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Potential of Artificial Intelligence (AI) Implementation for Improving Bridge Maintenance Management: A Case Study on Malaysia – Singapore Second Link Expressway

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Abstract

Maintenance is the activity carried out to conserve, care for, operate, and regulate buildings, facilities, equipment, building services, infrastructure, and its environment to meet current standards and maintain the value of utilities and facilities to be safe to use. Based on previous studies, lack of funds and technology are weak factors in bridge maintenance management. The existing system cannot accommodate extensive data, and the data analysis time is extended. This case study focuses on the Bridge built to connect Malaysia and Singapore, the Malaysia - Singapore Second Link Expressway. The study investigated the potential use of Artificial Intelligence (AI) to improve maintenance management of the Malaysia-Singapore Second Link Expressway. This study aims to examine the current challenges of technology implementation in maintenance management and further discuss the potential performance of AI to improve maintenance management. The study used qualitative methods with a semi-structured interview approach. The respondents involved consisted of four people: the assistant director of operational monitoring, a civil engineer, and an assistant engineer from LLM and PLUS Berhad. The collected data was analyzed using content analysis to provide information from respondents on the potential implementation of AI to improve bridge maintenance management of the Malaysia - Singapore Second Link Expressway. The main finding is that researchers are aware of current technologies being implemented, such as BIM and IoT, along with the significant challenges faced, namely cultural clarity and technology. The second most essential findings leading to the potential implementation of AI are efficiency and effectiveness in the workplace, quality improvement, and product safety and enhancement. In conclusion, this research contributes to an in-depth understanding of technological practices, current challenges, and potential implementation of AI in improving bridge maintenance management for the Malaysia - Singapore Second Link Expressway.

1. Introduction

Artificial Intelligence (AI), an advanced digital technology, has transformed most sectors in Malaysia, including the construction and maintenance industry. AI fields such as machine learning, natural language processing, robotics, computer vision, optimization, automatic planning, and scheduling were utilized to solve complex problems and assist people in making decisions in the real world (Abioye *et al.,* 2021). In response to weak performance growth, researchers began investigating AI to simplify operations and increase production (Regona *et al.,* 2022). Maintenance was a sector in great need of AI applications, especially for the maintenance management of infrastructure such as bridges. Reliable records of past and current bridge conditions were needed in bridge maintenance practice for engineers to plan preventive maintenance operations (Shim *et al.,* 2017). Despite this, construction remained one of the least digitized industries in the world and continued to need help with the beneficial use of AI and other digital technologies. However, many gray areas exist in studying AI application trends, future potential, and adoption barriers in the construction industry (Abioye *et al.,* 2021). The maintenance phase of complex engineering assets was the longest-lasting and most resource-intensive phase of their life cycle, and more efficient maintenance management could contribute to more efficient use of resources and cost optimization (D'Amico, 2022). Therefore, it was essential to study the potential application of AI, especially in maintenance management, to make it a core component of adopting technology in the construction sector.

1.1 Research Background

Due to many surrounding factors, every built structure is not exempt from defects and structural damage in building elements (Taupek, 2016). These damages and defects require maintenance activities to repair them. Bridges deteriorate over time due to creep, corrosion, and cyclic stress (Nettis *et al.,* 2022). Based on inspection and evaluation, maintenance activities are usually performed according to schedule or after infrastructure failure (Wu *et al.,* 2021). Bridge maintenance ensures that all bridge components remain in working and adequate condition so that the structure can continue to serve its intended purpose for an extended period, as intended when it was designed and built (Wu *et al.,* 2021). Due to the lack of mechanization in the industry and the fact that most of it still needs to be done manually, managing bridge maintenance can be dangerous, time-consuming, and costly (Chen & Hoang, 2014).

In most developed countries, such as Japan, the latest technology has been widely used in maintenance management (Chen & Hoang, 2014). In recent years, implementing AI techniques has increased mechanization and provided superior competitive advantages over more conventional methods. The subfield of artificial intelligence (AI) has been used to solve complex problems and facilitate decision-making in difficult real-world situations. The fourth industrial revolution, also known as Industry 4.0, is focused on automation, data-driven technology, and implementing advanced artificial intelligence techniques in the manufacturing sector (Abioye *et al.,* 2021). based on many previous studies, applying AI in infrastructure maintenance is challenging. However, the maintenance industry must strengthen efforts to apply AI more widely to improve bridge maintenance management procedures. Using AI in construction will benefit industry players and the country, especially under maintenance management. These systems will mature and develop in the next few decades, making it easier to imagine maintaining the structure with them. Therefore, this study examines the potential implementation of Artificial Intelligence (AI) in parallel with the current challenges of technology implementation in maintenance management.

1.2 Problem Statements

The construction of bridges has played a crucial role in the evolution and development of human society, with most bridges in Malaysia being concrete. The construction process has evolved, with the Malaysia-Singapore Second Link Expressway being a prime example of this. Bridge maintenance planning (BMP) faced numerous challenges due to the age and wear and tear of existing bridges, as well as the need for regular inspections and maintenance (Hurt, 2016). Bridges are complex structures that often encounter fluctuating temperatures, moisture, and forces, making them difficult to observe and maintain (Huthwohl, 2016). Each country's laws influenced bridge inspections, and those responsible for administering bridge repair had to adhere to strict regulations for environmental protection (Liu *et al.*, 2020). This made upkeep more time-consuming and challenging.

According to Brownjohn & Moyo (2001), Bridge Health Monitoring (BHM) was used to monitor the Malaysia–Singapore Second Link Expressway. BHM helped bridge designers understand how bridges functioned by detecting signs of deterioration, calculating the risk of collapse, detecting indications of excess, and estimating the remaining life of the bridge. However, constant monitoring generated a large amount of data, which was challenging to store and took longer for engineers to analyze. Implementing BHM was the most challenging task because it required intelligent data analysis and selecting which data processing and interpretation duties to prioritize. In Malaysia, the exorbitant start-up costs associated with using AI technology in construction work have emerged as a critical barrier to widespread adoption in the construction sector (Omar *et al.,* 2022). AI systems

could have reduced the danger of surveillance, alerted agents to potential problems, and been used to educate individuals about the likelihood of the bridge breaking. AI systems were rule-based expert systems that employed multiple information sources to assist reviewers (Marques, 2021).

However, more sophisticated technology must have been developed to utilize AI in repair management (Omar *et al.,* 2022). Cost factors made it difficult for developing nations like Malaysia to use AI in the construction industry, as most development corporations and lesser private companies require additional funding to advance this technology. Additionally, many obstacles to launching a business in the construction industry were present (Omar *et al.,* 2022). In conclusion, standard maintenance management methods had to be enhanced to resolve all employee issues and achieve the best maintenance management outcomes. This study examined how Artificial Intelligence (AI) could have been utilized and what would have been required to enhance the management of the Malaysia–Singapore Second Link Expressway. Therefore, the objectives of the study are to identify the current challenges and potential of Artificial Intelligence (AI) implementation in improving maintenance management for the Malaysia – Singapore Second Link Expressway.

The Malaysia-Singapore Second Link Expressway, a bridge connecting Malaysia and Singapore, has significant implications for the construction industry. By implementing AI in maintenance management, the bridge can be improved, and the use of the bridge can be launched further. Maintenance companies can solve problems faced during bridge monitoring, reducing workers' risks and providing more comprehensive solutions than traditional methods. This study contributes to the body of knowledge by providing new insights for academics, researchers, management and maintenance teams, and developers focused on bridge construction. It offers a new approach to AI application in management and maintenance, providing opportunities for in-depth studies and systematic management with AI knowledge. This study reduces work risks and improves care, highlighting the importance of AI in bridge maintenance management. In conclusion, the application of AI in bridge maintenance management should be given a chance and best utilized to improve maintenance management levels in a better direction.

2. Literature Review

2.1 Maintenance Management in Bridge Construction

Maintenance management is crucial for the safety and functionality of bridges, which are essential infrastructures that connect people and places. It involves planning, coordinating, and controlling operations to maintain bridges in good condition, including inspection, maintenance, and restoration. However, the complexity of bridge management and maintenance data makes manual processing impossible. Big data processing technologies like cloud computing and deep learning are used for data storage, cleaning, and analysis. According to Byun (2021), Bridge management systems (BMS) have been developed worldwide to maintain the performance of newly constructed and existing bridges. However, these 2D systems help to analyze and manage massive data. A bridge's remaining life and worth of a bridge can be used as scientific evidence to make informed decisions. Bridge maintenance administration requires a high-tech system due to its significance in promoting economic and social progress. Bridges are essential for the transportation system and are recognized as one of the most critical infrastructures.

2.2 Bridge Maintenance Management Overview

Effective maintenance management of major bridges should be based on their actual condition. A suitable scheme for bridge inspection carefully allows for the identification of damage, malfunction, and wear of some bridge elements and ancillary items before any adverse risk befalls the bridge structure and users (Jensen, 2013). Based on inspection results, strategies can be easily updated to facilitate risk assessment and improve maintenance management skills (Rafiq, 2010). Bridge inspections are usually done periodically according to a set schedule. A quality inspection comes from the way or method used to inspect the bridge. Three levels of inspection can be done to find out the problem on the bridge:

(i) Routine inspection
(ii) General inspection
(iii) Special inspection

2.3 Importance of Bridge Maintenance Management

Bridge maintenance is a critical aspect of infrastructure management, ensuring the bridge's safety, functionality, and longevity. Regular maintenance is required to prevent potential failures and improve the infrastructure's deteriorating condition. Inadequate maintenance can increase structural defects, reduce load-bearing capacity, and increase vulnerability to extreme events (Frangopol and Soliman, 2017). Proper maintenance practices, including inspection, monitoring, and restoration, are required to identify structural deterioration, detect safety hazards, and implement timely repair or rehabilitation measures (Mikhailov *et al.,* 2019). Effective maintenance

can significantly enhance bridges' durability and overall performance, extending their service life. It is also essential to optimize resource allocation, focus on critical maintenance requirements, and implement cost-effective strategies (Li *et al.,* 2020). Bridge maintenance management is also crucial for preserving and enhancing infrastructure resilience, considering the effects of climate change, catastrophic events, and evolving traffic patterns (Bocchini *et al.,* 2018). By implementing effective maintenance practices, transportation agencies and infrastructure owners can safeguard the integrity and functionality of bridge infrastructure for the benefit of society.

2.4 Technology Implementation in Bridge Maintenance Management

2.4.1 BIM

BIM is crucial for managing information throughout a project's life cycle, enhancing bridge-building processes from design to operation (Chipman *et al.,* 2016). Shim and Chipman developed an infinite bridge data management system using a schematic information system and BIM authoring. This system can be customized for other bridge types, saving time and money (Shim *et al.,* 2017). A uniform BIM standard is essential for efficient information sharing across phases and software, reducing duplicated effort (Wan, 2019).

2.4.2 IoT

The Internet of Things (IoT) is expected to reach 75 billion connected devices by 2025, a nearly triple growth from 2019. IoT ecosystems consist of web-enabled intelligent devices that gather, transmit, and act on data from their surroundings. IoTs have been used to inform asset maintenance management decision-making in part (Brous *et al.,* 2017). Sandoval *et al.* (2016) suggest that IoTs can gather bridge sensor data regularly or in real-time to provide a scientific foundation for maintenance choices. With an estimated 75 billion internet-connected devices by 2025, IoT can create a ubiquitous global computer network. Adi *et al.* (2020) argue that IoT facilitates the interchange of meaningful information gathered by sensors, which is evaluated for real-world decision-making and action.

2.4.3 Big Data

Roshandeh (2014), highlighted that big data has been widely applied in bridge engineering, including fatigue life analysis, degradation modeling, and cost optimization. Cui *et al.* (2023) highlights the use of real-time dynamic health monitoring systems to collect extensive data for condition assessment and damage detection. However, the application of big data in bridge engineering is still in its early stages. MDEC (2022) predicts that Malaysia's big data analytics market will grow to approximately RM7.85 billion by 2025, compared to US$1.1 billion in 2021. Table 1 shows the technology implementation in bridge maintenance management discussed by previous studies.

Table 1 *Technology implementation in bridge maintenance management*

No	Technology Implementation in Bridge Maintenance Management	Author
1	BIM	Chipman *et al.* (2016) Shim (2017) Wan *et al.* (2019)
2	IOT	Sandoval *et al.* (2016) Brous *et al.* (2017) Adi *et al.* (2020)
3	Big Data	Roshandeh (2014) Cui *et al.* (2023) MDEC (2022)

2.5 Challenges of Technology Implementation

2.5.1 Cultural Issues and Explainable

Technology integration in new systems faces challenges such as interpretability and cultural issues. Cultural challenges include bias, diversity, and social influence, while explainability is associated with the technical system's openness and interpretability. Organizational culture can also pose issues, such as resistance to change,

fear of job loss, and scepticism about the efficacy of the technology. Training programs and activities are crucial to address these challenges to close the skills gap between the current workforce and the technical requirements of new technologies (Danaher, 2018). Understanding the decision-making process of emerging technology systems is essential to maintain accountability, fairness, and user confidence (Li *et al.,* 2022). New technology systems should conform to social standards and prevent fostering or escalating harmful cultural stereotypes (Mittelstadt *et al.,* 2019). Addressing public concerns by providing concise explanations of the advantages and risks of the technology is essential for promoting public acceptance. A thorough understanding of cultural challenges and a dedication to explainability are necessary to integrate technology in bridge maintenance management successfully.

2.5.2 Computing Power and Internet Connectivity

The importance of computing in bridge maintenance management has significantly increased with the introduction of advanced technologies like BIM, IoT, big data, and AI. These technologies have transformed bridge structures' efficiency, safety, and stability. However, the main challenge in implementing these technologies is the demand for substantial computing power, which can hinder the analysis of structural health data and the detection of potential problems (Malekloo *et al.,* 2022). Another major challenge is relying on a reliable, high-speed Internet connection for transparent data transfer and communication between bridge nodes and central monitoring systems (Abdulkarem *et al.,* 2020). Many bridges are located in remote or rugged locations, where internet connectivity may be more reliable and available. Investing in state-of-the-art computing capabilities enables on-site data processing, reducing reliance on core computing resources. Researchers have investigated the use of mesh networks and satellite communications to overcome the shortcomings of the Internet and understand different communication strategies for bridge maintenance in remote areas. The successful implementation of bridge maintenance technologies depends on overcoming the challenges associated with a lack of access to computers and the Internet. A thorough understanding of cultural challenges and a dedication to explainability are necessary to integrate technology in bridge maintenance management successfully.

2.5.3 Talent Shortage

Technology implementation requires skilled professionals with machine learning, data analysis, and programming expertise. Ismail *et al.* (2019) stated that although the demand for IR 4.0 technology talent is increasing rapidly, more qualified individuals must meet this demand. The talent shortage in implementing IR 4.0 technology is a significant challenge for organizations seeking to utilize new technologies successfully. Despite the increasing demand for skilled professionals in machine learning, data analysis, and programming, more qualified individuals are needed. This talent shortage poses significant challenges to the transformation of business operations, with an expenditure budget of RM 210 million from 2019 to 2021. Addressing this issue is crucial for successful technology implementation and fostering research, innovation, and development (Behie *et al.,* 2023).

2.5.4 Ethics and Governance

Ethical considerations are crucial in integrating advanced technology into bridge maintenance, as it presents managerial challenges. These challenges include addressing privacy and data security issues and ensuring algorithmic fairness and regulatory compliance. Albahri *et al.* (2023) state the importance of obtaining critical infrastructure data and highlight the ethical responsibilities of stakeholders in ensuring the confidentiality and integrity of information collected from bridge monitoring systems. Stakeholder participation is essential for promoting participatory decision-making and ensuring a fair distribution of technological benefits (El Khatib *et al.,* 2022). Robust encryption and access control methods are necessary to address ethical concerns related to data privacy and security in bridge maintenance. Ethical considerations require thoroughly examining algorithms to identify and correct biases, ensuring fair and equitable outcomes (O'Neil, 2017). Navigating these complex ethical considerations is essential for the responsible and successful use of technology in bridge maintenance management.

2.5.5 High Initial Costs

Investments in technology, including infrastructure, hardware, software, and qualified personnel, can be costly and time-consuming. The initial costs of developing and deploying new systems can pose significant challenges for organizations (Maqbool, 2023). Governments can use tax credits, subsidy tools, and internal initiatives to overcome these obstacles. The upfront costs of acquiring IR 4.0 technology and building infrastructure can be a significant barrier for smaller organizations, which may need more financial resources to make substantial initial

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investments (Chui *et al.,* 2018). Mhlanga David (2020) notes that high start-up costs frequently discourage smaller organizations from adopting new technologies. Guo *et al.* (2020) state that companies must carefully evaluate the costs and benefits of IR 4.0 technology projects to ensure their viability and return on investment. Governments should employ tax credits, subsidy tools, and internal initiatives to overcome these financial challenges. Table 2 shows the challenges of technology implementation discussed by previous studies.

Table 2 *Challenges of technology implementation*

No	Challenges of Technology Implementation	Author
1	Cultural Issues and Explainable	Danaher (2018) Li *et al.* (2022) Mittelstadt *et al.* (2019) Monuko *et al.* (2020)
2	Computing Power and Internet Connectivity	Malekloo *et al.* (2022) Abdulkarem *et al,* (2020)
3	Talent Shortage	Ismail *et al.* (2019) Behie (2023)
4	Ethics and Governance	Albahri *et al.* (2023) El Khatib *et al.* (2022) O'Neil (2017)
5	High Initial Costs	Maqbool (2023) Chui *et al.* (2018) Mhlanga & David (2020) Guo *et al.* (2020)

2.6 Potential of Artificial Intelligence in Bridge Maintenance

2.6.1 Competitive advantages

As a result, the suggested AI technique is a viable tool for assisting bridge maintenance decision-makers (Cheng & Hoang, 2014). According to Pokorni (2021), AI may be used in dependability and maintenance. According to a literature study, AI is used more in maintenance than in trustworthiness. Progress in artificial intelligence is unavoidable; hence, it is critical to understand its possible uses in reliability and maintenance and its potential flaws (Pokorni, 2021). The use of artificial intelligence technology enhances the development and progress of automation while also resolving difficult control concerns (Wang, 2014). It has the advantages of fast data acquisition, high resolution, and easy operation (Zhang & Yuen, 2022).

2.6.2 Efficiency and effectiveness in the workplace

Artificial Intelligence (AI), the dominating digital technology in recent years, has substantially contributed to improving corporate operations, service procedures, and industrial production (Abioye, 2021). This is because AI allows people to execute previously impossible activities rapidly. Artificial intelligence offers significant potential advantages for both the public and corporate sectors. Better planning, targeting, and customization of government services may provide a much-needed quantum leap in effectiveness and efficacy (Chui, 2017). The Malaysian government owns many bridges, which is particularly valuable for improving government services.

2.6.3 Product quality and safety improvement

Previous research findings emphasized the benefits of artificial intelligence in bridge condition monitoring and demonstrated its potential use in network-level decision-making for preventative maintenance (Lim & Chi, 2019). Artificial intelligence applications boost the development and progress of automation while also resolving complicated control concerns (Wang, 2014). The designed robot system can perform remote bridge inspections while lowering human dangers and increasing efficiency and data dependability, allowing for more rational bridge maintenance methods (Lee *et al.,* 2009).

2.6.4 Enhanced operations

An intelligent society analyses human needs using AI to create the most efficient automated operational procedures, taking issues and stimuli into account humanely, with structures that can collect and learn human behaviours in a modern digital setting (Foresti, 2020). As a result, AI can improve operations, notably in the administration of bridge maintenance, via the analysis and subsequent examination of bridge issues. The industry's goal of lowering operating costs has driven asset owners to use novel asset maintenance technology (Samatas, 2021). Table 3 shows the potential of artificial intelligence in bridge maintenance management highlighted by previous studies.

Table 3 *Potential of artificial intelligence in bridge maintenance management*

No	The Potential of Artificial Intelligence in Bridge Maintenance Management	Author
1	Competitive advantages	Zhang & Yuen (2022) Cheng & Hoang (2014) Pokorni (2021) Wang (2014)
2	Efficiency and effectiveness in the workplace	Abioye *et al.* (2021) Chui *et al.* (2017)
3	Product quality and safety improvement	Lim & Chi (2019) Wang (2014) Lee *et al.* (2009)
4	Enhanced Operations	Samatas *et al.* (2021) Foresti (2020)

3. Research Methodology

3.1 Research Design

This study used a qualitative method approach to achieve the objectives set. According to Crawford and Irving (2009), a qualitative research design was deemed suitable for exploratory research. Given the nature of exploration, case studies were employed as the primary research strategy, and data collection was carried out through semi-structured interviews and document analysis as a research technique (Goldblatt, 2011). The purpose of semi-structured interviews was to obtain accurate information related to the study through interviews with individuals associated with the conducted study, such as engineers, facility engineers, facility managers, maintenance managers, contractors, maintenance contractors, architects, and other parties involved in the work of maintenance and maintenance management. Qualitative research only required a few respondents, but it could obtain quality data by focusing only on a small sample in one group (Moser, 2018). Appendix A shows several phases of the methodological flow used in this study.

3.2 Malaysia – Singapore Second Link Expressway: A Case Study

The Malaysia-Singapore Second Link Highway, inaugurated in 1998, connects the Johor-Singapore Causeway and has been designed by UEM for thirty years. The bridge connects the terminal 1.92 kilometres above the sea and Singapore's Ayer Rajah Expressway. The Malaysian government and Singapore signed an international agreement in 1994 specifying the bridge's design, building, operation, and maintenance duties. The bridge is faster than the Causeway due to improved traffic flow in both directions. In 1980, Johor Menteri Besar Othman Saat proposed a second relationship between Malaysia and Singapore, with Gelang Patah proposing to reduce the number of vehicles on the slope. Despite the proposed changes, traffic flow remains congested during festive holidays and peak times. Each government builds its part of the bridge, including a 44-kilometer road, a Customs, Immigration, and Quarantine complex, three toll plazas, two rest areas, and other services and facilities. The bridge can accommodate 200,000 cars per day and is still used by Malaysians and Singaporeans.

3.3 Data Collection

Data collection was essential to the research methodology, as it allowed researchers to gather relevant and reliable information to address their research questions. This process involved identifying and selecting appropriate data sources, such as surveys, interviews, observations, and existing databases. A study by Poth (2022) used a mixed methods approach involving qualitative and quantitative data collection techniques. Interviews were conducted with participants to gather in-depth insights into their experiences and perceptions and administered surveys to

collect numerical data for statistical analysis. In another study by Sutton (2015), data collection involved direct observation, field notes, and video recording of participant behaviour. This method allowed the collection of rich and detailed data, which was then analyzed using thematic analysis. Overall, the data collection process in methodological research was essential to gather diverse and robust information, allowing researchers to draw informed conclusions and contribute to knowledge in their respective fields.

3.4 Data Analysis

Data analysis was the main component that provided results from data collection and was used as a basis for decision-making. The primary purpose of data analysis was to make informed decisions based on a better understanding of the available data. Among the steps involved in analyzing the data was collecting data through interviews with the parties involved. Next, each data received was edited and compiled. Then, it went through the process of data interpretation, and all the data that had been available was processed through reporting and visualization using data content analysis. Finally, decision-making was done after all data processes were done. In this study, qualitative content analysis was used because it was a widespread method in the field of research (Ruslin *et al.,* 2022). Data collected through interviews (primary data) and literature review (secondary data) answered all questions and achieved the study's goals.

4. Results and Discussion

The study uses qualitative methods collected through virtual interviews, including mobile phone communications, Google Meet, and other device tools that contribute to hybrid data collection. Since this study is a case study, it is difficult for researchers to get the right respondents. At the same time, artificial intelligence (AI) is a new technology, that takes work to get respondents who know it. In the early stages, the researcher contacted the respondent via company phone call but was advised to contact the respondent via the email provided and call back for certainty. The number of respondents were set from the beginning to facilitate work to find information and get the respondent. However, only two representatives from the two maintenance management companies agreed to cooperate in providing feedback to this interview. Data collection took approximately two months and two days, from October 1, 2023, to December 2, 2023, for all four respondents. Before the real data collection was conducted, the pilot test undertaken to test the instrument can be used and easy to understand by the respondents. Table 4 shows the pilot test results based on the respondent's comments.

Table 4 *Pilot test*

No.	Comments	Improvement
1.	No column for Experience in Bridge Maintenance on Malaysia – Singapore Second Link Expressway in respondent background (Section A)	The improvement by putting the new column for Experience in Bridge Maintenance on Malaysia – Singapore Second Link Expressway in respondent background (Section A)
2.	Confused about the flow arrangement of questions in each section	Corrected the arrangement of the questions
3.	The questions in section E are quite difficult to interpret and difficult to understand	The question is changed to a sentence form that is easier to understand
4.	Several questions are combined into one question for sections C – D	The questions were changed and summarized into one short question
5.	Need to check the grammatical error	The grammatical error in every question has been corrected

4.1 Respondent's Background

As for the qualitative study method, respondents were approached through the interview method. Speak directly or through online conversations. It is essential to ensure that the respondents are in advance for these types of case studies to ensure that the data obtained is accurate and can achieve the objectives set. The correct determination of respondents also provides that they can answer the questions asked based on their knowledge and experience throughout the work. Before starting a question that achieves objectives, the respondent's background should be stated to complete the demographic collection status. The respondents' set includes 'company name,'' position,'' working experience,' and 'scope work.' For this case study, the respondents focused on two companies managing infrastructure in Malaysia: PLUS Berhad and Lembaga Lebuhraya Malaysia (LLM). The two companies selected were based on a case study focused on Malaysia's second link bridge - Singapore. However, only two representatives from each company made the total number of respondents four. Respondents

include an assistant director of operations monitoring, a civil engineer, and an associate civil engineer. Table 5, shows the brief details of the respondents. Based on the analysis results, the respondents had sufficient knowledge and experience to answer the questions asked.

Table 5 *Respondents' background*

Respondents (R)	Company	Positions	Experience in Bridge Maintenance	Experience in Maintenance of Malaysia – Singapore	Scope of Work
R1	PLUS	Civil Engineer (Southern Region Asset Maintenance and Management Department)	13 years	8 years	• Manage and plan maintenance • Give instructions on maintenance works • Supervise maintenance works
R2	PLUS	Associate Civil Engineer (Southern region Asset Maintenance and Management Department)	7 years	5 years	• Perform periodic maintenance • Support civil engineers in the implementation of maintenance • Collect road and bridges data
R3	LLM	Assistant director of operations monitoring	20 years	17 years	• Conducting risk assessments • Organizing coordination meeting Supervising
R4	LLM	Assistant engineer (civil) of the southern region	10 years	6 years	• Perform periodic maintenance • Support civil engineers in the implementation of maintenance • Collect road and bridges data

4.2 Introduction to Artificial Intelligence (AI) Implementation for Improving Bridge Maintenance Management for Malaysia – Singapore Second Link Expressway

To achieve the objectives, it is essential to ensure that respondents have sufficient knowledge and experience to answer every question asked, especially about the implementation of AI in maintenance management as well as the application of current technologies and challenges issues faced during the management of the Malaysia-Singapore Second Link Expressway bridge. Questions about the respondents' experience and knowledge of Artificial Intelligence (AI) are issued. All respondents provided answers based on their experience and expertise, all of whom had yet to gain specific experience in bridge maintenance management using AI applications. Based on their knowledge and expertise, all respondents currently use IR 4.0 technologies, such as IoT and BIM, for bridge maintenance management methods. This helps researchers understand the current practices and technologies used at the Malaysia - Singapore Second Link Expressway. Here are the statements from four respondents who responded based on their knowledge and understanding of AI's application to bridge maintenance management.

"Artificial Intelligence (AI) application in bridge maintenance has evolved worldwide. However, Artificial Intelligence (AI) has yet to be introduced or developed in bridge maintenance management in Malaysia. But there was just an early exposure to workers, especially in the operations and monitoring section." (R1)

Despite significant global breakthroughs in using artificial intelligence (AI) for bridge maintenance applications, Malaysia has not yet wholly integrated or developed AI for its bridge maintenance management system. Besides that, Respondent 3 stated that.

"Our team was previously exposed to using Artificial Intelligence (AI) in Malaysia through a briefing session with technology developers outside the organization. However, it is only an early exposure, and the stage of development has not yet been determined. At the moment, we are just focusing on the development of BIM and IoT and Big Data technology in the maintenance and operation management of the infrastructure." (R3)

The integration of Building Information Modelling (BIM) and Big Data and IoT technologies is being prioritized for efficient management of infrastructure operations and maintenance for the Malaysia – Singapore Second Link Expressway. The following is R2's statement regarding his knowledge of AI in Malaysia.

"Based on my knowledge, there is an application of Artificial Intelligence (AI) in Malaysia, but it focuses on building construction, operation, and maintenance. As for the management of bridge maintenance, no technology developer has yet been able to meet the requirements and specifications required by us to develop this Artificial Intelligence application." (R2)

According to R4, Malaysia acknowledges AI applications in building construction, operation, and maintenance, but challenges arise in finding developers capable of meeting specific requirements for bridge maintenance management.

"AI technology belongs to IR 4.0 and is comparable to BIM, IoT, and Big Data. It is a way-facilitating technology that can bring benefits such as time savings and operating costs. It is also able to help save workforce in doing activities, especially involving monitoring the state of the bridge" (R4)

Respondents 1, 2, 3, and 4 expressed similar feedback on their knowledge and experience using Artificial Intelligence (AI). This helps researchers learn that Artificial Intelligence has yet to be fully developed and introduced in Malaysia, especially in the bridge maintenance sector. Nevertheless, it was found that they were given initial exposure by organizations in connection with Artificial Intelligence (AI) as they could explain based on their knowledge of which Artificial Intelligence is an IR 4.0 technology.

Introduction to the implementation of Artificial Intelligence (AI) to improve bridge maintenance management for the Malaysia – Singapore Second Link Expressway is still in the starting stage. Respondents stated they had not yet applied Artificial Intelligence (AI) technology in maintenance management. Nevertheless, they have been exposed early to using Artificial Intelligence (AI) in Malaysia. Through the response, the researchers concluded that the application of Artificial Intelligence (AI) in Malaysia is not yet comprehensive and has not wholly entered the operational and maintenance sector (Omar *et al.,* 2022). Table 6 below shows the summary of the introduction of Artificial Intelligence (AI) to improve bridge maintenance management found among the respondents. Table 6 shows the summary of the introduction of AI implementation for improving bridge maintenance management for the Malaysia-Singapore second link expressway.

Table 6 *Summary of introduction to artificial intelligence (AI) implementation for improving bridge maintenance management for Malaysia – Singapore second link expressway*

Statement	R1	R2	R3	R4
Introduction to Artificial Intelligence (AI) Implementation for Improving Bridge Maintenance Management for Malaysia – Singapore Second Link Expressway.				
Never been involved with a project that uses AI	✓	✓	✓	✓
Just an early exposure	✓	✓	✓	✓
Maintenance of bridges in Malaysia has yet to apply AI	✓	✓	✓	✓
Use of BIM, IoT, and Big Data technology.	✓	✓	✓	✓

4.3 The Current Challenges of Technology Implementation in Bridge Maintenance Management for The Malaysia – Singapore Second Link Expressway

The question is divided into two parts to answer the first objective of the technological implementation challenge for managing bridge maintenance. The first part is the IR 4.0 technology developed in Malaysia: BIM, IoT, and Big Data. This question helps researchers understand clearly and more deeply the current technology used and being

developed by maintenance management in Malaysia – Singapore Second Link Expressway. Respondent 1 stated that the organization's use of Building Information Modelling (BIM) is restricted to the design phase of infrastructure development projects. Here is the statement given by the respondent.

"BIM is still in development; its use in our organization is only in infrastructure construction projects involving the design phase. Special groups have been trained and sent to attend special courses of exposure to the operation of these technologies. The development of the technology took a long time due to a lack of technologists who could not be met." (R1)

Respondent stated that the bridge management and maintenance sector necessitate collaboration with outside specialists for comprehensive research and technical advancement during operation and maintenance stages.

"The bridge management and maintenance sector had particular specifications and requirements to be met before a technology can be developed. The organization has been working with external parties with the expertise to conduct extensive research and research to ensure that the technology can be developed to the phase of operation and maintenance." (R2)

In addition to BIM, IoT and Big Data are technologies debated in interview questions with respondents. IoT is a physical device technology that connects to the Internet and enables devices to communicate and share data. IoT in Malaysia has developed at the level of infrastructure monitoring and management. It is used to monitor and detect any damage

on roads and bridges. Such is the use on the Malaysia - Singapore Second Link Expressway. Based on the statement by respondent 3, A system based on the Internet of Things (IoT) has been implemented to oversee the upkeep of roads and bridges along the Malaysia – Singapore Second Link Expressway.

"The use of IoT in managing bridge and road maintenance on the Malaysia Second Link – Singapore has been developed. It uses a device such as a sensor installed on a road to detect any damage or defect. The damage can be detected automatically in 24 hours and then converted to a form of data accessible to the management." (R3)

According to respondent 4, drone technology has been utilized to examine perilous regions like submerged bridges and riverbeds.

"Apart from using sensors, we also use drone methods that connect to our computing devices. These drones are used to survey the hard bridge areas for human labour to access, such as at the bottom of the bridge and inside the river." (R4)

Next, Big Data is also part of the IR 4.0 technology questioned in this interview. Big Data is still developing, and its development is becoming increasingly important as technology advances. Big data refers to collecting, analyzing, and interpreting data in large numbers to produce complex results. As well as using Big Data to measure the risk of damage based on installed sensors. It helps in minimizing maintenance activities on site. Here is the data analysis related to interviews with respondents concerning Big Data technology. Respondent 2 stated that partnerships with technology developers are advancing the utilization of big data in infrastructure maintenance, particularly road maintenance.

"Big data has been applied in stages. there is collaboration with technology developers and the process is phased. Big data is used in parallel with the use of IoT that uses sensors to measure the risk of damage faced and the assessment is done automatically without requiring us to go down to the site and make a manual assessment first." (R2)

According to the statement by respondent 1, the use of big data in road maintenance is limited to this industry because of the relatively high costs involved in its development.

"Its use is limited to road maintenance only. relatively high costs are required in its development and need to be done in phases. There are technology developers who come to give exposure and offer their services to develop this technology widely for infrastructure such as bridges." (R1)

Based on feedback from the respondents, it can be concluded that IR 4.0 technology has been applied to the management of bridge maintenance at the Malaysia Bridge – Singapore Second Link Expressway. Nevertheless,

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every technology developed and adopted is still at the beginning stages and requires in-depth research to improve each technology. Effective research can impact the use and operation of the technology itself. Therefore, every organizational management must provide an opportunity to adopt new technologies to produce effective working methods and deliver quality services to consumers.

The current technology implementation in managing bridge maintenance for the Malaysia - Singapore Second Link Expressway states that there are three main focuses of using IR 4.0 technology in managing bridge maintenance for the Malaysia - Singapore Second Link Expressway. It is a growing use of Big Data, BIM, and IoT but is still a comprehensive development and research stage. Nevertheless, difficulties such as high initial investment costs, data management, and the need for qualified personnel may arise (Lu *et al.,* 2019). Continuous research can further develop the use and implementation of new technologies to help address every challenge faced. Bridge maintenance management has been revolutionized by combining technology improving efficiency and safety—Big Data, IoT, and BIM. All parties in the organization play a key role in ensuring the smooth running of the technology. Table 7 shows a summary of the current technology implementation in bridge maintenance management for the Malaysia- Singapore Second Link Expressway.

Table 7 *Summary of the current technology implementation in bridge maintenance management for the Malaysia – Singapore Second Link Expressway*

Statement	R1	R2	R3	R4
Current Technology Implementation in Bridge Maintenance Management For The Malaysia – Singapore Second Link Expressway				
(i) BIM				
Experience			✓	✓
Potential	✓	✓	✓	✓
Issues	✓	✓	✓	✓
(ii) IoT				
Experience	✓	✓	✓	✓
Potential	✓	✓	✓	✓
Issues	✓	✓	✓	✓
(iii) Big Data				
Experience	✓	✓	✓	✓
Potential	✓	✓	✓	✓
Issues	✓		✓	

The second part of this section answers questions relating to current challenges faced in implementing technology in the management of bridge maintenance for the Malaysia – Singapore Second Link expressway. All respondents answered this question well based on their experience in bridge maintenance management. Refer to appendix D, describes each answer obtained from the respondents regarding the challenges faced. Here is the statement given by the respondent.

"At the beginning stages of this new technology being applied, it is quite impactful for workers due to their lack of skills, making it difficult for them to adapt. Experience and knowledge must be gained from the courses and briefings provided by the organization. External experts are called to provide briefings and at once assist employees practically." (R1)

According to the statement by respondent 3, to address personnel's difficulties when adjusting to new technologies, the organization partners with technology developers and establishes collaborative alliances with universities.

"To ensure that employees are always aware of the current situation and help them prepare for adopting new technologies, we are always open to collaborating with technology developers to provide employees with optimal exposure and trust in new technologies. There is a collaboration with the University for research purposes on developing new technologies." (R3)

The openness and acceptance of employees are also essential to ensure that all processes related to the application of the technology and its users can be satisfied with the current situation without any problems. Therefore, the organization should attract the interest of its employees in learning knowledge and seeking experience in venturing into new technologies.

"ICT parties fully manage computing systems and internet connectivity. They will work on managing device system availability and internet connection matters. If there are any problems, the management will continue to refer to the ICT Management." (R4)

Computing systems and internet connectivity are vital points that must be emphasized in the development to ensure the smooth running of IR 4.0-related technologies. Therefore, it is essential to establish a special committee under an organization that can maintain and control the computing system and internet connection that involves the use of this technology. To address the current need for technology experts in the job market, the organization actively seeks competent individuals by advertising opportunities and attracting specialists, especially those certified in Building Information Modelling (BIM). Below is the statement by respondent 1.

"Technology expert consumption is very much a career market rebuttal nowadays. For example, BIM specialists who have a specialized qualification certificate. Our organization has always opened opportunities through advertising to recruit new employees with expertise." (R1)

Based on the statement by respondent 4, to overcome the organization's limited technical knowledge, consistent communication is maintained with external technology developers.

"As we lack technology experts inside the organization, outside experts that are technology developers will always keep in touch with us to ensure the smooth use of this technology." (R4)

Respondent 3 stated that the organization recruit's individuals from other sources and partners with institutions for research initiatives to address the knowledge gap.

"At present time, we have been conducting joint research cooperation with the University for a comprehensive study of the development of BIM. Also, collaboration with PLUS and LLM is one of the drivers for establishing effective and quality operational and maintenance management." (R3)

When it comes to new technologies within an organization, a comprehensive regulatory framework is needed to ensure that the use of technology can be adequately controlled. Also, it is essential that the involvement of acts can guide employees.

"In the organization, there is a special act used to control and protect employee ethics regarding the use of technology. It is one of the organization's initiatives to ensure that no issues are imminent or can affect the technology. In Malaysia, a governance framework also manages all risks of using this new technology." (R1)

Despite the obstacles, implementing technology in bridge maintenance management has excellent benefits. Next, researchers found that every development and application of new technology has challenges faced by organizations. Table 8 shows a summary of the challenges in implementing new technology applications in the maintenance management sector. The challenges faced are culture and explainable technology, computing power and internet connectivity, talent shortage, collaboration, ethics, and governance. However, the main challenge that the management of bridge maintenance for the Malaysia - Singapore Second Link Expressway emphasizes is cultural and can explainable technology. Organizational leadership needs to devise strategies to overcome this problem of work culture and understanding of technology. Training programs and activities are essential to bridge the skills gap between the current workforce and the technical requirements of new technologies (Li *et al.,* 2022). Comprehensive and continuous training should attract employees to adopt new technologies in existing norms. Addressing public concerns by providing a simple and understandable explanation of the advantages and risks of the technology is essential to promote public acceptance (Zou *et al.,* 2017). Table 8 shows the summary of the challenges faced while implementing the current technology for the Malaysia - Singapore Second Link Expressway bridge.

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Table 8 *Summary of the challenge technology implementation in bridge maintenance management for the Malaysia – Singapore Second Link Expressway*

Statement	R1	R2	R3	R4
Challenge Technology Implementation in Bridge Maintenance Management for the Malaysia – Singapore Second Link Expressway				
Cultural and Explainable	✓	✓	✓	✓
Computing Power and Internet Connectivity	✓	✓	✓	✓
Lack of Talent	✓	✓	✓	✓
Ethics and Governance	✓	✓	✓	✓

4.4 The Potential of Artificial Intelligence (AI) Implementation in Improving Maintenance Management for the Malaysia – Singapore Second Link Expressway

The potential implementation of Artificial Intelligence (AI) in improving maintenance management for the Malaysia-Singapore Second Link Expressway was answered by all the respondents in which it affects the four factors that have been discussed such as competitive advantage, efficiency and effectiveness in the workplace, improving product quality and safety, and also enhanced operations. Here are the statements given by the respondents. Respondent 1 stated that Artificial Intelligence (AI) excels in data analysis and aids management teams in decision-making. On the other hand, it is a helpful tool for making optimal decisions on future operational procedures.

"In my opinion, like other IR 4.0 technologies, AI can analyze data more easily and, at the same time, help make decisions for the management team through the data obtained. It is beneficial to solve problems that are passed more effectively. It is a facilitation for the team in determining the best decision that should be taken to do the next process." (R1)

The perpetual and rapid detection and identification capabilities of artificial intelligence (AI) offer a clear advantage in efficiently and promptly gathering data, transcending the limitations of humans in this regard. Below is the statement by respondent 4.

"AI can regulate and detect damage or defects that occur regardless of time, which is not possible for humans to do. It thus helps the acquisition of data quickly and effectively." (R4)

Although the use of AI has yet to be introduced in the bridge maintenance sector, its potential can be well known by the respondents following the initial disclosure made by the organization. The potential of AI to compete with other IR 4.0 technologies can be increased if technology developers can help with its implementation in the maintenance sector. According to statement respondent 1, AI implementation effectively improves the understanding of damage by analyzing data, resulting in more accurate damage diagnosis and enabling informed decision-making for maintenance tasks.

"With the effective use of AI, the detected damage will be more specific. The detected damage will be changed in the form of data that has been analyzed and thus help in decision-making for maintenance work to be carried out." (R1)

The integration of AI is essential in minimizing the requirement for physical on-site examination and identification, similar to the utilization of Big Data, IoT, and BIM. It was stated by the respondent 3.

"Like the use of Big Data, IoT, and BIM, AI technology is beneficial in reducing the work of investigation and detection on construction sites. Before the existence of IR 4.0 technology in Malaysia, the entire human workforce was deployed to obtain data and detect damage that occurred on roads or bridges. It is risky because our team is exposed to a dangerous environment." (R3)

The safety and health of employees while performing their duties is the responsibility of the organization's superiors. Providing a safe workplace environment and reducing the risk of accidents as much as possible is very important to ensure that workers can be protected and the quality of work can be improved.

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"The use of technology helps more careful planning before any work is done. It saves operational costs maintenance time, and reduces errors made during the data analysis process until the operational work on site is done." (R2)

Based on the feedback from the respondents, the potential for implementing artificial intelligence (AI) to improve maintenance management for the Malaysia - Singapore Second Link Expressway is high and can be implemented if given the opportunity. Technology developers and experts need to conduct in-depth studies and specialize in the bridge maintenance sector. Stakeholder engagement ensures AI can compete with other IR 4.0 technologies.

The potential implementation of Artificial Intelligence (AI) in improving maintenance management for the Malaysia - Singapore Second Link Highway respondents stated that there is potential for competitive advantage, efficiency, and effectiveness in the workplace, as well as improving the quality and safety of operational products. Efficiency and effectiveness in the workplace are the most discussed potential of Artificial Intelligence (AI). Factors of potential competitive advantage are determined through increased efficiency and impact on the quality of infrastructure services. Better planning, targeting, and customization of government services may offer a much-needed quantum leap in effectiveness and efficacy (Chui, 2017). Table 9 shows the potential of artificial intelligence (AI) implementation to improve maintenance management for the Malaysia - Singapore Second Link Expressway.

Table 9 *Summary on potential of artificial intelligence (ai) implementation in improving maintenance management for the Malaysia – Singapore Second Link Expressway*

Statement	R1	R2	R3	R4
The potential of Artificial Intelligence (AI) Implementation in Improving Maintenance Management for the Malaysia – Singapore Second Link Expressway				
Competitive Advantage	✓	✓	✓	✓
Efficiency and Effectiveness in the Workplace	✓	✓	✓	✓
Product Quality and Safety Improvement	✓	✓	✓	✓
Enhanced Operations	✓	✓	✓	✓

5. Conclusion

The development and implementation of new technology in Malaysia, as well as in the maintenance sector, has become necessary. It is to ensure that the quality of service and services delivered will improve and meet the demand of the growing maintenance sector. Many issues are unraveled when no technology implementation in maintenance management, fragile service systems, and user-desired standards have yet to be reached. As a result, this study was carried out to describe the challenges faced during the development and implementation of new technology and further unearth the potential for Artificial intelligence to be implemented in bridge maintenance management, especially on the Malaysia-Singapore Second Link Expressway. The respondents who participated in this research were those involved in bridge maintenance management for the Malaysia-Singapore Second Link Expressway. A qualitative method is a semi-structured virtual interview using Google Meets, WhatsApp, and e-mail. However, only two representatives from each company participated in the discussion, making the total number of respondents four people.

Based on the data study on introducing artificial intelligence to improve the maintenance management of the Bridge for the Malaysia - Singapore second link expressway, all respondents admitted that they were only given initial exposure related to artificial intelligence technology. It is related to previous studies, AI technologies continue to advance rapidly, driven by improvements in computational power, big data availability, and algorithm design breakthroughs. Respondents also stated that they have never been involved in using artificial intelligence. However, at the same time, respondents said that there are other technologies used for bridge and road maintenance management, namely Big Data, BIM, and IoT. This means there is acceptance of new technology in managing Bridge maintenance for the Malaysia - Singapore second link expressway even though it is still at the research and development stage.

This research focuses on the challenges of technology implementation in bridge maintenance management for the Malaysia - Singapore Second Link Expressway. The study aims to understand the current technology used by maintenance management and its impact on predictive maintenance. The research divides the question into two parts: identifying the current technology used by the management, and the challenges faced during technology implementation.

The research highlights the importance of IR 4.0 technology, which combines Big Data analysis with BIM and IoT technologies for predictive maintenance. Machine learning algorithms can detect trends, identify abnormalities, and anticipate future degradation and maintenance needs. Maintenance organizations must cooperate with technology developers and experts to conduct comprehensive research related to new technologies in the bridge infrastructure maintenance sector, especially AI technology. The main challenges faced during technology implementation in bridge maintenance management include culture and understandability. Organizational culture problems can prevent the use of technology by creating obstacles such as reluctance to change, doubts, and fear of moving jobs. To overcome these challenges, management must provide employees with deep understanding and practical training to adapt to new norms and technologies. Involving external technology experts can help organizations implement new technology effectively, leading to quality work results and effective services.

The Malaysia - Singapore Second Link Expressway is a vital infrastructure project that has the potential to significantly improve maintenance management. The study conducted by Chen *et al.* and Abioye *et al.* highlights the potential of artificial intelligence (AI) in enhancing maintenance management. AI offers several advantages, including competitive advantage, efficiency, workplace effectiveness, product quality and safety improvement, and operational improvements. AI-powered decision support systems provide more accurate and timely decision-making, leading to cost savings and better resource allocation efficiency. AI technology is particularly useful in infrastructure maintenance sectors, such as monitoring, maintaining, and analyzing data for a bridge's life cycle. It can detect damage quickly and automatically, leading to increased efficiency and effectiveness. Additionally, AI can enhance the quality of operations and services delivered, ensuring user satisfaction and continued support. As AI continues to dominate, it is crucial for research and organization cooperation to explore its implementation, ultimately benefiting the organization.

The maintenance sector plays a crucial role in infrastructure development, as bridges undergo routine maintenance to ensure their functionality and prevent user inconvenience. The success of a building depends on its conservation and the maintenance process helps the construction sector progress. Establishing a good relationship between the body of knowledge and the maintenance sector is essential, as new technology is needed to remain relevant and produce better work quality. The body of knowledge should play a role in creating practical research to facilitate the implementation of new technology, especially AI, in the bridge maintenance sector in Malaysia. Scientific bodies should research to provide exposure and in-depth understanding to all parties involved in the bridge maintenance sector. The body of knowledge also helps reduce and control risks during technology implementation in the bridge maintenance sector. Bridge maintenance organizations should be more open to collaborating with bodies of knowledge.

The Malaysia - Singapore Second Link Expressway bridge maintenance management organization is considering potential AI deployment to enhance the quality of services and operations. The construction industry, which is the foundation of the maintenance sector, needs to adapt to technology in its implementation process. The maintenance management sector, including bridge maintenance, is crucial for ensuring the long-term functionality of the construction industry. Prioritizing the maintenance management sector in implementing new technology can improve work quality and save operating costs. Researchers can enhance their understanding of AI implementation in maintenance management for the Malaysia - Singapore Second Link Expressway bridge. Further research should focus on the implementation process of IR 4.0 technology and employee acceptance of new technology. Researchers should seek more thorough information on this topic to establish objectives more deeply. Future research should also explore employees' favor of implementing new technology for the Malaysia - Singapore Second Link Expressway bridge maintenance management system.

In conclusion, the research carried out has been completed without any related problems, achieved all objectives, and has answered all the questions raised in knowing the current challenges of technology implementation and also the potential of AI implementation to improve the maintenance management of the Malaysia - Singapore Second Link Expressway bridge. Despite experiencing some constraints, the researcher overcame them and collected and analyzed relevant data through actual respondents related to this case study. All the data obtained, and the recommendations given will be able to provide benefits to the construction industry, especially for the bridge maintenance sector in Malaysia.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Nurul Athirah Zol, Narimah Kasim;* ***data collection:*** *Nurul Athirah Zol;* ***analysis and interpretation of results:*** *Nurul Athirah Zol;* ***draft manuscript preparation:*** *Nurul Athirah Zol, Narimah Kasim, Hamidun Mohd Noh, Mohd Hilmi Izwan Abd Rahim. All authors reviewed the results and approved the final version of the manuscript.*

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Appendix A: Research Methodology Flowchart