National Program for the period from 1981 to 1986 was based on the following strategies:

- Development of an effective management system for bridge structures at the network level (i.e., a group of bridges), which will allow for optimal use of available resources.

In the concept of the bridge management system developed by US bridge industry specialists:

- The quality of the information block;
- Historical data analysis module;
- Database module;
- Maintenance and operation module;
- A module for choosing between large-scale maintenance, repair, or maintenance at the network level;
- Level docking module;
- Reporting module.

The need to know the state of each bridge and the formalization of this state in the database is mandatory. To achieve this goal, the use of bridge condition prediction is necessary, including network-level prediction. The level docking module is used to switch to object-by-object planning.

3. Results and Discussion

The improvement of the Bridge Management System was a response to the need for a more effective mechanism for justifying and making management decisions. To achieve this goal, two integrated software projects were developed: the Pontis bridge management system [5,6] and the Bridgit system BMS [7,8]. Both systems are based on different principles; in particular, Pontis uses a bottom-up approach, while Bridgit BMS follows a "from top to bottom" approach.

The Pontis system uses various field programs as input and develops an implementation plan based on available resources. In the Bridgit system, the source of BMS is the budget, and the goal is the rational use of resources with the help of a regulatory framework. The Pontis system has become more widespread due to its flexibility and consideration of the complexity of bridge structures, which consist of many elements with their own condition. Using the Markov model, the Pontis system allows you to plan construction maintenance work. The experience of the USA shows that regular work on planned and preventive maintenance can reduce the total loss for repair or reconstruction of the bridge by four times.

Thus, work programs in the Pontis system are placed on the basis of the analysis of various strategies of bridge operation.

It is necessary to provide a bridge structure management system that has access to information about the state of each bridge and can predict its changes over time. It is important to be able to forecast on a network level and plan based on individual objects. Bridge management systems such as Pontis and Bridgit have been developed for effective management decision making and more reasonable use of resources [5,7].

The Pontis system uses a "bottom-up" approach, in which the initial data are various programs, and the system itself develops an implementation plan, taking into account the available resources. The Bridgit system uses the budget as a starting point and relies on the regulatory framework to find rational ways of using resources.

The Pontis system has gained more popularity because it is more flexible and takes into account the complexity of bridge structures, which consist of many separate elements with their own operational condition. This system uses a Markov model, where about 20% of buildings change to a different state every 5 years. Long-term use of the Pontis system in the USA has yielded positive results, showing the advantage of investing in building maintenance. Studies have shown [9] that regular preventive maintenance work can reduce total losses for bridge repair or reconstruction by four times.

The work programs posted in the Pontis system are based on the analysis of various bridge operation scenarios and help ensure optimal planning.

The management system of bridge structures in Germany is based on a clear understanding of the goal and is formed by defining the target function, including decision-making rules [10]. This function includes a priority function that is compared to an optimization criterion. In the hierarchy of management goals, the main goal "Conservation of consumer values" is noted, which has three main sub-goals related to the activities of the bridge administration: control of the state of bridges, current maintenance measures, and targeted repair work.

The control of the state of bridge structures is of particular importance, since the results of the survey and reports drawn up by the organization engaged in operation are the only source for systematic and periodic assessment of the state of bridges. This is the basis for determining priority maintenance measures. "Current measures" determine the actual requirements for the maintenance of bridges, including small volumes of work aimed at preserving the integrity of the structure and individual structural elements. Measures involve the implementation of measures that prevent damage in advance and are of great importance for the preservation of bridges.

When forming the urgency of measures in the bridge management system in Germany, a point assessment of various factors is used, which can be automated and easily applied by organizations that operate bridge structures, despite the possibility of errors. Additionally, the German bridge management system recommends using the Kraft model to determine the priority indicator for bridge repair [10]. This model includes four elements of strength assessment: damage zone assessment, damage development tendency, effect on other structural elements, and effect on vehicle load capacity. This approach makes it possible to bring the bridge management system in Germany as close as possible to advanced American systems and is optimal for preserving structures.

The French approach to the Bridge Construction Management System is known as the OA-MeGA method [11], based on detailed information obtained by means of point assessment of the condition of buildings and determining the priority of repair works using the point system. This approach involves the following stages:

- Study of the object: inspection of bridge structures annually and periodic diagnostics to collect detailed information about their condition;
- Data archiving: saving the received information in the appropriate archive for further use and analysis;
- Maintenance Information Processing: analysis and evaluation of bridge maintenance data;
- Financial assessment of the state of objects: consideration of financial aspects during the assessment of the state of bridge structures;
- Budget planning: development of a budget that takes into account the costs of repair work;
- Implementation of the plan to ensure the quality of work: execution of the planned work in compliance with the established standards.

The main feature of the OA-MeGA method is the combination of economic planning with an objective assessment of the priority of repair works [11]. At the same time, the method takes into account the subjective assessment of damage, since the patterns of damage and their dynamics have not yet been fully studied. Five operational states are used in the OA-MeGA system. The point system in the bridge repair priority indicator determines the ranked number, designated as the JGG indicator, which depends on the assessment of structural damage.

The UK began the development of a new Bridge Management System in 1987, implementing the 15-year Bridge Assessment and Strengthening Programme. This program included a transition to a new bridge management concept [12]. Within the framework of this concept, two different methods of state assessment are included in the management structure: deterministic and probabilistic.

The deterministic method is used for structures with minor deviations from the standard state or in cases where the structure meets the load-bearing capacity requirements. The probabilistic method of assessing the condition of the structure is used when it is necessary to solve the question of the sequence of bridge repairs within the existing budget constraints. Both methods use five operational states and five inspection methods depending on complexity.

A similar approach to bridge management is used in Sweden [13]. Although each European country implements its own bridge management system, in recent years, there has been an influence of the American approach to defining the main principles.

In 1999, the report "Adaptation of the Pontis forecasting model to the conditions of Hungary" was held in the state of Colorado (USA) [14]. During adaptation, modernization of the Pontis system is used with the use of matrices of element transition probabilities from one state to another. The construction and analysis of such matrices is an important step before making decisions, as they allow for determining the time and costs for repairing bridge elements from minimal to optimal. The Pontis system actually represents the bridge structure as a Markov model, since it consists of a large number of elements with their own state matrices.

Such approaches to bridge management allow countries to effectively ensure the safety and preservation of bridge structures, taking into account the condition of the structures and budget constraints. Bridge management systems in Finland and Denmark are based on subjective condition assessments and forecasting [15,16]. In Denmark, for example, the Danbro bridge management system [17] is the second generation and is used not only in Denmark itself, but also in some other countries. It includes the following components:

- Application of specified rules for inspection, quality control, maintenance, repair, and preparation of the budget;
- Laws and rules for all hierarchical levels of bridge operation management;
- Availability of databases about bridges;
- Software.

The analysis of the structure of the bridge management system shows that in the chain of actions from obtaining information to the management decision is the planning of maintenance and repair of bridges based on the comparison of different operation strategies. The operation of bridge control systems is based on the following conditions:

- The calculation of the residual resource or durability is the main factor for choosing the optimal strategy for the operation of bridges;
- Real ideas about the condition of materials and structures and their changes over time. The degradation of structures is determined by an expert. An operation can be carried out in three different strategies: without repair, with early repair, and with a major repair. With reasonable planning of maintenance costs during the first 15 years of operation, a bridge structure can remain without repair for 25 years or more. Types of work for each strategy are determined depending on the level of degradation of structures and the forecast of its spread for a period of 20–25 years.

In Canada, in addition to the Pontis system, the Bridgit system is also implemented [18]. In Canada, Finland (SIHA system) [19], and the new KUBA-MS bridge management system under development in Switzerland, the already proven Pontis and Bridgit systems are used as a basis. The American Bridge Management System can assess the losses caused by the degradation of any bridge. The American, Finnish, Swedish, Danish, and English systems provide calculations and analysis of various strategies for the operation and repair of bridges. Optimization calculations are performed in the Finnish, Hungarian, French, and Danish systems, and the systems of the USA, England, and Denmark provide for long-term planning.

Along with the development of different bridge management systems, each country focuses on its own characteristics and requirements. For example, in Canada, the Bridgit system is designed to meet Canadian standards and regulations for bridge operations, such as the Canadian Bridge Maintenance Code of Practice. In Finland, the SIHA system is based on subjective assessments of the state of bridges and forecasting. It takes into account Finnish design standards and expert knowledge to assess the condition of the bridge and determine optimal operational strategies.

The KUBA-MS bridge management system, developed in Switzerland, uses the basic principles of the Pontis and Bridgit systems, but takes into account local conditions and requirements. The KUBA-MS system focuses on long-term planning and optimization calculations aimed at ensuring the effective use of resources and the preservation of bridge structures.

An important step in improving the management of risks and the monitoring of existing bridges is the Italian practice outlined in Ministerial Decree number 578, dated 17 December 2020 [20]. This document entails the adoption of principles for managing the risk of existing bridges and defines requirements and guidelines for the dynamic monitoring system.

Specifically, it involves the implementation of standards for the classification, risk management, safety assessment, and monitoring of bridges, viaducts, embankments, overpasses, and similar structures. These standards apply to assets existing along national roads or highways managed by Anas S.p.A. or highway concessionaires.

The summary of Bridge Management Systems (BMS) from different countries will be presented in Table 1.

Table 1. Bridge Management Systems (BMS) Summary.

Country	Main Features of BMS
USA	- Usage of Pontis and Bridgit systems
Germany	- Clear goal understanding and formation by defining target function with decision-making rules
France	- Utilizes OA-MeGA method for detailed condition assessment and priority determination
UK	- Implementation of 15-year Bridge Assessment and Strengthening Programme, transition to new bridge management concept, and usage of deterministic and probabilistic state assessment methods
Sweden	- Implements own bridge management system
Hungary	- Adaptation of Pontis forecasting model using transition probability matrices
Finland	- Utilizes subjective condition assessments and forecasting
Denmark	- Utilizes Danbro system for inspection, quality control, maintenance, repair, and budgeting
Canada	- Usage of Pontis and Bridgit systems
Italy	- Implementation of new risk guidelines for classification and risk management, safety assessment, and monitoring of existing bridges

4. Conclusions

Considering the influence of different bridge management systems, it can be concluded that different countries use a combination of subjective assessments of bridge condition, forecasting, calculations, and analysis of operation and maintenance strategies. These approaches help ensure the safety, reliability, and optimal use of bridge structures in each country, taking into account their unique needs and constraints.

Based on the data provided, the following conclusion can be drawn: the countries that are engaged in the development and implementation of bridge management systems are actively working to ensure the safety, reliability, and optimal use of their bridge structures. They take into account their own standards, regulations, and peculiarities, but also rely on already proven systems that have been successfully used in other countries. This reflects the constant interaction, the sharing of experience, and the efforts to implement best practices in the field of bridge management.

The use of subjective condition assessments, forecasting, calculations, and analysis of various bridge operation and repair strategies is a common approach in many bridge management systems. This allows countries to effectively plan maintenance and repair work, ensure optimal use of resources, and preserve bridge structures for long periods of time.

In general, the development of bridge management systems is an important component for ensuring the safety and stability of the transport infrastructure. Interaction and exchange of experience between countries contribute to the further development of this industry and the improvement of the management of bridge structures, both at the local and international levels.

Author Contributions: Conceptualization, A.S.; validation, A.S. and A.B.; formal analysis, A.B.; investigation, A.S. and A.B.; writing—original draft preparation, A.S. and A.B.; writing—review and editing, A.B.; visualization, A.B.; supervision, A.S.; project administration, A.S. and A.B.; funding acquisition, A.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the EU NextGenerationEU through the Recovery and Resilience Plan for Slovakia under the project No. 09I03-03-V01-00104.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: No new data were created or analyzed in this study. Data sharing is not applicable to this article.

Acknowledgments: We also gratefully acknowledge the financial support by the VEGA Grant Agency of the Slovak Republic, grant number 1/0230/22.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

BMS	Bridge Management System

References

1. Ryall, M.J. *Bridge Management*; Elsevier: Amsterdam, The Netherlands, 2001.
2. Farrar, C.R.; Worden, K. An introduction to structural health monitoring. *Philos. Trans. R. Soc. A Math. Phys. Eng. Sci.* **2007**, *365*, 303–315. [CrossRef] [PubMed]
3. Hudson, S.W.; Carmichael, R.F.; Moser, L.O.; Hudson, W.R.; Wilkes, W.J. *Bridge Management Systems*; NCHRP Report 300, Project 12-28(2); Transportation Research Board, National Research Council: Washington, DC, USA, 1987.
4. Hudson, W.R.; Carmichael III, R.F.; Uddin, W.; Wilkes, J. Annual Transportation Convention ATC and Jaarlikse Vervoerwesekonvensie JVK. In Proceedings of the Annual Transportation Convention = Jaarlikse Vervoerwesekonvensie, Csir Conference Centre, Pretoria, South Africa, 4–7 August 1986; Volume 2b.
5. Hajdin, R. Bridge Management Systems. *Struct. Eng. Int.* **1998**, *3*, 98. [CrossRef]
6. Golabi, K.; Shepard, R. Pontis: A system for maintenance optimization and improvement of US bridge networks. *Interfaces* **1997**, *27*, 71–88. [CrossRef]
7. Small, E.P.; Philbin, T.; Fraher, M.; Romack, G.P. Current status of bridge management system implementation in the United States. In Proceedings of the 8th International Bridge Management Conference, Denver, CO, USA, 26–28 April 1999; Volume 2.

8. Hawk, H. BRIDGIT: User-friendly approach to bridge management. *Transp. Res. Circ.* **1999**, *E-7*, 1–15.
9. Thompson, P.D.; Najafi, F.T.; Soares, R.O.B.E.R.T.O.; Kerr, R.I.C.H.A.R.D. Development of Pontis user cost models for Florida. In Proceedings of the Eighth International Bridge Management Conference, Transportation Research Board, Denver, CO, USA, 26–28 April 1999.
10. Szabó, L. Sustainability, creativity and innovation in project management–Model development for assessing organizational performance through projects. *Vez.-Bp. Manag. Rev.* **2016**, *47*, 3-18. [CrossRef]
11. Lefeuvre, J. OA-MéGA: Une méthode de gestion automatisée des ouvrages d'art. *Rev. Gen. Routes (RGRA)* **2000**, *785*, 67–68.
12. Rafiq, M.I. *Health Monitoring in Proactive Reliability Management of Deteriorating Concrete Bridges*; University of Surrey: Guildford, UK, 2005.
13. Roelfstra, G.; Hajdin, R.; Adey, B.; Brühwiler, E. Condition evolution in bridge management systems and corrosion-induced deterioration. *J. Bridge Eng.* **2004**, *9*, 268–277. [CrossRef]
14. Gáspár, L.; Lublóy, L. Adaptation of Pontis prediction model to Hungarian conditions. In Proceedings of the International Bridge Management Conference, Denver, CO, USA, 26–28 April 1999.
15. Kähkönen, A.; Marshall, A.R. Optimization of Bridge Maintenance Appropriations with the Help of a Management System—Development of a Bridge Management System in Finland. In *Bridge Management*; Harding, J.E., Parke, G.A.R., Ryall, M.J., Eds.; Springer: Boston, MA, USA, 1990; pp. 101–111.
16. Wang, Y.; Chen, Z.; He, Z.; Yuan, H. A brief introduction of the Danish bridge management system. *Guangdong Highw. Traffic* **1994**, *3*, 48–61.
17. Lauridsen, J.; Lassen, B. The Danish bridge management system DANBRO. In *Management of Highway Structures*; Das, P.C., Ed.; Thomas Telford Publishing: London, UK, 1999; pp. 61–70.
18. Hammad, A.W.; Yan, J.; Mostofi, B. Recent development of bridge management systems in Canada. In Proceedings of the 2007 Annual Conference and Exhibition of the Transportation Association of Canada: Transportation-An Economic Enabler (Les Transports: Un Levier Economique) Transportation Association of Canada (TAC), Saskatoon, SK, Canada, 14–17 October 2007.
19. O'Connor, D.; Drumm, R. Bridge management systems: Advancing the science. *TR News* **1994**, *173*, 17–21.
20. Linee Guida per la Classificazione e Gestione del Rischio, la Valutazione della Sicurezza ed il Monitoraggio dei Ponti Esistenti. Decreto Ministeriale N. 578 del 17/12/2020. Available online: https://www.mit.gov.it/normativa/decreto-ministeriale-numero-578-del-17122020 (accessed on 27 October 2023).