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Bridge maintenance parameters: a case study of railway bridges in Pakistan

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Abstract:
Ensuring railway bridges' safe and efficient operation is fundamental to infrastructure management. This study comprehensively analyses critical parameters in bridge maintenance, encompassing maintenance standards, regular inspections, funding, training, and technology adoption. Leveraging a Google survey administered to Pakistani railway bridge engineers and inspectors, the research provides insights into the existing maintenance landscape and avenues for enhancement. SPSS analysis was employed to scrutinise the survey data. Timely repairs, utilisation of high-quality materials, and the proactive replacement of damaged components emerge as pivotal factors underpinning effective bridge maintenance. However, the perceived suboptimal standard of maintenance for Pakistan Railways (PR) bridges necessitates substantial improvements. While current maintenance procedures exhibit moderate effectiveness, they warrant refinement. Overcoming the challenges of insufficient funding and inadequate training is paramount in bridge maintenance. Furthermore, harnessing technological advancements offers promise but demands specialised training and considerable investments. This study highlights the crucial significance of regular inspections, emphasising the urgency of increasing inspection frequencies in Pakistan. These findings are a foundation for developing more efficient and effective bridge maintenance programs, safeguarding the longevity and safety of railway bridges within the broader transportation framework.

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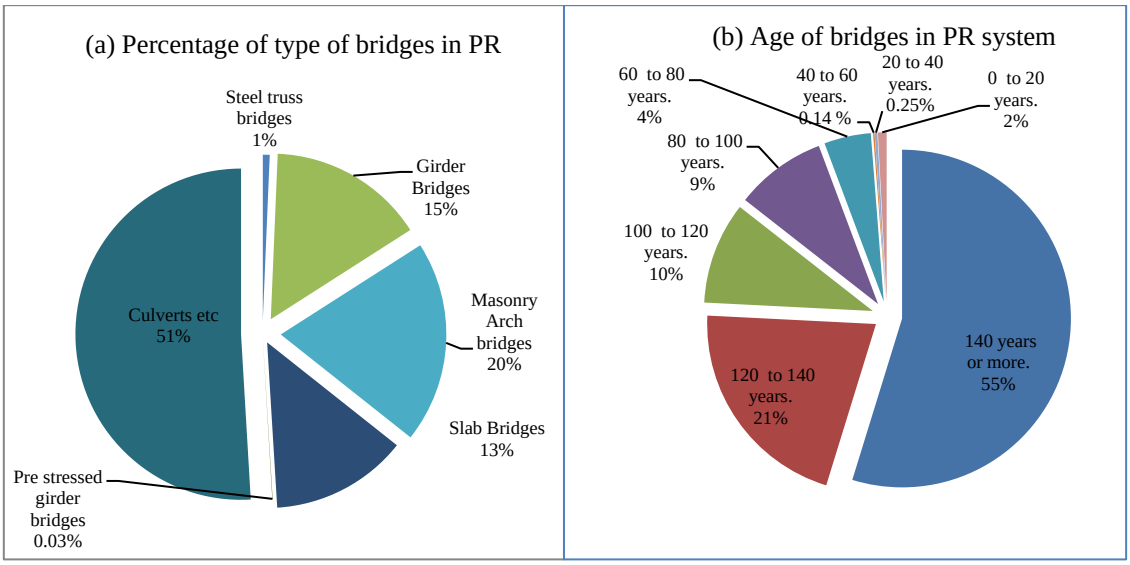
1. Introduction

Pakistan Railways (PR) has around 13959 major and minor bridges, 86% of which have more than 100 years of life (Pakistan Railways, 2020-21). Old railroad bridges support live loads that differ significantly from their original design specifications due to increased traffic flow, higher speeds, and axle loads. Accurate and current information on traffic patterns is necessary for evaluating fatigue, deterioration, load, and strength. These bridges are valuable structures that require maintenance to increase their life and load-carrying capacity. A plan is needed to maintain these structures and efficiently use available resources. The data in Figure 1 shows that 86% of bridges of PR have more than 100 years of life and completed their life. So, it is necessary to maintain and repair the bridge timely. In the past 20 years, PR constructed only 2% of bridges.

Bridges are essential in constructing transportation networks as they significantly impact their functionality, effectiveness, cost efficiency, and durability (Costa & Figueiras, 2012). Railway bridges play a vital role in facilitating rapid and seamless communication and transportation between cities throughout a nation. As such, they are instrumental in driving a country's economic and infrastructure development (Krishna & Sengupta, 2017). In the Pakistan Highway Department, there is currently no mechanism for periodically assessing the state of bridges; however, in PR bridges are inspected periodically. An inspection schedule has already been prepared for each stakeholder (Manual, P. B, 1992).

Figure 1: (a) Percentage of type of bridges in PR, and (b) Age of bridges in PR system



This paper discusses the importance of routine inspection and maintenance for extending the life of bridges, particularly railway bridges in Pakistan. Due to economic difficulties, it has become challenging to reconstruct old bridge structures, including steel triangulated, masonry, and concrete bridges. Visual inspections are conducted to detect issues like corrosion and fatigue cracks, and rail joints are identified as the weakest part of a bridge. The article proposes

cutting-edge frameworks and methodologies for planning bridge inspections and maintenance decisions. There is a lack of research on maintenance parameters for railway bridges in Pakistan, and accurate and timely inspections are crucial for optimizing maintenance strategies. The study aims to investigate common maintenance issues, and the roles of stakeholders and compare practices and challenges across different divisions of the PR system through a comprehensive survey of railway officials and professionals involved in bridge maintenance in Pakistan. The study results will provide valuable insights for policymakers and professionals to improve the safety and reliability of railway infrastructure in Pakistan.

2. Literature review

Inspecting bridges is primarily performed to ensure public safety. The secondary goal is to protect the remaining life of our structures by identifying flaws early and rectifying them (Bettis, 2022). The most crucial primary step in assessing a bridge's physical health is a bridge inspection, which helps decide the best course of action, such as maintenance, repair, rehabilitation, strengthening, or replacement (BIEM, 2018). Owing to the Silver Bridge collapse in 1967, which resulted in the deaths of 46 individuals, the National Bridge Inspection Program was established in 1968 (Lee, 2014). In response to the bridge collapses over the Mianus River and Schoharie Creek in the 1980s, caused by hanger failure and pier scour, the federal authorities supplied new policy memorandums for examining fracture-critical details and underwater components (Swenson, 1991). The first American Association of State Highway and Transportation Officials (AASHTO) inspection manual, which was published in 1970 and revised in 1974, contains the basic data necessary for documenting, grading, and evaluating the load capacity of bridges. The National Bridge Inspection Standards (NBIS) were created in 1971 to offer directions and recommendations as well as to create uniform and consistent standards for the various highway authorities. Each state was obliged to maintain a bridge inspection organization under the criteria established in the AASHTO manual (AASHTO, 1970).

In the United States, inspection of bridges can be performed in a variety of ways, these inspections are initial, routine, in-depth, damage, fracture critical, underwater, and special inspection (AASHTO, 2011). For bridges that are to be inspected, different types of inspections are conducted to check their condition and track any damage or degradation. Each inspection serves a distinct role and contributes to the bridge's safety and dependability (Hearn, 2007). The Federal Highway Administration (FHWA) recommends that most bridges undergo routine inspections for no more than 24-month periods. Inspectors can then notice and analyze any faults or deterioration. Specific bridges, however, may necessitate more frequent inspections due to their age, traffic characteristics, and existing defects. Bridge owners might cut inspection periods to fewer than 24-months in such instances (FHWA, 1995).

Inspections of bridges are also critical in Bangladesh for detecting and quantifying faults. There are four sorts of inspections of bridges these are routine, periodic, emergency, and detailed

investigation. Visual inspections are carried out on foot, by vehicle, or from a distance. Close-up and distant-view visual inspections are used, with periodic examinations frequently employing close-up visual inspection methods (BIM, 2018; AASHTO, 2019). Bridge maintenance is essential to prevent deterioration and ensure traffic safety. Routine maintenance involves cleaning, small-scale repairs, and obstacle removal. Preventive Maintenance Program (PMP) minor includes small-scale repairs, replacement, and partial repainting. PMP major involves large-scale repairs, replacement, repainting, strengthening, and reconstruction. These measures are necessary to maintain the safety and integrity of bridges and ensure they can handle increasing traffic demands. The bridge engineer in charge of structural evaluation shall review the available plans, repair history, and inspection data to assess and arrange to obtain the required additional information as may be necessary to assist in the structural evaluation of the bridge. (Public Works and Government Services Canada, 2023).

The “bridge inspection manual” of Public Works and Government Services Canada outlines six types of bridge inspections: comprehensive, general, component, maintenance, special, and monitoring. Each inspection type involves different levels of examination, and various techniques are used to identify safety issues and track component performance over time. The findings of the study are documented, and the condition rating and priority code are adjusted accordingly. Inspections must be carried out by qualified personnel under the direction of a bridge engineer.

The performance of Finland's bridge maintenance is similar to Sweden's. Finland has less than 21,000 bridges, but the exact number is unknown due to voluntary registration by municipalities and private owners. Common issues in Finland include concrete weathering, waterproofing problems, and drainage and joint issues. The Finnish requirements mainly focus on road slabs, edge beams, transition structures, and drainage systems, and joints and drainage pipes must be cleaned annually. The increasing pollution burden is a significant hurdle in achieving the United Nations’ goals for a sustainable society (Zia *et al.*, 2023a). The contractor is responsible for annual inspections, and revisions with contractors have improved work performance (Andersson, 2022). To maintain bridges, engineers or teams conduct inspections to identify flaws and evaluate causes, structural suitability, and construction defects.

There is currently no mechanism in the Pakistan Highway Department for periodically assessing the state of bridges. Usually, money is used for annual maintenance funds as well as special maintenance funds. However, the two funds are mainly used for bridges that have previously demonstrated a major threat and level of deterioration. Moreover, due to inadequate bridge rehabilitation and engineering expertise, funds are spent on bridge aesthetics rather than necessary repairs.

In PR, inspections of bridges are conducted periodically. Different frequencies are fixed for different parts of the bridge. The minimum inspection time is 6 months, and the maximum is 5 years. A detailed inspection of bridges is necessary for effective planning and execution of

maintenance and repair work and for bridge replacement with minimal traffic disruption. This is particularly important for old bridges that may not meet current regulations and may have been damaged by weather and other factors (Indian Railway, 1998). Inspection aims to identify and quantify deterioration caused by various factors such as loads and environmental impacts (Bien *et al.*, 2007).

There are two types of inspections: general and technical. General inspections are superficial, general, principal, or special and are scheduled in the way and works manual (Manual, 1969). Technical inspections are carried out by technical staff and cover camber and distortion readings, rivet testing, and span movement measurements. Load-carrying capability is determined by bridge standards (Manual, 1992). There are two types of inspections: general inspections and technical inspections. General inspections are conducted once a year by an inspector of works for foundations, substructure, protection works, and obvious defects in superstructure like painting. The permanent way through which inspectors conduct general inspections twice a year for track on bridges, and waterways, oiling of roller bearings, cleanliness of top of abutments and piers, and obvious defects in substructure and superstructure (Manual, 1969).

The Assistant Executive Engineers (AENs) conduct general inspections annually for all aspects mentioned for the Inspector of Works (IOW) and Permanent Way Inspector (PWI). Joint inspections are conducted once a year for all bridges on the main line from Kiamari to Peshawar Cantt via loop and chord by Assistant Executive Engineers (AENs) and Assistant Ferry Crossing Engineers (AFXs), and entries are made and signed jointly in bridge registers maintained by Assistant Executive Engineers (AENs). Technical inspections are conducted by technical staff of the bridge branch and are based on the type of bridge and the frequency of inspection ranges from once a year to once in five years. Bridges with reverse camber, wrought iron/early steel spans, spans having rail and road traffic on the same deck, and girder spans on sections having more than 50 trains per 24 hours are inspected once every three years, and the foot-over bridges and road over bridges are inspected once every five years by the inspection team (Manual, 1992).

Structural Health Monitoring (SHM) ensures the long-term safety of large bridges. It allows for continuous and periodic assessments of civil infrastructure integrity. SHM systems have developed significantly over the years, especially in advanced sensing technology and sensors. (Yu & Ou, 2017). It is essential to establish an SHM system for the performance of bridges to monitor bridge performance and help bridge owners make the best choices. In SHM the Global Positioning System (GPS) is considered an important part. Multi-constellation GNSS uses have evolved into an essential choice for SHM systems with the overview of the BeiDou Navigation Satellite System (BDS) and the entire procedure of the Global Navigation Satellite System (GLONASS) (Xi *et al.*, 2021).

Expertise is needed in four areas to design and operate a bridge health monitoring system.

These are designing, constructing, operating, and maintaining long-span bridges, instrumentation technologies, graphical Computer-aided design (CAD) and information technologies, and numerical analytical technologies, for data broadcast, processing, and imagining (Wong, 2004). Owing to manual data gathering, the existing bridge examination practices are limited. A conceptual framework that integrates Building Information Modelling (BIM) and advanced computing and imaging technologies is proposed to improve these practices. This framework allows for detecting defects in bridge components such as cracking, corrosion, or settlement. The importance of selecting appropriate construction materials for sustainable construction is relevant to bridge maintenance as the choice of materials impacts bridges' longevity and maintenance requirements (Zia *et al.*, 2023b). BIM is used as the focal point for information collection throughout the project lifecycle, enabling engineers and inspectors to make more informed decisions about the structure's current condition. The proposed framework has the potential to revolutionize current bridge inspection practices and improve the management of bridge assets (Chan & Guan, 2016).

According to the Inspector of Ferry Crossing (IFX/Tech), Pakistan Railway (PR) uses the latest devices for testing bridges. These devices are strain smart gauges and Linear Variable Differential Transformer (LVDT). This information was obtained through personal communication with an IFX/Tech representative. While there is no publicly available reference material regarding the testing of bridges in the PR, the use of advanced devices by IFX/Tech is a positive step towards ensuring the safety and structural integrity of the railway bridges (Ahmad, 2023).

3. Research methodology

The research methodology for studying bridge maintenance involves a Google survey administered to assistant inspectors, inspectors, and engineers from seven divisions of PR. This survey aims to examine the effectiveness and efficiency of existing maintenance parameters and procedures for railway bridges in Pakistan. The questionnaire survey covers areas such as the importance of bridge maintenance, critical factors influencing maintenance, current railroad bridge standards, the efficiency of current maintenance procedures, specialized personnel requirements, common maintenance problems, factors influencing maintenance, inspection, funding, training, and technology. The area covered by these questionnaire survey covers the standard of bridge structure maintenance, important factors affecting maintenance, inspection, funding, training, existing railroad bridge structure standards, the effectiveness of present maintenance procedures, dedicated personnel requirements, common maintenance problems, and technology. In making decisions about the latest technology implementation, allotting the budget properly, and ensuring that maintenance techniques are effective and efficient, the findings can support bridge owners and operators in making decisions about new technology adoption, allocating resources appropriately, and ensuring that maintenance methods are effective and efficient. The areas that need additional study and development can also support the identification.

4. Results and discussion

4.1. Maintenance parameters of bridges

This study focuses on five significant bridge maintenance factors. These include regular inspection, funding, maintenance standards, training, and technology. Ensuring the safety of passengers and goods training all these factors play an essential role in maintaining the strength of the railroad bridge's structure. This study will thoroughly understand the elements that affect the standard of railway bridges and make recommendations for improving existing bridge maintenance techniques by exploring these factors in depth.

4.1.1. Standard of maintenance

For consistent and safe operation, the standard of maintenance refers to the level of attention and maintenance provided to a bridge. Methods, recommendations and rules are provided for maintaining, repairing, and monitoring. To identify specific advance maintenance plan and maintenance requirements, it is vital to recognize the bridge's design, operation, and construction. The plan must comprise steps for routine inspection and monitoring to determine and fix any deterioration or damage that could risk the integrity of the bridge. It should also specify the duties, timetables, and accountability for all bridge components of the structure.

Table-1: Important role in the maintenance of bridges

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Inspectors	58	69.0	69.0	69.0
	Supervisor	4	4.8	4.8	73.8
	Manager/Administrator	16	19.0	19.0	92.9
	Ministry	6	7.1	7.1	100.0
	Total	84	100.0	100.0	

The table-1 shows that 58 (69%) of the 84-participant stated that "inspectors" play an essential role in maintaining bridge structure. The next high figure is "ministry" with 6 (7.1%) respondents, and "manager/administrator" was selected by 16 (19%) respondents. Only 4 participants (4.8%) selected "supervisor" as their answer.

Most of the respondent's (69%) response is important to note, which might seem biased, were inspectors. The surveyed population perceives inspectors to show a vital role in the maintenance of bridge structures. However, inspectors are directly connected to the condition assessment and maintenance of bridge structures, this is not surprising. It makes sense to assume that they are more conscious of their duty to ensure the integrity, protection, and maintenance of the bridges in their jurisdiction. It is likewise significant to point out that the study was given to workforces at all categories of the railway organization involved in the maintenance of bridges: assistant inspectors, inspectors, engineers, supervisors, and

managers/administrators. Inspectors may have been the group with the most participants in the survey, but their answers were not the only ones considered. Despite the possibility of bias in the survey results, they still offer important information about how the population as a whole views the critical role inspectors play in maintaining bridges. The table-1 provides valuable insights into the perceived important role in bridge maintenance among the surveyed population and can be used to inform the discussion and conclusions of the research study.

Table-2: Important factors for the maintenance of bridges

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Regular inspections	8	9.5	9.5	9.5
	Timely repairs	50	59.5	59.5	69.0
	Replacement of damaged parts	9	10.7	10.7	79.8
	Use of high-quality materials	11	13.1	13.1	92.9
	Schedule Maintenance	6	7.1	7.1	100.0
	Total	84	100.0	100.0	

The table-2 shows that regular inspections received the lowest frequency and valid percentage with only 8 responses, accounting for 9.5% of the total responses. The majority of the participants, 59.5%, identified timely repairs as the most important factor for maintaining bridges, with 50 responses. The replacement of damaged parts received 10.7% of the responses with 9 participants identifying it as the most important factor. Similarly, using high-quality materials was identified as the most important factor by 13.1% of the participants with 11 responses. Finally, schedule maintenance received 7.1% of the responses, with 6 participants considering it the most important factor.

Table-3: Current standard of railway bridges in Pakistan

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very confident	1	1.2	1.2	1.2
	Confident	37	44.0	44.0	45.2
	Neutral	12	14.3	14.3	59.5
	Not confident	32	38.1	38.1	97.6
	Not at all confident	2	2.4	2.4	100.0
	Total	84	100.0	100.0	

Table-3 shows that out of the 84 participants, only 1 (1.2%) reported being “very confident” about the current standard of railway bridges, while 37 (44%) reported being “confident.” 12 participants (14.3%) were “neutral” in their response, indicating they neither had confidence nor lacked confidence in the current standard. 32 (38.1%) participants reported being “not confident” in the current standard, while only 2 participants (2.4%) reported being “not at all confident.”

Table-4: Current maintenance procedure of PR bridges

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very effective	6	7.1	7.1	7.1
	Somewhat effective	45	53.6	53.6	60.7
	Not Very Effective	31	36.9	36.9	97.6
	Not at all effective	2	2.4	2.4	100.0
	Total	84	100.0	100.0	

Table-4 presents that the majority of the 84 survey participants (53.6%) rated the current maintenance procedures for bridges under PR as somewhat effective, while 7.1% rated them as very effective. However, 36.9% of participants believed that the procedures were not very effective. Only 2.4% rated them as not at all effective. These results suggest room for improvement in current maintenance procedures to ensure safety and longevity of the bridges.

Table-5: Division of PR likely to require specialized personnel

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Peshawar	2	2.4	2.4	2.4
	Lahore	11	13.1	13.1	15.5
	Multan	1	1.2	1.2	16.7
	Sukkur	39	46.4	46.4	63.1
	Karchi	23	27.4	27.4	90.5
	Quetta	8	9.5	9.5	100.0
	Total	84	100.0	100.0	

Table-5 presents the frequency and percentage of the divisions of the PR that are likely to require specialized personnel for bridge maintenance. The divisions listed are Peshawar, Lahore, Multan, Sukkur, Karachi, and Quetta. The division that is most likely to need specialized staff for bridge maintenance was named by 2 (2.4%) of the 84 respondents as Peshawar, 11 (13.1%) as Lahore, 1 (1.2%) as Multan, 39 (46.4%) as Sukkur, 23 (27.4%) as Karachi, 8 (9.5%) Quetta, and 0 Rawalpindi.

Table-6: Common maintenance issues faced in bridges

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Structural damage (in superstructure Steel maintenance)	9	10.7	10.7	10.7
	Masonry maintenance (In Sub Structure Pier, Abutment, Wing wall, return wall, ballast wall maintenance)	60	71.4	71.4	82.1
	Track	14	16.7	16.7	98.8
	Others	1	1.2	1.2	100.0
	Total	84	100.0	100.0	

A total of 84 responses are included in Table-6, which provides information on the most frequent maintenance-related bridge issues. Masonry maintenance in the sub-structure is the most frequent problem, with a frequency of 60 and a valid percent of 71.4%. The track-related problem is the second most frequent, with a frequency of 14 and a valid percentage of 16.7%. Moreover, with a frequency of 9 and a valid percent of 10.7%, structural damage to the super-structure is the third most frequent problem. One response, however, does not fall into any of the other categories.

Table-7: Factors effecting on the maintenance of the bridge

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Age of the bridge	9	10.7	10.7	10.7
	Traffic volume	19	22.6	22.6	33.3
	Climate and environmental conditions	3	3.6	3.6	36.9
	Cost	9	10.7	10.7	47.6
	Safety considerations	44	52.4	52.4	100.0
	Total	84	100.0	100.0	

Table-7 shows that 52.4% of the respondents chose safety concerns as the factor most frequently affecting bridge maintenance. Traffic volume was ranked as the second most significant factor by 22.6% of respondents, followed by cost (10.7%), bridge age (10.7%), and climate and environmental conditions (3.6%). Overall, Table-7 offers useful insights into the perceived factors that respondents say impact bridge maintenance. Based on the perceived importance of each factor, these insights can be used to create effective maintenance strategies for bridges and prioritize maintenance efforts.

4.2. Inspection

Identifying structural or functional problems with a bridge requires inspection. Visual inspections, non-destructive testing, and load rating evaluations are all part of it. To find issues and fix them before they become serious safety hazards, routine inspections are crucial. Due to the stress and wear brought on by heavy trains passing frequently, railway bridges require a thorough and rigorous inspection regime.

Table-8: Importance of regular inspection of PR bridges

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very important	5	6.0	6.0	6.0
	Important	64	76.2	76.2	82.1
	Neutral	15	17.9	17.9	100.0
	Total	84	100.0	100.0	

Regular inspection of railway bridges is important, according to the majority of survey participants (82.1%), as shown in Table-8 who rated it as either "very important" or "important." Only 6% of respondents strongly agreed that routine inspection was important, while 76.2% thought it was important but not essential. In addition, 17.9% of the respondents chose "neutral" indicating that they are neither strongly in favour of nor against routine inspections of railway bridges. Overall, the survey indicates widespread awareness of the significance of routine inspections to ensure the functionality and safety of railway bridges.

Table-9: Current frequency of inspection PR bridges

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very frequently	1	1.2	1.2	1.2
	Frequently	9	10.7	10.7	11.9
	Occasionally	13	15.5	15.5	27.4
	Rarely	55	65.5	65.5	92.9
	Never	6	7.1	7.1	100.0
	Total	84	100.0	100.0	

The majority of respondents, as shown in Table-9, claimed that PR bridges are only occasionally (15.5%), occasionally (15.5%), and frequently (10.7%) inspected. Very Few (1.2%) or Never (7.1%) is selected by a minority of respondents and claimed that railway bridges are inspected.

Table-10: Proposed frequency of inspection purposes for PR bridges

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Monthly	8	9.5	9.5	9.5
	Quarterly	14	16.7	16.7	26.2
	Annually	55	65.5	65.5	91.7
	Other	7	8.3	8.3	100.0
	Total	84	100.0	100.0	

Table-10 contains information on the suggested inspection frequency for railway bridges. According to the data, 9.5% of the 84 respondents suggested monthly inspection, 16.7% suggested quarterly inspection, 65.5% recommended annual inspection, and 8.3% suggested other frequencies.

Table-11: Time spent by inspectors to inspect a bridge

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Less than 1 hour	53	63.1	63.1	63.1
	1-2 hours	18	21.4	21.4	84.5
	2-4 hours	9	10.7	10.7	95.2
	More than 4 hours	4	4.8	4.8	100.0
	Total	84	100.0	100.0	

The timings and duration of time given to the inspection of railway bridges has a significant role. According to Table-11, the majority of inspectors (63.1%) spent less than 1 hour inspecting a bridge, 21.4% of inspectors spent 1-2 hours, 10.7% spent 2-4 hours, and only 4.8% spent more than 4 hours inspecting a bridge.

4.3. Funding

The most important 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.

Table-12: The biggest challenges they face while inspecting bridges

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Limited funding	54	64.3	64.3	64.3
	Limited access to advanced technology	13	15.5	15.5	79.8
	Lack of skilled labour	16	19.0	19.0	98.8
	Difficulty in accessing certain areas of the bridge	1	1.2	1.2	100.0
	Total	84	100.0	100.0	

Table-12 reveals the major challenges faced for proper inspection of the bridges. According to 64.3% of respondents, a lack of funding is the biggest difficulty inspectors face when inspecting bridges. Limited access to cutting-edge technology is the second-largest challenge, according to 15.5% of respondents, and a shortage of skilled labour is the third-largest challenge, according to 19% of respondents.

Table-13: Importance of funding

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very Important	66	78.6	78.6	78.6
	Important	14	16.7	16.7	95.2
	Neutral	2	2.4	2.4	97.6
	Not Important	1	1.2	1.2	98.8
	Not at all Important	1	1.2	1.2	100.0
	Total	84	100.0	100.0	

Table-13 shows the importance of funding to properly maintain the railway bridges. The majority of respondents (78.6%) believed that funding is very important for maintaining railway bridges, including the response of 16.7% as important.

Table-14: Allocation of funding for the maintenance of bridges

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	64	76.2	76.2	76.2
	No	17	20.2	20.2	96.4
	Maybe	3	3.6	3.6	100.0
	Total	84	100.0	100.0	

According to Table-14, 76.2% of survey respondents think money should be set aside for bridge maintenance, while 20.2% disagree. 3.6% of the total are unsure. Most respondents acknowledge the significance of funding for bridge maintenance because timely repair and inspection are essential to ensuring the longevity and safety of bridges. Proper funding allocation is required to avoid accidents or bridge failures, which can be risky and expensive.

4.4. Training

Training is essential to bridge maintenance because it gives the workforce the knowledge, abilities, and education needed to complete maintenance tasks effectively and efficiently. Training programs should be developed to address the workforce's particular needs and bridge maintenance requirements. Regular refresher training may also be necessary to keep the workforce current with maintenance technology and techniques advancements. Adequate and effective training is crucial for successful bridge maintenance programs.

Table-15: Adequacy of training

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes, training is adequate	3	3.6	3.6	3.6
	Training could be improved	74	85.7	85.7	89.3
	Training is inadequate	9	10.7	10.7	100.0
	Total	84	100.0	100.0	

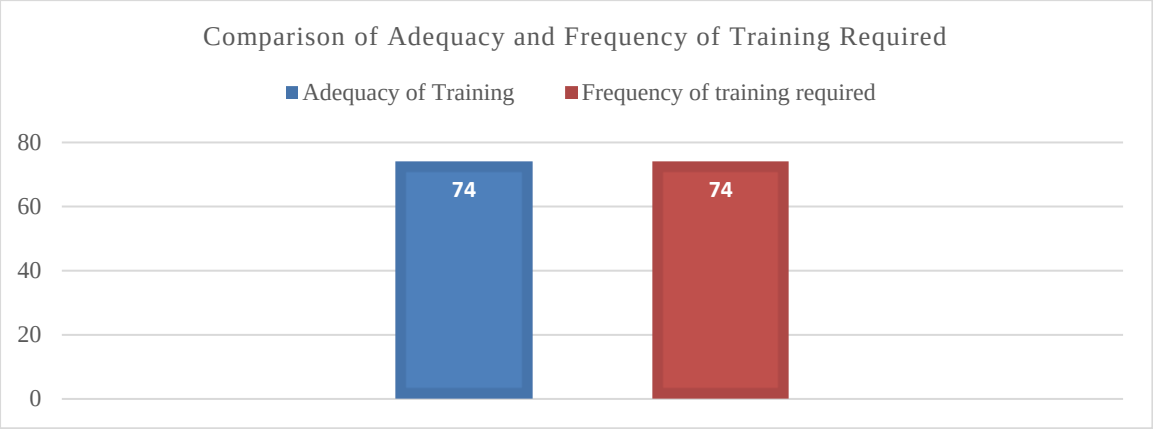
Table-15 shows participants' responses on the adequacy of training to identify issues on railway bridges. Out of the 84 participants, only 3 (3.6%) believe that the training is adequate. On the other hand, the majority of participants 72 (85.7%), believe that the training could be improved, while 9 (10.7%) believe that the training is inadequate.

Table-16: Frequency of training required

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Once a year	74	88.1	88.1	88.1
	After two years	4	4.8	4.8	92.9
	After three years	6	7.1	7.1	100.0
	Total	84	100.0	100.0	

Table-16 shows the proposed schedule of training as suggested by the participants. A total of 84 participants responded to the question. Most of the participants, i.e., 74 (88.1%) suggested that the training should be conducted once a year, while 4 (4.8%) participants suggested it should be conducted after two years, and 6 (7.1%) participants suggested it should be conducted after three years.

Figure 2: Comparison of adequacy and frequency of training required



The comparison in figure-2 highlights the majority opinion in both Table-15 and Table-16, emphasizing the need for improvement in training adequacy and the preference for conducting training sessions annually among the participants. There is a strong relation between both.

4.5. Technology

The use of 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 particular training and expertise and the cost of these technologies can be substantial.

Table-17: Role of technology in improving maintenance of PR bridges

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	None	2	2.4	2.4	2.4
	Limited	5	6.0	6.0	8.3
	Some	9	10.7	10.7	19.0
	Significant	64	76.2	76.2	95.2
	Critical	4	4.8	4.8	100.0
	Total	84	100.0	100.0	

Technology has a “significant” role, in improving the maintenance of railway bridges according to most of the respondents, 76.2% as shown in Table-17, also 4.8% of respondents

consider that technology's role as “critical.” Only a few percentages of respondents, the technology has no role in maintenance according to 2.4% of participants.

Table-18: Using technology in the condition assessment of bridges

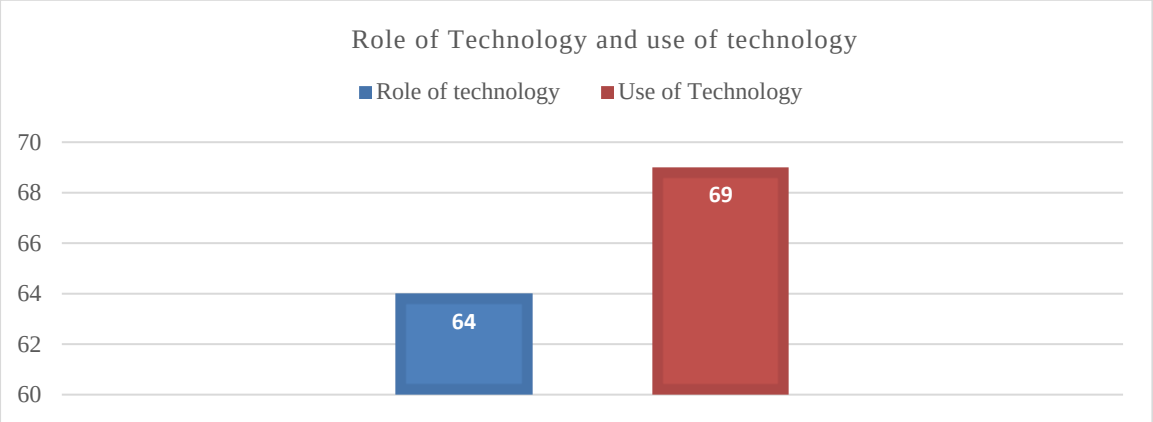
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Never	69	82.1	82.1	82.1
	Rarely	12	14.3	14.3	96.4
	Occasionally	2	2.4	2.4	98.8
	Frequently	1	1.2	1.2	100.0
	Total	84	100.0	100.0	

In the condition assessment of bridges, Table-18 represents the frequency and percentage of responses to the question about the usage of technology. Out of 84 respondents, only one respondent (1.2%) reported using technology frequently. The majority (82.1%) stated that they had not ever used technology for the assessment of bridge conditions. 14.3% of respondents reported they are using technology rarely, while only 2.4% stated it occasionally.

4.6. Comparison between the role of technology and the use of technology

Significant portion of respondents identify the importance of technology in bridge maintenance selected by most of the respondents and majority of them do not presently use technology for condition assessment of bridge structure. A possible gap between the awareness of technology's importance and its practical application in bridge inspections is indicated by the study.

Figure 3: Comparison of the role of technology role and use of technology



5. Conclusions and recommendations

5.1. Standard of Maintenance

In conclusion, the standard of maintenance is a critical parameter for ensuring the safe and efficient operation of bridges. The survey results of maintenance standards provide valuable

insights into the perceived important role and suggest that inspectors play an important role in bridge maintenance according to the majority of the respondents. The most important factors for bridge maintenance include timely repairs, the use of high-quality materials, and the replacement of damaged parts.

The current standard of railway bridges in Pakistan is perceived to be suboptimal by most respondents, with only a small percentage reporting confidence in the current standard. The current maintenance procedures are perceived to be somewhat effective but with room for improvement.

The divisions of Pakistan Railways (PR) that are most likely to require specialized personnel for bridge maintenance are Sukkur and Karachi, and the most common maintenance issues are related to masonry maintenance in the sub-structure, track maintenance, and structural damage in the super-structure.

A commonly perceived factor affecting bridge maintenance is safety considerations, followed by traffic volume. These provide valuable insights for the authorities to improve the maintenance procedures and ensure the safety and longevity of the bridges.

5.2. Regular inspection

A crucial parameter in ensuring the prompt detection of any structural or operational problems with railway bridges is regular inspection. The majority of survey participants pointed out the value of routine inspections. The majority of respondents indicated that inspections of railway bridges take place only rarely, which means that the frequency of inspections is insufficient. Bridge maintenance and management professionals can use the proposed frequency of inspection purposes table to develop a useful and effective inspection schedule. It was also discussed how long it takes inspectors to inspect a bridge, and it was found that most inspectors can finish the inspection in less than an hour. To ensure the continued safety and functionality of railway bridges, a thorough and rigorous inspection regime is required.

5.3. Funding

To maintain a bridge's functionality and safety, maintenance is required. Effective bridge maintenance requires adequate funding because it makes sure that the tools, materials, and labour are all available. Insufficient funding may cause maintenance to be put off, inspections to occur less frequently, and maintenance activities to be of lower quality. Limited funding is the biggest problem inspectors face when inspecting bridges, according to 64.3% of survey respondents. In another survey's majority of respondents acknowledged the critical role that funding plays in preserving the safety and functionality of railway bridges. To find and fix any damage or deterioration before it becomes a major issue, proper funding allocation for bridge maintenance is required. Insufficient funding could lead to bridge failures or accidents, which

can be costly and dangerous if maintenance is neglected. Therefore, to ensure public safety and well-being, authorities must allocate enough funding for bridge maintenance.

5.4. Training

The conclusions drawn from the findings indicate that training is a vital aspect of programs for maintaining bridges. To ensure that the workforce responsible for maintaining bridges has the skills and knowledge to carry out their duties efficiently and effectively, adequate and effective training programs are essential. However, the findings show that improvement is needed in the training delivered for identifying issues on railway bridges as only a small portion of participants thought it was adequate.

Most contributors selected that training should take place annually, which is valuable evidence for the organizations in charge of maintaining railway bridges. To keep the employees up to date with fresh developments in bridge maintenance technology and practices regular refresher training may also be essential.

Overall, it is understandable that the establishment of suitable and fruitful training plans should be a topmost priority for organizations in authority for maintaining railway bridges to ensure the achievement of their maintenance procedures. Training is an important aspect to take into account when developing and applying bridge maintenance programs.

5.5. Technology

In conclusion, in the maintenance of bridges technology has important effects. Drones, non-destructive testing methods, and computer software stand cases of technological developments that can result in further exact assessments, superior proficiency, and better-quality safety for both inspectors and the overall public. The price of these technologies can be high, and their operation might require particular knowledge and skills. To ensure the efficiency of bridge maintenance programs, it is vital to take technology into account in program development and operation. Agreed that the majority of respondents thought they had not ever used technology for condition assessment, the study results from the contributors propose that there is room for upgrading in the implementation of technology used for bridge condition assessment. There is a necessity for additional training programs to stretch the worker's skills to use these technologies efficiently, as incorporating advanced technology into bridge maintenance programs might be significant in enhanced maintenance and reduced risks related to bridge failure.

5.6. Recommendations

Based on the results, it is evident that Pakistan's railway bridge maintenance standards need to be improved. To ensure the longevity and safety of the bridges, the authorities responsible for

maintaining them should focus on timely repairs, the use of high-quality materials, and the replacement of damaged parts.

There is a need for more frequent inspections because most respondents said that railway bridge inspections only take place rarely. Bridge maintenance and management professionals can use the proposed frequency of inspection purposes table to develop a valuable and effective inspection schedule.

Effective bridge maintenance requires adequate funding. The government should set aside enough money to ensure that the equipment, materials, and labour 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.

The workforce responsible for maintaining railway bridges must be prepared with the skills and knowledge required to perform their duties effectively and efficiently. Regular training programs and refresher courses may be required to keep the workforce current with new developments in bridge maintenance technology and techniques.

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 must obtain the training and knowledge to operate these technologies skilfully.

Data Availability Statement

The information that supports the study's conclusions is presented in the MS Survey Data repository at

https://docs.google.com/spreadsheets/d/1k5F96RolBCzmqkmkLLlYNEs799dg_Qv08iuG1U_Jkb4/edit?usp=sharing

This data was together with Google Survey and is saved in Google Drive. To keep the contributors' privacy, all personally identifiable info has been separated. Owing to concerns about privacy or intellectual property, there might be limitations on information access.

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