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Factors Influencing Bridge Inspection in Developing Countries, Challenges and Future Directions: A Systematic Literature Review

Tuba Arshad
Universitas Indonesia, tubaarshad713@gmail.com

Dr. Rully Andhika Karim

Ayomi Dita Rarasati

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FACTORS INFLUENCING BRIDGE INSPECTION IN DEVELOPING COUNTRIES, CHALLENGES AND FUTURE DIRECTIONS: A SYSTEMATIC LITERATURE REVIEW

[1]Tuba Arshad[*], [2]Rully Andhika Karim, [3]Ayomi Dita Rarasati

[1]Civil Engineering, Faculty of Engineering, Universitas Indonesia, Indonesia

**Correspondence: tubaarshad713@gmail.com*

ABSTRACT

Bridges are very important to promote economic growth, mitigate poverty, and address persistent environmental issues. With the construction of new bridges, it is crucial to have an effective bridge inspection procedure. But most developing countries are still struggling in this field. This review examines common factors affecting bridge inspection in developing countries and their impact on bridge condition and performance while exploring strategies to improve those factors in developing countries in a systematic review. A total of 172 articles were identified through an explorative search of Direct Scopus, Google Scholar, and hand-search with limitations of the years 2013 to 2024. Only 15 articles were considered and classified based on the related topic of research study and keywords, such as Inspection of infrastructure, Improvement of bridge inspection, maintenance, and developing countries related articles. The findings from previous research studies show that the factors budget, resources, policies/Laws/regulations, Bridge age, and transparency are the factors that influence bridge inspection practices in developing countries. It is important to work on these factors to improve bridge inspection in developing countries. The recommendations from previous studies that can improve these factors are exploring new funding sources, enhancing the training programs, introducing cutting-edge technologies, updating standard guidelines every year, developing a centralized online portal to give regular updates of inspection data, and advocating for long-term planning. Therefore, this analysis concludes that bridge inspection practices can be improved in developing countries by improving all those factors.

Keywords: *Bridge inspection; Developing countries; Inspection infrastructure; Improvement strategies; Transportation infrastructure*

INTRODUCTION

In this modern era of transportation, where flyovers, bridges, and underpasses are common features of almost all cities, there is a need for a compelling monitoring and management system to assess the health of critical city infrastructure. Any damage to these structures, particularly bridges, may reduce their lives and induce the risk of collapse that can cause economic and physical damage. Therefore, stronger, and safer bridges are imperative to minimize financial losses from rehabilitations and save lives (Azeem et al., 2021).It has been observed that there is no effective bridge maintenance plan in most of the developing countries and that in most cases maintenance is carried out after an event has occurred and resulted in severe damage and caused a public outcry. Also, developing countries have limited budgets for maintaining their assets. Therefore, it is very important to have an assessment criterion as a development tool to optimize the use of scarce maintenance budgets and get the most out of aging bridge networks.

There is currently no mechanism in the Pakistan Highway Department for periodically assessing the state of bridges (Uddin et al., 2023a). There is a tremendous load of pending rehabilitation works on bridges in many developing countries like Pakistan. Such problems can be seen in most of the national highways in Pakistan (Qureshi et al., 2017a). Pakistan has seen regular disasters in the form of bridge collapses due to poor construction quality and monitoring, and irregular maintenance schedules (Inam et al., 2023a). According to the Roads and Highways Department (RHD) of Bangladesh, there are 4,507 bridges under the department, of which 996 are Bailey bridges. Of them, 973 have steel decks while the rest have wooden decks (The Daily Star, 2020). Due to a lack of repair, maintenance, and supervision, most of the Bailey bridges suffer from a high rate of deflection. A bridge failure causes a huge loss of life and assets and interrupts mobility. Inspection of bridges and regular data observations are essential for safe, durable, and smooth bridge operation (n.d.-a).

The study highlights a distinct pattern of failure of bridges in India, and the causes of failure are different from those of developed nations. There have been considerable effects on users when a bridge fails, causing causalities as well as injuries apart from other effects on day-to-day working and regional economy. The failure of bridges imposes a strain on surface transportation and an economic burden because of socio-economic disturbances (Garg et al., 2022a). Thailand and Indonesia are still expanding and seeking the most optimum bridge inspection and maintenance regulation. Updating the inspection manuals is necessary to meet the needs of each country, particularly the developing countries (Puspitasari et al., 2023a).

The objective of this paper is to systematically review the previous studies on bridge inspection in developing countries and its improvement through identifying the factors/challenges, and future strategies. Two Research Questions are defined to structure this review. These questions investigate the (a) What are the factors affecting bridge inspection practices in developing countries? (b) What are the recommendations that can improve the factors affecting bridge inspection in developing countries?

METHODOLOGY

Searching Strategy

This systematic review uses the PRISMA9I999 software for the article selection (Shamseer et al., 2015) including eligibility and screening. The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) method is a comprehensive and structured approach to ensure transparency and rigor in the reporting of systematic reviews and meta-analyses. Screening research articles using the PRISMA method involves several steps that align with the PRISMA checklist and flow diagram. The publication is limited from 2013 to 2024 and all are in English language. The keywords and controlled vocabulary concepts are applied to the research topic. Two databases were used (Scopus and ScienceDirect). The search was limited to keywords, peer-reviewed journal articles, and abstracts in English language. The hand-searching method is also used in this search strategy. See the table below for the search terms and keywords.

Table 1 Keywords of the study focus. *(search strategy)*

P: Product or process	I: Impact(s) of interest	F: Flows	T: Type(s) of life cycle assessment
"future directions" OR policy OR challenges	Inspection w/5 infrastructure or "survey infrastructure" or investigation W/5 infrastructure or Transportation w/3 Infrastructure	Bridge or Culvert or flyover or highways	Improvement OR improvements

Literature Screening and Inclusion/Exclusion Criteria

The articles that are not related to bridge inspection/maintenance are excluded. The included articles are related to bridge inspection/maintenance in developing countries and some of them are from developed countries to make a comparison. The study's screening process began by excluding non-English articles, and then the remaining citations underwent a first round of screening for relevancy based on their abstracts or full documents. In the second round, irrelevant and duplicate articles were filtered out using specific inclusion criteria. The primary inclusion criterion for the studies was documentation of the bridge inspection in developing countries. The challenges developing countries are facing and factors that are affecting the inspection of bridges in developing countries. Studies were excluded if they did not mention the bridge inspection, infrastructure inspection, challenges for the inspection, and factors affecting the inspection of bridges. The review focuses on the factors affecting the inspection of bridges like funds, resources, advanced technology, policies, qualified bridge inspection engineers, and their impacts on bridge inspection. Previous studies and literature were included for a comprehensive analysis of the challenges of bridge inspection in different developing countries.

Quality assessment

The study used research publications and review papers to collect high-quality documents. To ensure reliable findings, duplicates were reviewed and found using Rayyan before being exported to Mendeley. Article abstracts were carefully evaluated to ensure quality and relevance, and each study paper was carefully analysed to ensure validity and reliability.

Data cleaning

A systematic review attached to the PRISMA method has been previously suggested. The data cleaning process was facilitated by the Rayyan tool for literature reviews, which was subsequently exported in the RIS format for compatibility with the Mendeley application. The Mendeley application was then used to obtain PDF documents for the full text.

Results of the study

This review identified 182 original papers found through the database search. After removing 10 duplicate records and screening 172 papers by title and abstract, 161 were excluded because these studies were not specifically for inspection/maintenance. Most of these articles are related to the construction of transportation and infrastructure, 0 articles were retrieved. Following the full-text screening, 4 out of 11 papers were excluded because these were not related to bridges, resulting in 7 articles included in the review and 8 articles from hand searching so the total number of articles included in the review is 15. Consider **Figure 2**, a flow diagram of a database search profile. Most of these articles were published between 2013 to 2024 and were published in Pakistan, India China, Taiwan, Egypt, Bangladesh, Iran, USA, and UAE. Some of these articles were found by hand-searching (Amin & Okui, 2015; Garg et al., 2022b; Novak et al., 2018; Outay et al., 2020; Puspitasari et al., 2023b; Uddin et al., 2023b). In general, studies focused on bridge inspection in developing countries and its improvement (Amin & Okui, 2015; *Bridges in Bangladesh*, n.d.-b; Avelina et al., 2022; Ilbeigi & Pawar, 2020; Joshi, 2023; Qureshi et al., 2017b; Uddin et al., 2023b). All studies have mentioned the factors that affect bridge inspection in developing countries. Two studies mentioned the reasons for the collapse of bridges in previous years in developing countries (Garg et al., 2022b; Inam et al., 2023b). Two studies are the comparison of developed countries and developing countries (Avelina et al., 2022; Puspitasari et al., 2023b).

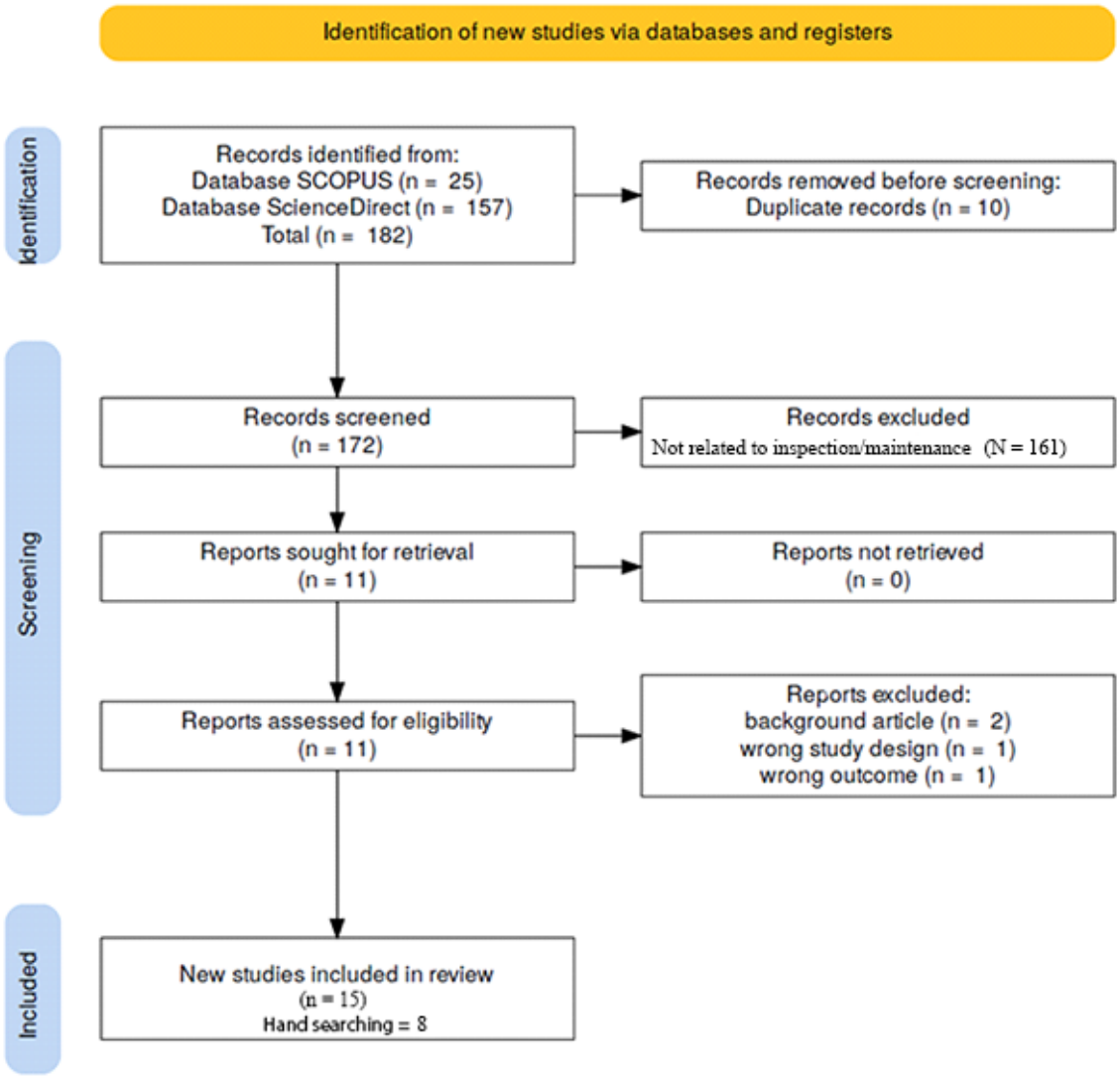

Figure 1 Flow diagram of database search (PRISMA)

Source: (Moher et al., 2015)

Table 2 General characteristics of articles

Author	Title	Country	Journal	Limitation of Study
(Qureshi et al., 2017b)	Investigation regarding bridge expansion joints deterioration in Pakistan and its remedial measures	Pakistan	Tecnical Journal Uet Taxila Pakistan	used limited data images for inspectin.
(Hina Inam 2023)	Smart and Automated Infrastructure Management: A DeepLearning Approach for Crack Detection in Bridge Images.	Pakistan	Sustainability 2023, 15, 1866	use limited images to study the cracks. and research based on few types of cracksSelection biases.
(Yu-Han Chuang 2023)	A Big Data Approach for Investigating Bridge Deterioration and Maintenance Strategies in Taiwan.	Taiwan	Sustainability (Basel, Switzerland)	Used limited variances in the degree of deterioration.
(Sachidanand Joshi 2022.)	Recent Enhancement of indian bridge management system (IBMS TO UBMS)	India	Sachidan and Joshi IBMS/UBMS	Did not study advance technology
(DYoseok Jeong 2018)	Bridge inspection practices and bridge management programs in China, Japan, Korea, and U.S.	China	International Journal of Aviation Science and Technology	generalizability of findings.
(YaDina Mahmoud, 2019)	An assessment model for identifying maintenance priorities.	Egypt	Ain Shams Engineering Journal	Case Study limited to Egypt or developing countries.
(Dan SuID1, Yisheng Liu1., 2021)	Study on optimization of inspection mechanism of concrete beam bridge.	China	PLOS ONE | August 12, 2021	Limited to concrete bridges.
(Mohammad Ilbeigi, 2020)	Probabilistic Model for Optimal Bridge Inspection Interval.	Stevens Institute of Technology USA	Infrastructures 2020,	Insufficient factors

(WMijia Yang * and Chang Liu., 2021)	Possibility of Bridge Inspection through Drive-By Vehicles.	China	Appl. Sci. 2021, 11, 69.	Hard to use this method of inspection on highly rough surface.
(Junwon Seoa, 2018)	Drone-enabled bridge inspection methodology and application.	cross-sectional study/ Iran	Automation in construction 94((2018) 112-126	Use of drons
(Muhammad Ghiyas Uddin, 2023)	Bridge maintenance parameters: a case study of railway bridges in Pakistan.	Pakistan	Natural and Applied Sciences International Journal (NASIJ)	Limited Factors
(Hyunsik Kim 1, 2020)	Scenarios for Life Cycle Studies of Bridge Concrete Structure Maintenance.	Sustainability (Basel, Switzerland	Sustainability	Study limited to concrete bridges.
(Junwon Seoa, 2018)	Drone-enabled bridge inspection methodology and application.	cross-sectional study/ Iran	Automation in construction 94((2018)112-126	Use of drons
(David C. Novak, 2018)	Performance-related specification and payment modifiers in highway construction projects.	Vermont Agency of Transportation, Montpelier, Vermont, USA	IJQRM 35,10	Restricted data size ×
(Momtaz et al., 2023)	Multi-modal deep fusion for bridge condition assessment.	University of Virginia, Charlottesville, VA, USA	Journal of Infrastructure Intelligence and Resilience	Restricted data size
(Fatma Outay, 2020)	Applications of unmanned aerial vehicle (UAV) in road safety, traffic and highway infrastructure management: Recent advances and challenges.	College of Technological Innovation (CTI), Zayed University, Dubai, United Arab Emirates	Transportation Research Part A	Use of technology like drons

Note: X means articles that are not included

Background/Challenges different developing countries are facing in inspecting the Bridges

Insufficient funding and inadequate training are paramount in bridge maintenance in Pakistan. Furthermore, harnessing technological advancements offers promise but demands specialized training and considerable investments. Due to economic difficulties, it has become challenging to reconstruct old bridge structures, including steel triangulated, masonry, and concrete bridges (Uddin et al., 2023b). There is a tremendous load of pending rehabilitation works on bridges in many developing countries like Pakistan. Such problems can be seen in most of the national highways in Pakistan. However, it is a known fact that Pakistan does not have sufficient funds to be allocated for bridge repairs and hence only PKR 500 to 600 million is assigned yearly to maintain and renovate in total of over 5000 bridges. In addition to this, the lack of expertise has led the local authorities like provincial and national highway departments to flatten the depreciated bridges. In some places, this demolishing was done for only the superstructures but most of the time the whole structure was flattened (Qureshi et al., 2017b). The challenges Pakistan is facing are poor construction quality and monitoring, and irregular maintenance schedules. Many bridges have been collapsed over the last two decades in Pakistan, causing many casualties **Table 1** shows the location, year, and casualties caused by bridge collapses in Pakistan in the last two decades (Inam et al., 2023b).

Year	Name/Location	Casualties	Ref
2006	Kalpani Bridge, Marden KPK, Pakistan	70	[25]
2007	SherShah Bridge, Karachi Sindh, Pakistan	4	[26]
2007	Northern Bypass Bridge, Karachi, Sindh, Pakistan	10	[27]
2018	Kundal Shahi bridge, Neelam valley Kashmir, Pakistan	40	[28]
2018	Jagran Nullah, Neelum Valley Kashmir, Pakistan	25	[29]
2022	Hassanabad Bridge, Hunza Gilgit-Baltistan, Pakistan	-	[30]
2022	Gohati Bridge, Swabi KPK, Pakistan	-	[31]

Figure 1 Bridges Collapses in Pakistan (Inam et al., 2023b)

The data related to the failure of bridges that occurred during the period 1977–2017 in India have been collected from various sources, there have been considerable effects on users when a bridge fails, causing causalities as well as injuries apart from other effects on day to day working and regional economy. The failure of bridges imposes a strain on surface transportation and an economic burden because of socio-economic disturbances. The average age of failure of bridges is 34.5 years, which is very low compared to the expected design life. Regular inspection is mandatory to avoid this situation. The challenges India is facing are lack of funds, natural disasters, low-quality material during construction, poor design, and deterioration of the material because of no proper inspection practices.

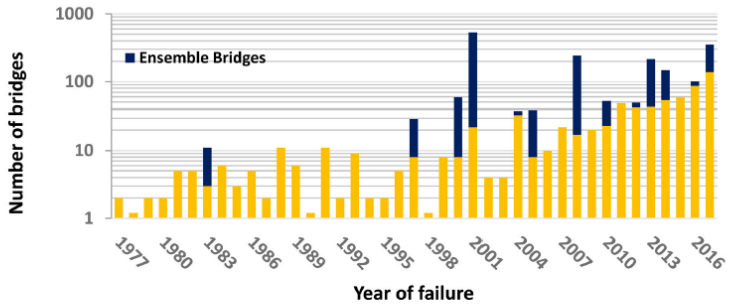

Figure 14. Year-wise distribution of failures of bridges (semi-log scale).

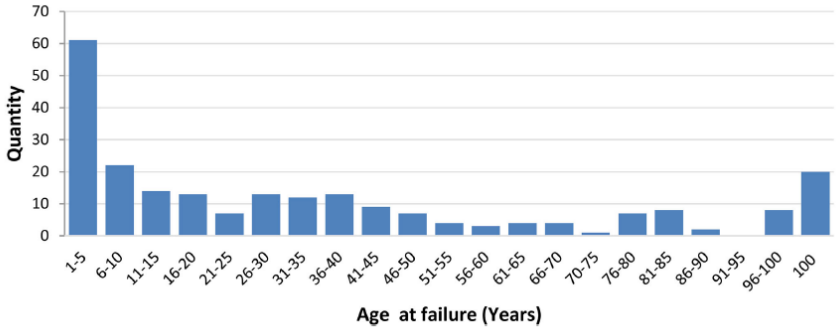

Figure 15. Number of bridges failed at different age groups.

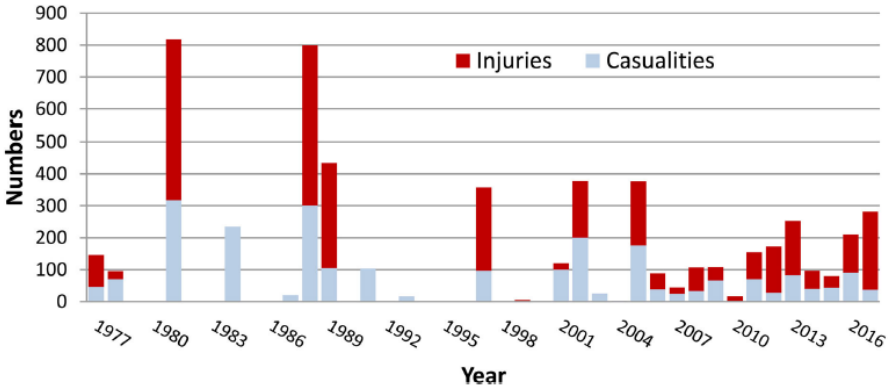

Figure 3 Failure of bridges in India from 1977-2017 (Garg et al., 2022b)

Thailand and Indonesia are still expanding and seeking optimum bridge inspection and maintenance regulations. Updating the inspection manuals is necessary to meet the needs of each country, particularly the developing countries (Puspitasari et al., 2023b). This concern suggests that there is room for improvement in the current bridge inspection practice in Indonesia. The challenges that Indonesia is facing in the bridge inspection field are a lack of advanced technology in the data collection system, improvement of supervision, and improvement of the bridge rating system. In Indonesia, advanced technology is only used for special inspection purposes. Non-destructive testing is widely used to examine a structure's condition without causing damage. In 2009, Structural Health Monitoring Systems (SHMS) was installed on a long-span bridge, Suramadu, to monitor the long-term conditions. The retrieved data was then processed to extract damage-sensitive information for further analysis to determine the bridge's health status. However, the detailed inspection to measure the bridge condition relies on the visual inspection in the field. The adoption of UAV and the data postprocessor can minimize human errors in extracting defective data and reduce

postprocessing time. Below fig is a comparison of Indonesian inspection practices with other countries (Avelina et al., 2022).

TABLE I
BRIDGE INSPECTION TYPES AND INTERVALS

Inspection	Description	Interval	Strengths
The U.S.			
Initial inspection	• Collect inventory data and set the interval for other inspections	• Within three months of opening	NSTM and underwater inspections help in identifying damages in critical structures that are often overlooked during routine inspections
Routine inspection	• Investigate the bridge's physical and functional condition	• Not to exceed 24 months*	
In-depth inspection	• Further investigation after a routine inspection	• Follow-up of routine inspection	
Damage inspection	• Assess damages caused by environment or human action	• Unscheduled	
NSTM inspection	• Examine NSTM, whose failure could cause bridge collapse	• Not to exceed 24 months*	
Underwater inspection	• Survey the sub-merged substructures	• Not to exceed 60 months*	
Special inspection	• Monitor a suspected defect or unusual characteristics	• At the discretion of the bridge owner	
The U.K.			
Safety inspection	• Identifying significant deficiencies can lead to danger	• At the discretion of the bridge owner	Structural assessment helps in detailed planning at the project level
General inspection	• Provide information on the physical condition	• At intervals of 24 months	
Principal inspection	• More comprehensive than a general inspection	• At intervals of 72 months*	
Special inspection (SI)	• Examine a particular element that is causing concern	• At intervals of 12 months; or after 6 SI*	
Inspection for assessment	• Provide the information for structural assessment		
Australia (Victoria)			
Initial inspection		• Within 12 months of opening	Exclusive attention to load rating helps in a more detailed analysis
Routine inspection	• Identify defects that might affect safety and/or serviceability	• Min. twice per year at max. 6-month interval*	
Structure condition inspection	• Measure the condition of structures	• At an interval of 2 – 5 years*	
Engineering investigations	• Survey a specific issue of an individual structure		
Monitor inspection	• Investigation of bridges that have deficient live-load capacity		
China			
Routine inspection	• Visual inspection to detect abnormalities in the element	• Monthly basis	The special inspection covers a thorough and detailed assessment for in-depth analysis
Periodic inspection	• Quantify bridge health status	• At max. 3-year interval*	
Special inspection	• Bridge damage quantification, load rating, and serviceability assessment after extreme events		
Indonesia			
Inventory inspection	• Register the bridge inventory data	• After completion	Adequately collects the information require for analysis with less investment of resources
Routine inspection	• Monitor bridge safety and user convenience	• Annually	
Detailed inspection	• Assess bridge conditions	• At max. 5-year interval*	
Special inspection	• For non-visually detectable damage during a detailed inspection		

NSTM: Nonredundant steel tension member
** Adjustable based on risk assessments or bridge condition*

Figure 4 Comparison of Indonesian bridge inspection practices with other countries

In Bangladesh Based on the inspection and evaluation of 1185 bridges and 4003 culverts in the Cumilla and Rangpur zones. A significant number of bridges and culverts require emergency countermeasures. we need to look thoroughly at the low maintenance cost, choosing bridge forms that match the beautiful river setting of the country, and owning a resilient infrastructure offering the least life cycle cost for the future land transport network not only for Bangladesh but for the Asian region The challenges Bangladesh is facing are lack of funds and its distribution, lack of resources (Bailey Bridges in Bangladesh, n.d.-b).

Table 2. Safe and unsafe bridges according to deflection results by RTS (Due to dead load only).

No.	Bridge Name	Span, L (m)	Deflection Δ_{DL}, (mm)	AASHTO Limit (mm)	$\Delta \div L$	Remarks
1.	Kurir Chor Bridge	24.39	81	30.49	0.0033	Unsafe
2.	Baiguni Bridge	30.48	78	38.11	0.0026	Unsafe
3.	Hajibari Bridge	36.59	84	45.73	0.0023	Unsafe
4.	Katakhali Bridge	43.29	93	54.12	0.0021	Unsafe
5.	Chondidas Bridge	29.27	60	36.59	0.0020	Unsafe
6.	Bahuli Bridge	33.53	51	41.92	0.0016	Unsafe
7.	Boikunthopur Bridge	33.54	51	41.92	0.0015	Unsafe
8.	Kholishagura Bridge	24.39	36	30.49	0.0014	Unsafe
9.	Hasildoho Bridge	36.59	54	45.73	0.0014	Unsafe
10.	Pontarjan Bridge	39.63	54	49.54	0.0013	Unsafe
11.	Mohadebpur Bridge	41.15	42	51.07	0.0011	Safe
12.	Buruj Bridge	42.07	36	52.59	0.0009	Safe
13.	Sonai Bridge	18.29	12	22.87	0.0006	Safe

Figure 5 Bridges that are unsafe to use in Bangladesh.

Figure 5 is showing the names of bridges that are unsafe in Bangladesh. (Bailey Bridges in Bangladesh, n.d.-b) this study showing the main reason to bridge failure in over loading, but author mentions another big reason lack of inspection and maintenance. "Apart from the case of overloading, one unseen reason is uncovered in this paper. Due to lack of repair, maintenance and supervision, most of the bailey bridges suffer from high rate of deflection. A bridge failure causes huge loss of life, assets and interrupts mobility. Inspection of bridges and regular data observations are essential for safe, durable and smooth bridge operation."

Egypt currently maintains a road network of more than 64,000 km across the country, including more than 3,000 bridges. Statistics of GARBLT show that nearly 98% of the country's domestic cargo relies on this road network which means that this road network plays a major role in Egypt's national economy and have a significant impact on the daily activities of citizens. Yet those bridges and roads haven't been properly maintained to prevent their degradation and deterioration. It is a fact that about half of Egypt's bridges are 50 years old or older as reported by GARBLT's Referring to types of bridges in Egypt, reinforced concrete bridges constitute about 90% and steel bridges are less than 10% Due to all the aforementioned factors, it is very important to develop an assessment model for bridges in Egypt taking into consideration the limited financial resources of the country (Mohamed Mansour et al., 2019), this study mentions the many factors to identify the maintenance priorities strategies for bridges in Egypt. For example, it mentions the history of bridges, the life of bridges, construction year, climate, loading, etc, but it mentions another main factor inspection quality IQ" (Mohamed Mansour et al., 2019) In this study author mentioned that maintenance strategies can not be improved or measured correctly until IQ get improved.

Table 3 Summary of Factors Affecting Inspection of Bridges

Author	Focus of Study	Factors
(Liaqat A. Qureshi 2014)	Investigation regarding bridge expansion joints deterioration in Pakistan and its remedial measures	Budget, resources, negligence in inspection
(Hina Inam 2023)	Smart and Automated Infrastructure Management: A DeepLearning Approach for Crack Detection in Bridge Images	Budget, resources, Area/country previous data
(Yu-Han Chuang 2023)	A Big Data Approach for Investigating Bridge Deterioration and Maintenance Strategies in Taiwan	Data mining, lack of qualified bridge inspectors, less maintenance budget/funds
(Sachidanand Joshi 2022.)	Recent Enhancement of Indian Bridge Management System (IBMS TO UBMS)	Data collection/ Previous data, Data collection method, Experienced Bridge inspection Engineers experience
(DYoseok Jeong 2018)	Bridge inspection practices and bridge management programs in China, Japan, Korea, and the U.S.	Qualified Bridge inspectors, inspection Data, Bridge rating/Age

Author	Focus of Study	Factors
(YaDina Mahmoud, 2019)	An assessment model for identifying maintenance priorities.	Country Type, Budget, Bridge rating, Resource
(Mohammad Ilbeigi, 2020)	Probabilistic Model for Optimal Bridge Inspection Interval	Bridge rating, historical deterioration data, environmental factors, previous condition
(WMijia Yang and Chang Liu., 2021)	Possibility of Bridge Inspection through Drive-By Vehicles	Road Roughness, Vehicle acceleration
(Momtaz et al., 2023)	Multi-modal deep fusion for bridge condition assessment	Data Size
(David C. Novak 2018)	Assess the quality to maintain the transportation system	Historic Data, Budget
(Fatma Outay, 2020)	Using drones to inspect and maintain infrastructure	Budget/Funds
(Uddin et al., 2023b)	Bridge maintenance parameters	Standard maintenance, Funding, training, Technology
(Junwon Seoa, 2018)	Inspection of bridges by Drones	weather, environment, Location, qualitative data
(Hyunsik Kim 1)	The purpose of this study is to derive an appropriate method of calculating the environmental impact and cost caused by maintaining the concrete structure of a bridge during its service life.	Cost, Budget, Environmental impacts, Bridge rating, age, Service years
(PLOS ONE)	The objective of this study is to improve the inspection mechanism of concrete beam bridge and improve the efficiency and effect of bridge inspection.	Bridge technical condition rating, Geometric attribute, Structure attributes, Operating conditions, Environmental factor, Check and maintain history

RESULTS AND DISCUSSION

The factors that influence bridge inspection are outlined in **Table 3**, based on previous studies. A study by Uddin et al. (2023b) identifies the factors (standard maintenance, funding, training, technology) that affect bridge inspection in Pakistan, a developing country. Standard maintenance refers to the level of attention and maintenance provided to a bridge to ensure consistent and safe operation. It encompasses methods, recommendations, and rules for maintaining, repairing, and monitoring the bridge. To establish an effective maintenance plan, it is essential to consider the bridge's design, operation, and construction. The plan should encompass steps for routine inspection and monitoring to identify and rectify any deterioration or damage that could jeopardize the bridge's integrity. Additionally, it should delineate the responsibilities, timelines, and accountability for all components of the bridge structure.

The most crucial parameter of bridge maintenance is adequate funding, which guarantees the availability of the necessary resources to keep bridges in good condition. A thorough evaluation of the condition of bridges can help identify maintenance requirements and calculate associated

costs to ensure adequate funding. After surveying, according to 64.3% of respondents, a lack of funding is the most significant difficulty inspectors face when inspecting bridges. Training is essential to bridge maintenance because it gives the workforce the knowledge, abilities, and education to complete maintenance tasks effectively and efficiently. Training programs should be developed to address the workforce's needs and bridge maintenance requirements. Regular refresher training may also be necessary to keep the workforce current with advancements in maintenance technology and techniques. Adequate and practical training is crucial for successful bridge maintenance programs (Uddin et al., 2023b). Technology in bridge maintenance refers to the tools, equipment, and techniques used to inspect, analyze, and repair bridges. New technologies like drones, non-destructive testing techniques, and computer software and simulation tools can lead to more accurate assessments, increased efficiency, and improved safety. However, the execution of technology might involve training and expertise, and the cost of these technologies can be substantial (Uddin et al., 2023b). The main reason for problems in bridge inspection in developing countries is the deviation from specified construction procedures and the negligence of the maintenance departments due to several reasons. One of the reasons is budget and lack of funding (Qureshi et al., 2017b).

Due to the dwindling maintenance budget and lack of qualified bridge inspectors, bridge-management agencies in Taiwan need to develop cost-effective maintenance and inspection strategies to preserve the safety and functionality of their aging, natural disaster-prone bridges. Although Taiwan is a developed country but still it is facing challenges to improving factors like budget, qualified bridge inspection engineers, etc (Chuang et al., 2023).

Previous studies also indicate that bridge management systems in developed countries are heavily influenced by various factors, including the qualifications of bridge inspection officers (Jeong et al., 2018), inspection data, bridge rating/age, maintenance strategies, standards, funding, training, and technology (Mohamed Mansour et al., 2019). These aspects are essential for evaluating a bridge's overall condition and the condition of its elements. Factors such as bridge technical condition rating, geometric and structural attributes, operating conditions, environmental influences, maintenance history, cost, budget, environmental impacts, and qualitative data play a crucial role in bridge inspection (Ilbeigi & Pawar, 2020; Momtaz et al., 2023; Novak et al., 2018; Outay et al., 2020; Yang & Liu, 2021).. Studying and enhancing these factors is vital to optimize bridge inspection in developing countries.

Implications of Identified Factors on Bridge Inspection Practices and Steps to Improve Them

Table 3 shows the identified factors affecting bridge inspection practices in developing countries. The main factors are budget/funds, resources/advanced machinery/technology, regulations/policies, transparency, previous data, bridge age, and lack of training programs. Based on previous studies every developing country is facing problems in bridge inspection practices because of these factors (Uddin et al., 2023b). Despite these factors, several measures can be taken. If funding is insufficient, consider renting expensive equipment (Inam et al., 2023b). Establish long-term partnerships with vendors for expensive technology to provide support and training (Inam et al., 2023b). Explicit criteria for selecting a team of auditors should be developed, focusing on their track record. Publicly shared reports should include a transparent action plan, and an online portal should be created for transparency in public consultations and legislative processes (Qureshi et al., 2017b; Uddin et al., 2023b). A monitoring team consisting of expert engineers, researchers, policymakers, and industry experts should be established to oversee the creation and review of standards twice a year. Encourage supervisor feedback and suggestions (Uddin et al., 2023b). Use a tool like data

visualization that compiles and creates the report to highlight the performance. The public can access the dashboard to track financial expenditure and progress (Uddin et al., 2023b). Involvement and collaboration with the universities so new graduates can benefit and bring these advancements into practice (Inam et al., 2023b). Enhance Training and Certification Programs.

Furthermore, it is suggested that free online courses be offered so that they can be easily accessible (Uddin et al., 2023b). A database should be developed like the cloud or any other that can be easily accessible. In addition, a digital device should be provided to the inspection teams (Qureshi et al., 2017b). Resources for cutting-edge technology, such as drones, non-destructive testing methods, and computer software, may result in more accurate, more efficient, and safer inspections for both inspectors and the public. However, the workforce/bridge inspectors must obtain the training and knowledge to operate these technologies skillfully (Seo et al., 2018).

CONCLUSION

This study investigated that due to the lack of proper inspection repair, maintenance, and supervision, most of the bridges suffer from a high rate of Deterioration. There are a tremendous load of pending rehabilitation works on bridges in many developing countries(Qureshi et al., 2017b). A bridge failure causes a huge loss of life and assets and interrupts mobility. Inspection of bridges and regular data observations are essential for safe, durable, and smooth bridge operation.(, n.d.-a). Several studies show a significant impact of factors like budget, resources, qualified bridge inspectors, previous data, bridge age/rating, right training, and technology(Amin & Okui, 2015; Uddin et al., 2023b). Improvement of these factors like, budget, resources, transparency, training, and use of technology can improve the bridge inspection in developing countries (Amin & Okui, 2015; Inam et al., 2023b; Uddin et al., 2023b).

RECOMMENDATIONS

Based on the previous studies, it is evident that there are several factors influencing bridge inspection and maintenance in developing countries that need to be improved. To ensure the longevity and safety of the bridges, these factors affecting the bridge inspection practices need to be improved. Below are recommendations for some of the factors mentioned in the discussion part.

Regulations

In a bridge management system, regulations and policies are crucial. This factor has a high impact, according to our findings. The following policies should be considered:

1. Develop and update Comprehensive Standards and Guidelines

    Uniform Standards: Create uniform, comprehensive standards and guidelines for bridge inspection and maintenance that all states and municipalities must follow. This ensures consistency in the quality and thoroughness of inspections.

Regular Updates: Regularly update these standards to incorporate the latest technology, materials, and methods

2. Implement Advanced Inspection Technologies (Inam et al., 2023b).

Nondestructive Testing (NDT): Encourage the use of advanced nondestructive testing methods, such as ultrasonic testing, ground-penetrating radar, and thermographic inspections, to detect hidden defects.

Drones and Robotics: Utilize drones and robotic systems for inspections, particularly in hard-to-reach areas, to enhance accuracy and safety.

Structural Health Monitoring (SHM): Deploy SHM systems that use sensors to continuously monitor the health of bridge structures and provide real-time data on their condition.

3. Enhance Training and Certification Programs (Qureshi et al., 2017b)

Inspector Certification: Implement rigorous training and certification programs for bridge inspectors to ensure they are highly qualified and up-to-date with the latest inspection techniques and standards.

Continuous Education: Require ongoing education and training to keep inspectors and maintenance personnel informed about new technologies, materials, and methods.

4. Standardize Data Collection and Management

Centralized Database: Establish a centralized database for all bridge inspection and maintenance records to ensure data is easily accessible, shareable, and analyzable.

Digitalization: Promote the digitalization of inspection and maintenance records to improve data accuracy and reduce paperwork.

5. Enhance Regulatory Oversight and Enforcement

Regular Audits: Conduct regular audits (financial examination) of bridge inspection and maintenance programs to ensure compliance with standards and identify areas for improvement.

Penalties for Non-Compliance: Establish penalties for non-compliance with inspection and maintenance regulations to enforce adherence.

By taking these steps, governments and agencies can significantly improve the regulations and policies.

6. Foster Collaboration and Knowledge Sharing

Public-Private Partnerships: Encourage collaboration between public agencies and private sector experts to leverage their expertise and resources.

Industry Forums: Create forums for knowledge sharing among engineers, inspectors, and maintenance personnel to discuss challenges, solutions, and best practices.

7. Engage in Public Awareness and Education

Public Reporting: Provide transparent reporting to the public about the condition of bridges and the steps being taken to maintain and improve them.

Community Involvement: Engage local communities in bridge safety awareness campaigns to garner public support for maintenance initiatives.

8. Leverage Research and Innovation

Research Funding: Invest in research to develop new materials, methods, and technologies for bridge inspection and maintenance.

Implement pilot programs to test innovative approaches and technologies before wider adoption.

Budget/Funds

Effective bridge maintenance requires adequate funding. The government should set aside enough money to ensure that the equipment, materials, and labor needed for maintenance tasks are all available. Lack of funding could lead to bridge failures or accidents, which can be costly and dangerous if maintenance is neglected (Uddin et al., 2023b).

1. Develop a Strategic Funding Plan

Detailed Budget Proposal: Create a detailed budget proposal outlining specific funding requirements, expected outcomes, and timelines.

Prioritization: Prioritize bridge projects based on risk, usage, and condition to highlight urgent needs.

2. Engage with Policymakers and Stakeholders

Lobbying: Engage in lobbying efforts with local, state, and federal lawmakers to advocate for increased funding. Provide them with data and real-life examples of bridge failures and their consequences.

Stakeholder Meetings: Organize meetings with key stakeholders, including transportation departments, local governments, and industry experts, to build a coalition in support of increased funding.

3. Explore Alternative Funding Sources(Qureshi et al., 2017b).

Public-Private Partnerships (PPPs): Form public-private partnerships to leverage private investment in bridge inspection and maintenance.

Infrastructure Bonds: Advocate for the issuance of infrastructure bonds (by private corporations and by state-owned enterprises) to raise capital specifically for bridge inspection and repair projects.

4. Leverage Federal and State Programs

Federal Grants and Programs: Apply for federal grants and programs aimed at infrastructure improvement, such as those provided by the Federal Highway Administration (FHWA).

State Funding Opportunities: Explore state-level funding opportunities and advocate for the allocation of state transportation funds toward bridge inspection.

5. Measure and Report Outcomes

Performance Metrics: Develop and report on key performance metrics related to bridge conditions and inspection effectiveness.

Transparency: Maintain transparency in how additional funds are used and the outcomes achieved, to build trust and justify future funding requests.

6. Advocate for Long-Term Planning

Infrastructure Planning: Advocate for long-term infrastructure planning that includes sustained funding for bridge inspection and maintenance.

Sustainability Goals: Align bridge inspection funding with broader sustainability and resilience goals to secure more diverse funding sources.

Resources

1. For the Financial Resources

Funding for Equipment: Capital to purchase and maintain advanced inspection equipment and SHM systems (Inam et al., 2023b).

Operational Budgets: Sufficient funds to cover the costs of regular inspections, including personnel salaries, transportation, and logistical support.

Emergency Funds: Allocations for immediate repairs and additional inspections if critical issues are found

The use of cutting-edge technology, such as drones, non-destructive testing methods, and computer software, may result in inspections that are more accurate, more efficient, and safer for both inspectors and the public. However, the workforce/bridge inspectors must obtain the training and knowledge to operate these technologies skillfully (Inam et al., 2023b).

Transparency

1. To develop a centralized online portal (Uddin et al., 2023b). Working with IT professionals to create a secure and user-friendly online portal was beneficial. Integrate databases and ensure regular updates of inspection data and public communications strategies. Hire or appoint a communications specialist to manage public reporting and engagement activities and utilize social media and local news outlets to inform the public about available resources.
2. To engage with independent auditors, needs identify and contract reputable third-party audit firms to conduct regular reviews, and publicly share audit findings and corrective actions taken.
3. For policy advocacy, need collaborate with policymakers to develop regulations that support transparency. Participate in public consultations and legislative processes to advocate for necessary changes.

FUTURE RESEARCH

Further research can be done to exclude the less influential factors from highly influential ones according to the condition of every developing country by conducting surveys and taking validations from experts. It will help to work on the highly influential factors directly and make improving inspection practices easier.

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REFERENCES

Amin, A. F. M. S., & Okui, Y. (2015). Design , construction and maintenance of bridges in Bangladesh : In the past , present and future. *IABSE-JSCE Joint Conference on Advances in Bridges Engineering -III*, 978–984.

Assessment of dead load deflection of bailey bridges in Bangladesh. (n.d.-a).

Assessment of dead load deflection of bailey bridges in Bangladesh. (n.d.-b).

Avelina, N., Chang, T., & Chi, S. (2022). Comparative Study of Bridge Inspection Practices in Indonesia and Foreign Countries. *IEEE International Conference on Industrial Engineering and Engineering Management*, *2022-Decem*, 980–984. https://doi.org/10.1109/IEEM55944.2022.9989924

Azeem, M., Junaid, M. T., & Saleem, M. A. (2021). Correlated strength enhancement mechanisms in carbon nanotube based geopolymer and OPC binders. *Construction and Building Materials*, *305*. https://doi.org/10.1016/j.conbuildmat.2021.124748

Chuang, Y.-H., Yau, N.-J., & Tabor, J. M. M. (2023). A Big Data Approach for Investigating Bridge Deterioration and Maintenance Strategies in Taiwan. *Sustainability*, *15*(2), 1697. https://doi.org/10.3390/su15021697

Garg, R. K., Chandra, S., & Kumar, A. (2022a). Analysis of bridge failures in India from 1977 to 2017. *Structure and Infrastructure Engineering*, *18*(3), 295–312. https://doi.org/10.1080/15732479.2020.1832539

Garg, R. K., Chandra, S., & Kumar, A. (2022b). Analysis of bridge failures in India from 1977 to 2017. *Structure and Infrastructure Engineering*, *18*(3), 295–312. https://doi.org/10.1080/15732479.2020.1832539

Ilbeigi, M., & Pawar, B. (2020). A probabilistic model for optimal bridge inspection interval. *Infrastructures*, *5*(6). https://doi.org/10.3390/INFRASTRUCTURES5060047

Inam, H., Islam, N. U., Akram, M. U., & Ullah, F. (2023a). Smart and Automated Infrastructure Management: A Deep Learning Approach for Crack Detection in Bridge Images. *Sustainability (Switzerland)*, *15*(3). https://doi.org/10.3390/su15031866

Inam, H., Islam, N. U., Akram, M. U., & Ullah, F. (2023b). Smart and Automated Infrastructure Management: A Deep Learning Approach for Crack Detection in Bridge Images. *Sustainability (Switzerland)*, *15*(3). https://doi.org/10.3390/su15031866

Jeong, Y., Kim, W. S., Lee, I., & Lee, J. (2018). Bridge inspection practices and bridge management programs in China, Japan, Korea, and U.S. *Journal of Structural Integrity and Maintenance*, *3*(2), 126–135. https://doi.org/10.1080/24705314.2018.1461548

Joshi, S. (2023). Recent Enhancement of Indian Bridge Management System. *Structural Engineering International*, *33*(2), 283–290. https://doi.org/10.1080/10168664.2022.2130126

Mohamed Mansour, D. M., Moustafa, I. M., Khalil, A. H., & Mahdi, H. A. (2019). An assessment model for identifying maintenance priorities strategy for bridges. *Ain Shams Engineering Journal*, *10*(4), 695–704. https://doi.org/10.1016/j.asej.2019.06.003

Momtaz, M., Li, T., Harris, D. K., & Lattanzi, D. (2023). Multi-modal deep fusion for bridge condition assessment. In *Journal of Infrastructure Intelligence and Resilience* (Vol. 2, Issue 4). https://doi.org/10.1016/j.iintel.2023.100061

Novak, D. C., Sullivan, J. L., Reed, J., Gagulic, M., & Van Den Berg, N. (2018). Performance-related specification and payment modifiers in highway construction projects. *International Journal of Quality and Reliability Management*, *35*(10), 2348–2372. https://doi.org/10.1108/IJQRM-03-2018-0061

Outay, F., Mengash, H. A., & Adnan, M. (2020). Applications of unmanned aerial vehicle (UAV) in road safety, traffic and highway infrastructure management: Recent advances and challenges. *Transportation Research Part A: Policy and Practice*, *141*(July 2020), 116–129. https://doi.org/10.1016/j.tra.2020.09.018

Puspitasari, S. D., Harahap, S., & Ika Rahmawati, S. (2023a). Bridge inspection implementations and maintenance planning-A comparative analysis of a few distinctive countries. *AIP Conference Proceedings*, *2482*. https://doi.org/10.1063/5.0110943

Puspitasari, S. D., Harahap, S., & Ika Rahmawati, S. (2023b). Bridge inspection implementations and maintenance planning-A comparative analysis of a few distinctive countries. *AIP Conference Proceedings*, *2482*(April). https://doi.org/10.1063/5.0110943

Qureshi, L. A., Zia, S., & Sh, M. I. (2017a). Investigation regarding bridge deck deterioration in Pakistan and its remedial measures. *Proceedings of the 13th International Conference on Inspection, Appraisal, Repairs and Maintenance of Structures*, *19*(Iii), 65–74.

Qureshi, L. A., Zia, S., & Sh, M. I. (2017b). Investigation regarding bridge deck deterioration in Pakistan and its remedial measures. *Proceedings of the 13th International Conference on Inspection, Appraisal, Repairs and Maintenance of Structures*, *19*(Iii), 65–74.

Seo, J., Duque, L., & Wacker, J. (2018). Drone-enabled bridge inspection methodology and application. *Automation in Construction*, *94*(May), 112–126. https://doi.org/10.1016/j.autcon.2018.06.006

Shamseer, L., Moher, D., Clarke, M., Ghersi, D., Liberati, A., Petticrew, M., Shekelle, P., Stewart, L. A., Altman, D. G., Booth, A., Chan, A. W., Chang, S., Clifford, T., Dickersin, K., Egger, M., Gøtzsche, P. C., Grimshaw, J. M., Groves, T., Helfand, M., … Whitlock, E. (2015). Preferred reporting items for systematic review and meta-analysis protocols (prisma-p) 2015: Elaboration and explanation. *BMJ (Online)*, *349*(January), 1–25. https://doi.org/10.1136/bmj.g7647

Uddin, M. G., Ali, M., Ali, A., & Zubair, A. (2023a). Bridge maintenance parameters: a case study of railway bridges in Pakistan. *Natural and Applied Sciences International Journal (NASIJ)*, *4*(2), 1–21. https://doi.org/10.47264/idea.nasij/4.2.1

Uddin, M. G., Ali, M., Ali, A., & Zubair, A. (2023b). Bridge maintenance parameters: a case study of railway bridges in Pakistan. *Natural and Applied Sciences International Journal (NASIJ)*, *4*(2), 1–21. https://doi.org/10.47264/idea.nasij/4.2.1

Yang, M., & Liu, C. (2021). Possibility of bridge inspection through drive-by vehicles. *Applied Sciences (Switzerland)*, *11*(1), 1–28. https://doi.org/10.3390/app11010069