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A Systematic Review on Road Maintenance Budget Optimization Method Utilizing Technology

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ABSTRACT

Budget optimization for road maintenance is critical to ensure maximum production while minimising costs. In recent years, various technology-based approaches have been developed to optimize maintenance budgets. However, despite these advancements, there is still a lack of a structured approach to evaluate the acceptance and reliability of such technologies, particularly within the public sector. This study employed a Systematic Literature Review (SLR) to examine the extent to which technology acceptance and system reliability factors have been addressed in prior studies on road maintenance budget optimization. A total of twelve (12) technology acceptance factors and four (4) system reliability factors were identified from existing literature. Relevant publications were retrieved from major electronic databases using specific keywords related to road maintenance and budget optimization. After applying the inclusion and exclusion criteria, fifteen (15) relevant articles were selected and systematically reviewed. The findings reveal that only five (5) of the twelve identified technology acceptance factors were commonly addressed in the reviewed studies. Similarly, among the four (4) system reliability factors, only one (1) factor was consistently discussed across all publications. These results indicate that existing studies tend to focus more on technical optimization models while giving limited attention to behavioral and system reliability considerations. This study highlights the need to develop a comprehensive model that integrates technology acceptance and system reliability factors to evaluate technology-driven budget optimization methods. Such integration is essential to support more effective decision-making, enhance public-sector adoption of optimization technologies, and improve the sustainability of road-maintenance management.

Keywords: Optimization method; technology; road maintenance; technology acceptance; reliability

INTRODUCTION

Roads are one of the most important infrastructures that enable the movement of people, goods, and services (Majstorović & Jajac 2022). Roads contribute significantly to a country's economic and social development (Majstorović & Jajac 2022). Road maintenance is essential to preserve the road condition, provide a comfortable surface, and ensure road user safety (Chiou et al. 2025; Sohail et al. 2023; Ismail et al. 2021). However, due to limited budget for road maintenance with large numbers of ageing roads, road maintenance management is getting more complex, which necessitates budget optimization (Silva et al. 2024; Mahpour &-El Diraby 2022; Almeida et al. 2022). Furthermore, road maintenance costs are very high, which may complicate maintenance tasks (Chiou et al. 2025; Höglund et al. 2021; Shahid, 2019). Among financial management issues for road maintenance are challenges related to achieving effective expenditure (Majstorović & Jajac 2022; Akbar et al. 2019) and budget optimization (Guan et al. 2022; Blaauw et al. 2022). Ineffective expenditure leads to cost overruns and waste of financial resources (Ammar et al. 2022). Meanwhile, the inability to achieve budget optimization may prevent road agencies from maximizing production within minimal cost (Guan et al. 2022; Blaauw et al. 2022).

One key strategy for addressing the budget optimisation issue in road maintenance is to analyse relevant factors and apply an appropriate budget optimization method (Cano-Ortiz et al. 2024; Pereira et al. 2023; Lafioune et al. 2023; Mahpour & El-Diraby 2022; Truong et al. 2020). Budget optimisation is the process of maximizing production and minimizing road maintenance costs while ensuring road quality and safety (Guan et al. 2022; Blaauw et al. 2022). Optimizing financial resources is crucial in road maintenance management, given the substantial costs of administrative and maintenance contracts (Ismail et al. 2021). In addition, key factors influencing budget optimization encompassing policy formulation (Sasai et al. 2024), framework development (Santos et al. 2024), cost and benefit analysis (Wang & Levinson, 2023), life cycle cost analysis (Kumari et al. 2022), technological optimization (Peraka & Biligiri, 2020), financial risk planning (Ammar et al, 2022), as well as the assessment of external factors that may impact road maintenance budget optimization (Burghardt & Pashkevich, 2023; Guan et al. 2022). Among the budget optimization methods are Multi-Objective Optimization (MOO), often integrated with programming tools that utilizes evolutionary computation techniques such as Genetic Algorithm (Chong et al. 2024; Alqaili et al. 2021). The MOO method generates optimised maintenance decisions and enables the allocation of funding across the entire network (Chen 2023). A genetic algorithm (GA) is a computational technique that can address complex problems and support decision-making by providing a reasonable maintenance plan, while minimising costs and maximizing road performance (Silva et al. 2024; Alqaili et al. 2021).

Furthermore, integrating MOO methods with programming has been found to enhance the cost-effectiveness of road maintenance (Chong et al. 2024; Chen 2023). Road authorities in the public sector are administering large, complex datasets for road maintenance management (Augeri et al. 2019). However, there is limited evidence of the application of optimization methods utilizing technology (Amândio et al. 2021; Shadhar & Mahjoob, 2020) particularly in public construction projects (Camngca et al. 2022). For instance, while current technology, such as the Pavement Management System (PMS), mainly focuses on optimizing pavement condition and maintenance costs, most existing budget decision-making processes through these systems have yet to integrate the Multi-Objective Optimisation method employing an algorithm (Madushani et al. 2024). Therefore, it is imperative to assess the factors influencing technology adoption in the construction industry, particularly the adoption of the Multi-Objective Optimisation method utilising technology (Elkhayat et al. 2024). The Technology Acceptance Model (TAM), first introduced by Davis (1989), was developed to model user acceptance of Information Technology (IT) (Mata et al. 2024; Mukred et al. 2024; Daud et al. 2011). According to TAM, the individual's intention to use technology is influenced by the perceived usefulness and ease of use of the technology (Mata et al. 2024; Mukred et al. 2024; Daud et al. 2011).

Nevertheless, Hao et al. (2024) identified other key challenges in implementing MOO, including the design complexity, resource availability, scheduling, and path planning. The design of the models must be carefully considered, as inadequate design would compromise the algorithm's stability and reliability (Breznická et al. 2023). As such, evaluating the reliability of component-based software systems is of crucial (Tarinejad et al. 2021). System reliability is assessed through its ability to perform a function within a specified time which conducted through stages (Breznická et al. 2023).

Although efforts have been made to optimize road maintenance budgets using MOO methods integrated with technology, the extent of acceptance and reliability of these methods remains unclear. Despite varying perspectives on budget optimisation for road maintenance, there has been limited research on factors influencing technology-based optimization methods and on assessing system reliability. Therefore, the objective of this study is to identify the technology acceptance and system reliability factors and to evaluate the degree to which these factors are addressed in the selected publications. The significance of this study stems from its contributions to advancing knowledge on technology implementation in road maintenance, providing a basis for subsequent research.

METHODOLOGY

Figure 1 presents the methodology applied in this study. Technology Acceptance and Reliability Factors were initially identified through prior publications on technology, resulting in twelve (12) Technology Acceptance Factors and four (4) Reliability Factors. Subsequently, a Systematic Literature Review was conducted to identify publications on road maintenance budget optimization methods that use technology. The SLR process resulted in a total of fifteen (15) publications selected for assessment of the presence of Technology Acceptance and Reliability Factors.

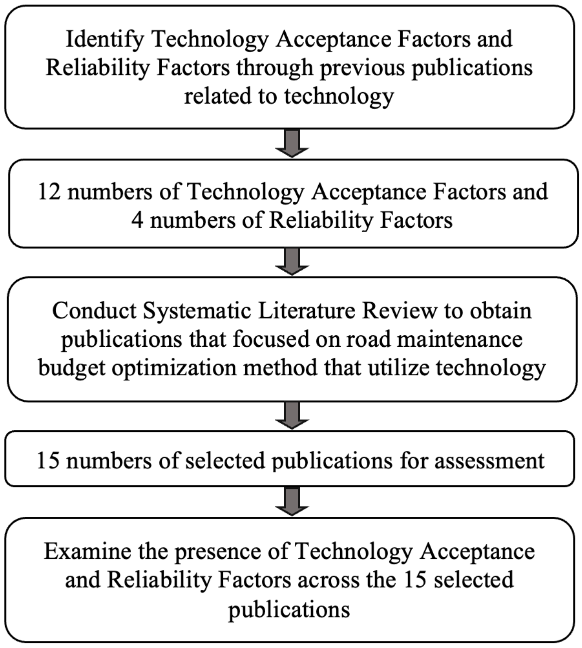

FIGURE 1. Methodology of the study

Systematic Literature Review (SLR) is a suitable technique for analyzing current knowledge and identifying research gaps (Dzulkifli et al. 2021; Maslesa et al. 2018) because it uses a systematic process of information acquisition that involves an initial search using keywords and listed databases. (Busalim & Hussain, 2016). Thus, this study employed a Systematic Literature Review (SLR) to analyze the existing knowledge on budget optimization methods utilizing technology for road maintenance and to identify the research gap. Figure 2 presents the SLR process which conducted through this study.

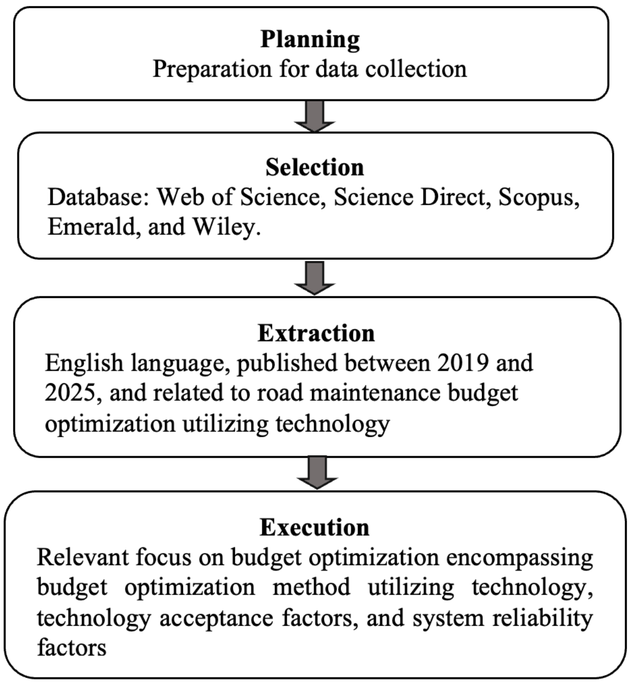

FIGURE 2. Systematic Literature Review Process

PLANNING

The first stage of planning begins with preparing for data collection, such as organizing the systematic literature review. The VOSviewer tool version 1.6.19 was used to conduct a bibliometric analysis and a key network analysis based on the Scopus database publication list using the search keywords "road maintenance budget optimization". In Figure 3, items and their connections are shown. Items are the object of interest, such as publications, researchers, or terms (Eck & Waltman 2023). The weight of an item indicates its importance, with higher weights indicating greater importance (Eck & Waltman 2023). Meanwhile, the connection indicates a relationship among items, such as bibliographic coupling links between publications, co-authorship links between researchers, and co-occurrence links between terms (Eck & Waltman 2023).

The results of VOSviewer indicate that among the important items or topics related to budget optimization using technology for road maintenance are maintenance, highway administration, pavements, costs, cost-effectiveness, pavement management systems, information management, and maintenance strategies. A heavy connection between the items of the pavement management system and other items indicates the necessity of technology application towards budget optimization efforts for road maintenance

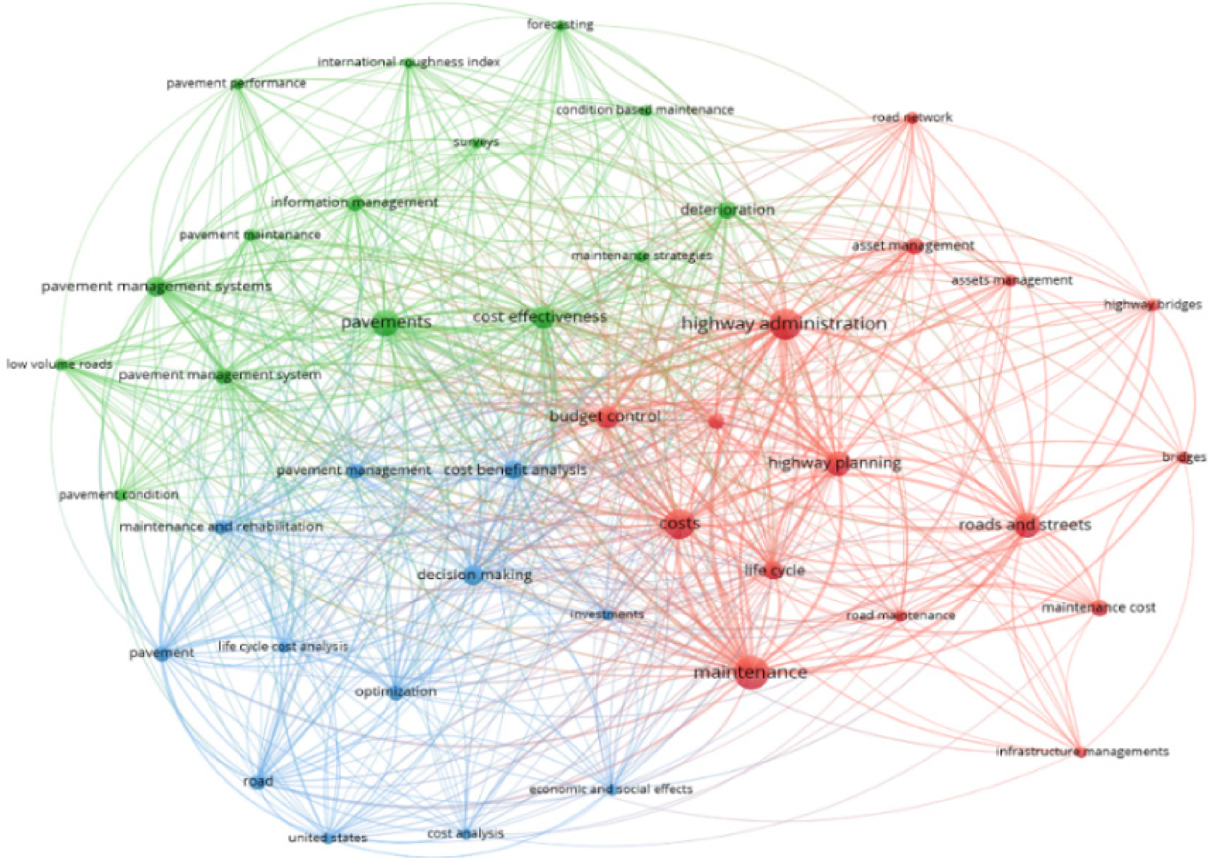

FIGURE 3. Key Network Analysis (Vosviewer)

Selection. In this step, using the search term "road maintenance budget optimization," data were retrieved from the electronic databases Web of Science, ScienceDirect, Scopus, and Emerald Insight (Table 1). The initial search resulted in a total of 5,041 publications.

TABLE 1. Search Strings

Database	Keyword
Web of Science	Keywords, open access, article: "road maintenance budget optimization"
ScienceDirect	Open access & open archive, subscribed journals, research articles: "road maintenance budget optimization"
Scopus	Keywords, article: "road maintenance budget optimization"
Emerald	Access, Article: "road maintenance budget optimization"

EXTRACTION

In this process, data was extracted according to the inclusion and exclusion criteria. The inclusion criteria comprised English-language articles published between 2019 and 2025 (Table 2). Articles that were review papers, other than English language, or published before 2019 were excluded. Following this filtering process, the total number of eligible publications reduced to 680.

TABLE 2. Inclusion and Exclusion Criteria

Criterion	Inclusion	Exclusion
Literature type	Article	Review
Language	English	Other than English
Timeline	2019-2025	< 2019

EXECUTION

In this stage, the focus was on budget optimization methods using technology, such as programming tools and algoriths. The process involved screening the titles, abstracts, and content of the publications to ensure they met the inclusion criteria for the current research. The inclusion criteria required that the publications be research articles, written in English, and published between 2019 and 2025. Publications that did not meet these criteria, such as review papers, written in languages other than English, and published before the year 2019, were excluded from the selection. As a result of this screening process, fifteen (15) eligible publications were identified and selected for further analysis. Figure 4 presents the flow diagram illustrating the selection process.

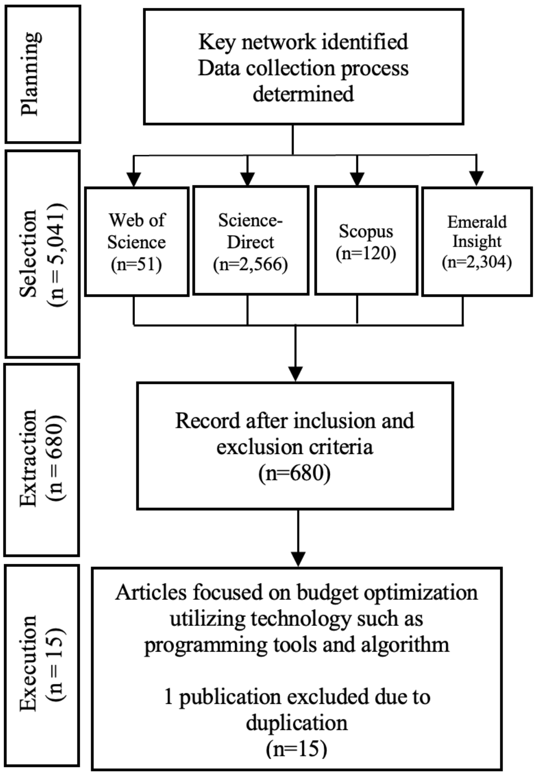

FIGURE 4. Flow Diagram of Selection Process

DATA EXTRACTION AND ANALYSIS

The authors employed the Technology Acceptance Model and the Technology Organizational Environment Framework (TAM-TOE) to identify acceptance of technology use (Figure 6). The Technology Acceptance Model (TAM) was initially developed by Davis et al. (1989) as a theoretical model of users' acceptance and use of technology (Qin et al. 2020) (Figure 5). It is considered one of the most popular models for technology adoption (Elkhayat et al. 2024; Qin et al. 2020). Qin et al. (2020), through the TAM extended model, which is known as TAM-TOE highlighted that there were four (4) main factors or external variables that influence Perceived Ease of Use (PU) and Perceived Usefulness (PU) of utilizing technology in the construction industry, which finally will influence the intention to use and actual use (Figure 6). Those main factors were technological, economic, organizational, and environmental (Qin et al. 2020). Technological factors encompass localization, standardization, and compatibility, while economic factors include cost and return on investment (Qin et al. 2020). Organizational factors included the organizational workflow, traditional thinking mode, support from management, and a number of experts and technicians. In contrast, environmental factors included national policy requirements, the popularity of the model, and competition from other companies (Qin et al. 2020).

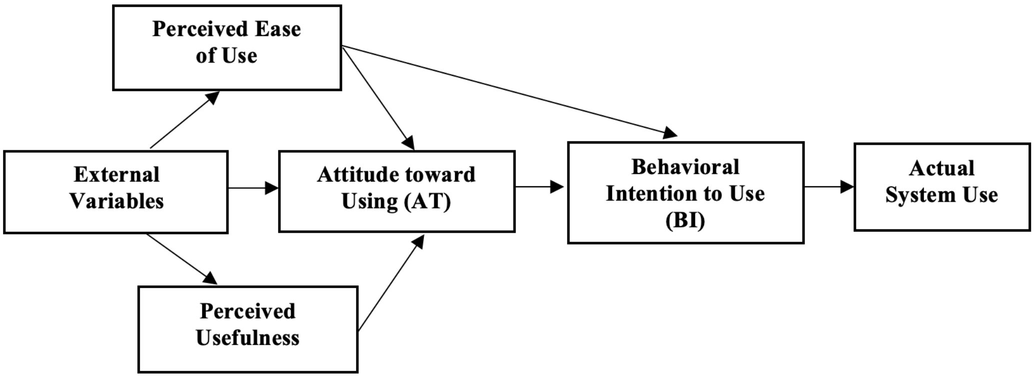

FIGURE 5. Technology Acceptance Model (TAM) (Davis, 1989)

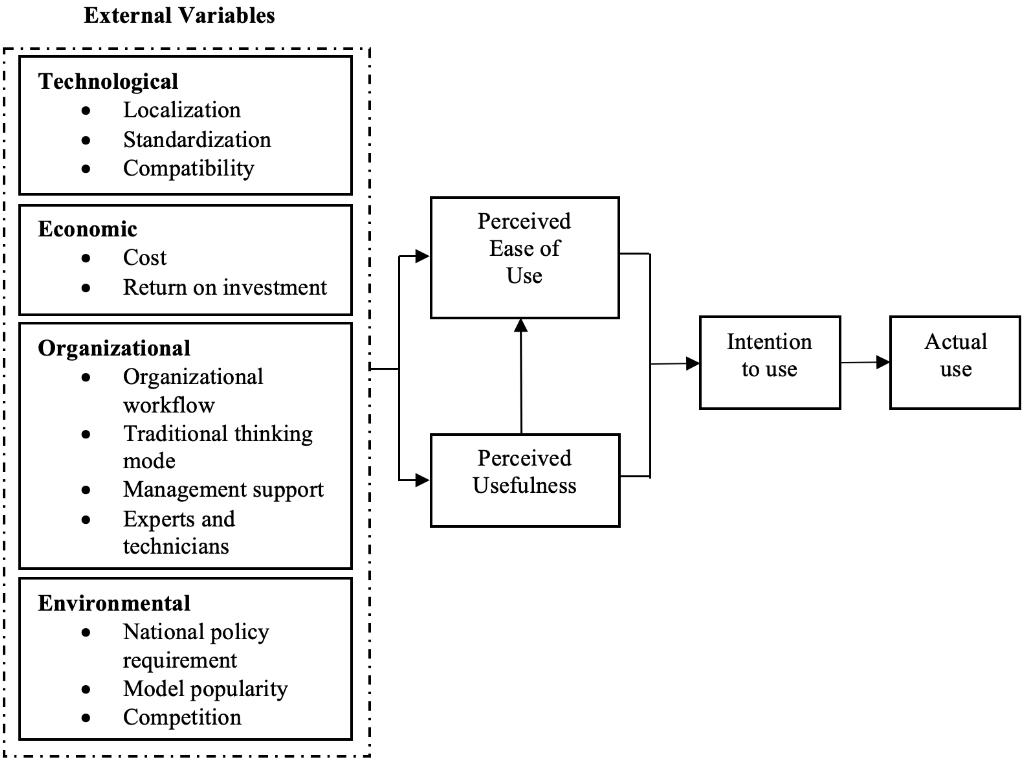

FIGURE 6. TAM-TOE Model (Qin et al. 2020)

Furthermore, as the reliability of a system significantly influences the required functions, such as speed, safety, and failure-freeness, the authors also extend the analysis to examine the factors affecting system reliability. Among the factors influencing system reliability are development, dependability, maintainability, and repairability (Breznická et al. 2023) (Figure 7). Development refers to the key specification and design decisions made across the life cycle, including design, manufacturing, operations, and support stages (Breznická et al. 2023). Dependability is the ability of an object to perform the required functions under specified conditions in a given time interval (Breznická et al. 2023). Maintainability refers to the ease and speed with which maintenance work can be carried out (Breznická et al, 2023). It relates to the processes of securing personnel, technical, materials, and maintenance technology (Breznická et al. 2023). Repairability refers to the ability to detect malfunctions and eliminate their consequences by carrying out repairs (Breznická et al. 2023).

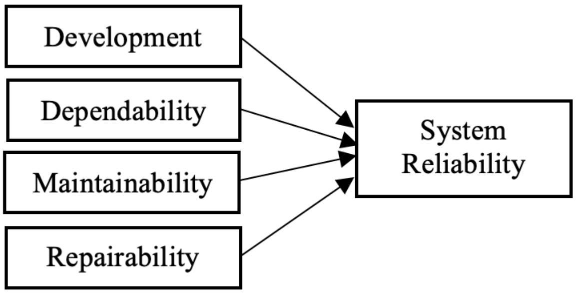

FIGURE 7. Factors Influencing System Reliability (Breznická et al. 2024)

RESULT

The list of included publications for review and description of each budget optimization method utilizing technology is described in Table 3. Due to budget constraints for road maintenance works, most of the publications aimed to obtain the optimal maintenance strategy through the Multi-Objective method to increase the benefit and minimize the cost (Ameri et al. 2019; Augeri et al. 2019, Shadhar & Majoob 2020; Alqaili et al. 2021; Amândio et al. 2021; Chen, 2023; Ling et al. 2024; Chong et al. 2024; Naseri et al. 2024). The benefits include a quality road (Dhatrak et al. 2020), ensuring road user's safety (Augeri et al. 2029), and minimizing environmental impact (Chong et al. 2024). Minimizing the costs represented by reducing road maintenance costs (Alqaili et al. 2021) or preparing a maintenance plan according to the annual budget obtained (Augeri et al. 2019).

In their study, all authors used computer-based technology, including algorithms. Towards optimization effort, most of the authors proposed decision-making model (Ameri et al. 2019; Augeri et al. 2019; Dhatrak et al. 2020; Philip & AlJassmi, 2023; Naseri et al. 2024; Silva et al. 2024) while some developed multi-objective method (Chen, 2023; Ling et al. 2024), multi-objective algorithm (Alqaili et al. 2021), optimization system (Amândio et al. 2021), optimization approach (Madushani et al. 2024), and optimization process (Shadhar & Majoob 2020).

All publications were based on a case study using actual pavement maintenance data. Data were collected from road departments and maintenance companies. To determine traffic impacts and road capacities, most authors defined road information, such as road classes and types. For instance, it was observed that arterial roads, which are capacity roads, were included in the publications as a sample of study, which underscores the importance of technology application for maintenance optimization in a complex road network (Alqaili et al. 2021; Philip & AlJassmi 2023). All publications have benefited from the technology application which assists in obtaining optimized maintenance and rehabilitation plans such as prioritizing maintenance based on the prediction of pavement distress (Philip & AlJassmi 2023; Dhatrak et al. 2020), climate impact towards pavement condition (Madushani et al. 2024), the critical path of maintenance work (Amândio et al. 2021), safety factors (Augeri et al. 2019), traffic loading factors (Silva et al. 2024; Philip & AlJassmi, 2023), and environmental factors (Philip & AlJassmi, 2023; Chong et al. 2024). It was also observed that the optimization strategies were developed based on the consideration of a determined annual budget for road maintenance (Augeri et al. 2019; Shadhar & Majoob, 2020; Alqaili et al. 2021). Nevertheless, as a way to determine the actual budget requirement, Ameri et al. (2019) have developed a model based on the consideration of indeterministic budgets, which provides several maintenance plans that is compatible with budget variations.

Most authors measure the effectiveness of budget optimization strategy that utilizes technology in the form of variables such as Pavement Condition Index (PCI) (Augeri et al. 2019; Shadhar & Majoob, 2020; Ling et al. 2024; Chong et al. 2024; Silva et al. 2024), International Rough Index (IRI) (Augeri et al. 2019; Madushani et al. 2024; Philip & AlJassmi, 2023; Naseri et al.2024), and maintenance cost (Ameri et al. 2019; Augeri et al. 2019; Dhatrak et al. 2020; Alqaili et al. 2021; Amândio et al. 2021; Chen, 2023; Ling et al. 2024; Madushani et al. 2024; Chong et al. 2024, Naseri et al. 2024). Apart from the significant contribution of the developed budget optimization strategies, the authors also defined several limitations that could further enhance the development. Those include requirement of a full parameter value (Chang et al. 2025; Ameri et al. 2019), adequate sample size (Philip & AlJassmi, 2023), depth of pavement damages (Chong et al. 2024), quantifying in economic terms for social and environment objectives (Augeri et al. 2019), comparison to other approaches (Shadhar & Majoob, 2020), distinct layers of pavement structure (Amândio et al. 2021), and considering other criteria to balance the objectives (Chen, 2023; Naseri et al. 2024).

TABLE 3. Description of Budget Optimization Method Utilizing Multi-Objective Method

No	Source(s)	Method/ Model	Data for Analysis	Benefit	Optimization Variable
1	Ameri et al. (2019)	Multi-Objective/ Two-Stage Stochastic Model	● Major road ●3 years plan	Several M&R plans compatible with budget variations	● Pavement condition ● Maintenance cost
2	Augeri et al. (2019)	Multi-Objective/ Decision-Rule Preference Model	● Main road network ● 23 KM length	Incorporate road safety factors	● PCI ● IRI ● Safety ● Maintenance cost
3	Shadhar & Majoob (2020)	Multi-Objective/ Genetic Algorithm	● Major road	Optimum maintenance alternative under limited budget	● Add service life 1.2 years ● 3.8% PCI increase
4	Dhatrak et al. (2020)	Heuristic Algorithm Approach	● 3 years plan	Considers deterioration propagation between facilities	● Deterioration propagation rate ● Maintenance choice
5	Alqaili et al. (2021)	Multi-Objective/ Integer Search Algorithm (ISA)	● Arterial, main, and local access roads ● 3 years plan	Improve PCR under limited annual budget	● PCR increase about 193% ● Cost saving about 29%
6	Amândio et al. (2021)	Multi-Objective/ Linear Programming Model	● Real motorway pavement rehabilitation project	Critical path of maintenance work and efficiency of allocated equipment	● Construction time ● Construction cost
7	Chen (2023)	Multi-Objective Optimization/ Dichotomic Approach Algorithm	● Road under Department ● 2 to 4 lane road ● 5 years plan	Generate optimized M&R decisions	● Annual budget ● M&R benefit ● Trade-off ratio
8	Ling et al. (2024)	Multi-Objective/ Incremental Dynamic Programming Model	● Airport pavement ● Middle runway, terminal runway, and taxiway ● 5 years plan	Analyze typical preventive maintenance technologies and PCI deterioration rates.	● PCI ● Maintenance cost
9	Madushani et al. (2024)	Genetic Algorithm (GA) Based Optimization Approach	● 20 roads under different climatic condition	Prioritize road that are highly vulnerable to climate impact	● CRI ● IRI ● Maintenance cost
10	Philip & AlJassmi (2023)	Bayesian Belief Network (BBN) Approach	● 32 road networks ● Arterial road ● 7 years' time frame data	Pavement performance prediction model under traffic and environmental factors	● IRI
11	Chong et al. (2024)	Muti-Objective/ U-Net Algorithm and TOPSIS model	● 700 images of different types of cracks ● 80 images of potholes	Recognize pavement distress dimension and achieve low-carbon economic maintenance strategy	● PCI ● 30.8% carbon emission reduction ● 20.81% maintenance cost reduction

continue...

...cont.

12	Naseri et al. (2024)	Multi-Objective/ Hybrid Algorithm incorporate robust Machine Learning (ML)	● Asphalt pavement ● 186 sections	Compare 3 types of algorithm in terms of IRI prediction accuracy	● International Rough Index (IRI) ● M&R cost
13	Silva et al. (2024)	Markvovian Chain Technique and Decision Tree	● 18 unpaved sections ● 88 paved sections ● Traffic counts	Statistical model for road deterioration and provides treatment options with cost	● PCI ● M&R cost
14	Chang et al. (2025)	Probabilistic-Based Pavement Performance Curves and Dynamic Calibration Method	● Asphaltic concrete road ● PCI	Probabilistic Pavement Performance Model that enhances Pavement Management System	● PCI ● M&R cost
15	Chiou et al. (2025)	Mixed-Integer Linear Programming Model	● 4 lane road ● 11.7 KM ● 20 pavement damages ● Asphalt concrete pavements	Provide treatment options, average PCI improvement, and budget requirement	● PCI ● M&R cost

Table 4 summarizes the factors of technology acceptance found through the Multi-Objective Optimization (MOO) strategy method utilizing technology under the main factor categories of technological, economic, organizational, and environmental. Under the technological category, it was observed that all of the publications do include localization factors, and most include standardization and compatibility factors. Localization represents clear contributions through a multi-objective strategy with technology utilization, such as maximizing pavement conditions under a limited budget for road maintenance (Alqaili et al. 2021). Standardization represents which construction phases were focused on the development of the strategy, with most publications focusing on the planning stage (Augeri et al. 2019; Shadhar & Majoob, 2020). In terms of compatibility, most studies show that the optimization techniques are compatible with software (Philip & AlJassmi, 2023; Ling et al. 2024; Silva et al. 2024), programming tools (Chen, 2023), and able to be integrated into the Pavement Management System (PMS) (Chang et al. 2025). Besides, under the main factor of economics, none of the publications highlighted the cost factor, such as the cost of developing an optimization strategy that utilizes technology. However, all publications do include the factor of return on investment (ROI), which highlights the potential ROI in terms of the benefit of the optimization strategy that utilizing technology such as optimizing maintenance funds (Alqaili et al. 2021; Silva et al. 2024), better use of the resource (Augeri et al. 2019), achieve timely maintenance (Dhatrak et al. 2020), minimize construction time, construction cost (Amândio et al. 2021), and carbon emission (Chong et al. 2024).

Referring to the factors under the organizational category, eight (8) publications include organizational workflow factor, and seven (7) publications include the traditional thinking mode factor. Meanwhile, few include experts and technicians' factors, and very few publications have management support factors. The organizational workflow factor found through the publications was the authority constraint, such as managing different management units for road maintenance work (Dhatrak et al. 2020) and the challenges to accommodate all stakeholder's expectations (Augeri et al. 2019). Traditional thinking mode factors include the transition from the traditional method to a Pavement Management System (PMS) (Augeri et al. 2019) improvement in pavement inspection from visual to technology-assisted (Chong et al. 2024), and the advantage of probabilistic model compared to deterministic techniques (Silva et al. 2024, Chiou et al. 2025). Experts and technicians' factors include the requirement of knowledge on the development of optimization strategy with technology utilization such as expert knowledge, expert opinion (Chang et al. 2025; Philip & AlJassmi 2023), data analysis (Augeri et al. 2019), and data improvement (Ling et al. 2024). Management support factor, which is the least factor found through the publications, was referred to the department support, especially on the availability of road maintenance data for optimization strategy development (Shadhar & Majoob 2020; Philip & AlJassmi 2023; Silva et al. 2024).

As for the environmental category, all publications include the model popularity factor, few include the national policy requirement factor, and none include the competition factor. Model popularity factor found through the publications was the clear benefit of the developed optimization strategy that utilizes technology such as improving the cost-effectiveness of maintenance works (Chen, 2023; Alqaili et al. 2021; Chong et al. 2024; Silva et al. 2024). National policy requirement factors include government objectives which to achieve optimum maintenance under limited budget (Silva et al. 2024), flexibility to policy (Augeri et al. 2019), the impact of political risk towards the maintenance budget (Ameri et al. 2019), the determination of the maintenance budget by the Treasury (Chen 2023), and the benefit of optimization technique utilizing technology to the policymaker (Naseri et al. 2024; Chiou et al. 2025).

TABLE 4. Technology Acceptance Factors for Budget Optimization Strategy Utilizing Technology

Category	Factor	Source(s)														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Technological	Localization	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Standardization	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓
	Compatibility	✓	✓	✓	✓	✓	✓	✓	✓		✓		✓	✓	✓	
Economic	Cost															
	Return on Investment	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Organizational	Organizational Workflow	✓	✓		✓	✓	✓	✓	✓	✓						
	Traditional Mode	✓	✓		✓		✓	✓				✓		✓	✓	✓
	Management Support			✓							✓			✓		
	Experts and Technicians		✓					✓	✓		✓	✓			✓	
Environmental	National Policy Requirement	✓	✓					✓					✓	✓		✓
	Model Popularity	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Competition															

Table 5 summarizes the factors of the reliability of the budget optimization technique utilizing technology such as development, dependability, maintainability, and repairability. In terms of development, all publications explained the process of strategy development that utilizes technology. The process involved mathematical formulation or equation (Ameri et al. 2019; Dhatrak et al. 2020; Chen, 2023; Madushani et al. 2024; Philip & AlJassmi, 2023; Naseri et al. 2024; Silva et al. 2024; Chang et al. 2025; Chiou et al. 2025), framework (Augeri et al. 2019; Chen, 2023; Philip & AlJassmi, 2023; Chong et al. 2024), flowchart (Shadhar & Majoob, 2020; Alqaili et al. 2021; Amândio et al. 2021), and process (Naseri et al. 2024). In terms of dependability, some publications do highlight the effectiveness of the method utilizing technology in terms of speed, such as a reduced solution time (Ameri et al. 2019, fast at analyzing MOO problem and obtaining Pareto solution (Chen, 2023), increase in speed algorithm training (Chong et al. 2024), and a fast software processing (Naseri et al. 2024). At the same time, maintainability and repairability factors were not identified in these papers, as the studies were exclusively centered on the development and implementation of the system.

TABLE 5. Reliability Factor for Budget Optimization Strategy Utilizing Technology for Road Maintenance

Source(s)	Method/ Solution Approach	Reliability	
		Development	Dependability
1	Two-Stage Stochastic Model Pavements	Formulation	Reduce solution time
2	New interactive multiobjective optimization approach	Framework	
3	Multi-objective Optimization	Flowchart	
4	Considering deterioration propagation in transportation infrastructure maintenance planning	Formulation	
5	Integer Search Algorithm: A New Discrete Multi-Objective Algorithm	Flowchart	
6	Intelligent planning of road pavement rehabilitation processes through optimization systems	Flowchart	
7	Network-level pavement maintenance and rehabilitation decision-making with the optimized annual budget	Framework	Fast analyze MOO problem and obtain Pareto solution
8	Preventive Maintenance Decision-Making Optimization Method	Equation	
9	A Genetic Algorithm-based Decision Framework	Formula/ Equation	
10	Time-series forecasting of road distress parameters using dynamic Bayesian belief networks	Framework	
11	Multi-Objective Optimization Integrating Pavement Image Segmentation and TOPSIS Methods	Framework and Equation	Increase speed of algorithm training
12	A novel technique for multi-objective sustainable decisions for pavement maintenance and rehabilitation	Mathematical Formulation and Process	Fast software processing
13	Probabilistic Markovian Process	Formula/ Equation	
14	Probabilistic-Based Pavement Performance Curves and Dynamic Calibration Method	Formula/ Equation	
15	Mixed-Integer Linear Programming Model	Formula/ Equation	

Additionally, to facilitate visualization and provide readers with insights into road maintenance budget optimisation strategies that utilize technology, schematic diagrams were developed based on the information presented in Table 4.

Figure 8 presents the Technological Category, which encompasses the Localization, Standardization, and Compatibility factors. Overall, these factors appear in most of the selected publications, indicating that the technology is progressing steadily, where the development of prediction models is goal-oriented, well-structured and enhanced through software tools.

As illustrated in Figure 9, technology utilization is primarily aimed at increasing return on investment, which translates into benefits, such as achieving optimal maintenance within limited budgets. However, the cost associated with the system was not emphasized in the reviewed studies, indicating potential for future research.

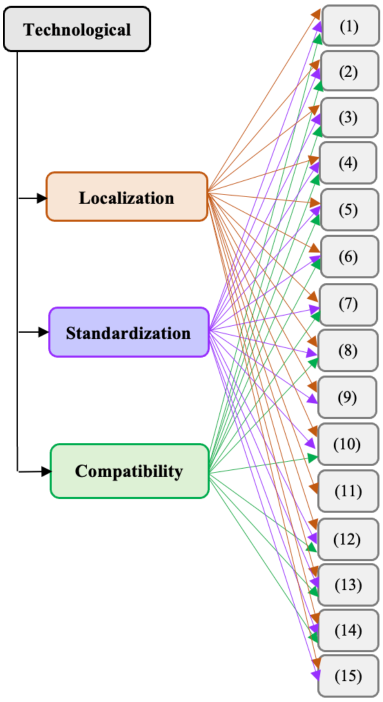

FIGURE 8. Schematic Diagram for Technology Acceptance Factor (Technological Category)

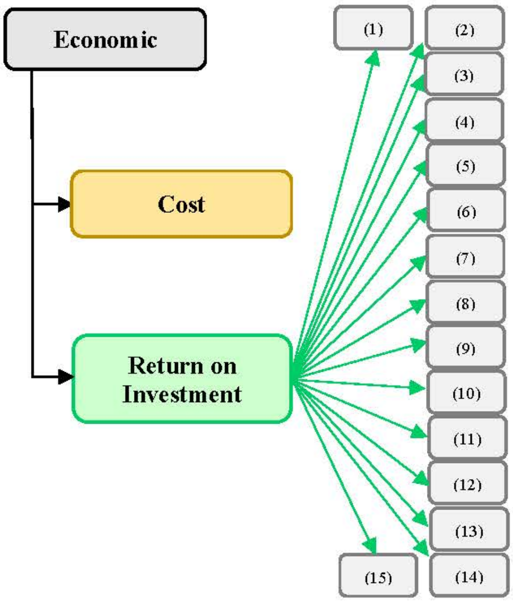

FIGURE 9. Schematic Diagram for Technology Acceptance Factor (Economic Category)

The results, as illustrated in Figure 10, indicate awareness of the importance of organizing factors, such as managing multiple stakeholders, enhancing competencies and the need to transform from traditional practices to modern technology-based management. Yet, the effectiveness depends heavily on the management support.

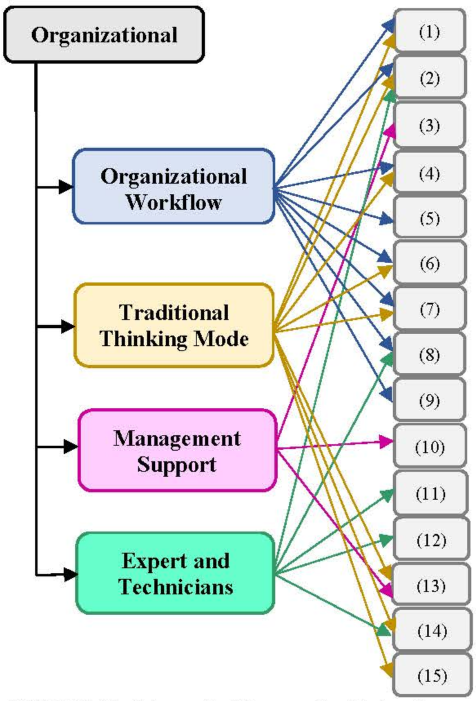

FIGURE 10. Schematic Diagram for Technology Acceptance Factor (Organizational Category)

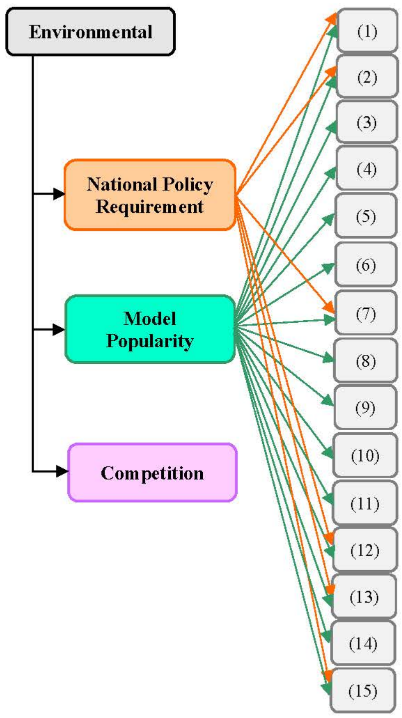

FIGURE 11. Schematic Diagram for Technology Acceptance Factor (Environmental Category)

The results presented in Figure 11 indicate that developed models or systems were primarily aimed at achieving cost-effective maintenance. Policy-related issues were also highlighted in several publications, suggesting that government or public administrations should provide for transforming road maintenance management into a data-driven system capable of analyzing large datasets, to facilitate long-term planning. Competitive aspects were not emphasized, as the reviewed studies focused predominantly on engineering applications, rather than business considerations.

DISCUSSION

Budget optimization methods that utilize technology are vital for road maintenance, as they help manage complex operations (Amândio et al. 2021) and develop an optimised budget plan (Shadhar & Majoob, 2020). An optimized budget plan refers to the planning of road maintenance works and budget that will maximize road quality (Dhatrak et al. 2020), ensure road users' safety (Augeri et al. 2019), minimize environmental impact (Chong et al. 2024), minimize construction time (Amândio et al. 2021), and reduce maintenance cost (Alqaili et al. 2021). However, the application of the budget optimization method utilizing technology is not widely used in the public sector, which could be due to limitations in the selected technology application, such as skills, resources, safety, and other factors (Camngca et al. 2022). This systematic review initially presents the strengths and limitations of the selected publications, specifically those related to the development of technology-based budget optimization methods. Among the strengths is the development of a method that uses technology to enable road agencies to optimise maintenance funds under constrained budgets (Shadhar & Majoob, 2020; Alqaili et al. 2021). Limitations of the study include the adequacy of the pavement samples (Philip & AlJassmi 2023; Amândio et al. 2021) and the inclusion of other criteria to balance the objective, such as social and economic factors (Augeri et al. 2019).

Determining the technology acceptance factor is crucial because it will reveal how it affects both intended and actual technology use (Qin et al. 2020). Accordingly, this review also highlights the publication's inclusion of technology acceptance factors. Basically, all publications have covered the factors of localization, standardization, compatibility, return on investment, and model popularity. All publications demonstrated a clear benefit of the method, with the primary goal of obtaining an optimized maintenance plan under limited-budget conditions (Shadhar & Majoob, 2020; Alqaili et al. 2021). Most of the methods were developed purposely to assist decision-makers during the planning phase of the road, which is critical to a project's success (Ameri et al. 2019). Technology use has been a major advancement, with software applications assisting in analysing data effectively and obtaining the most optimal maintenance solution (Augeri et al. 2019). Additionally, the factors of organizational workflow and traditional thinking were discovered through some of the publications. Several publications emphasized the method's capacity to handle the intricacies of the management level (Dhatrak et al. 2020) and to manage the expectations of various stakeholders (Augeri et al. 2019). Nevertheless, other important factors were less frequently mentioned in the publications, including experts and technicians, national policy requirements, and management support. The factors of cost and competition were absent from the publications. This suggests that to increase the acceptance of technology in the public sector, all of these factors need to be included.

High-level system reliability is also crucial, as it will prevent system failure, reduce risk, and increase system readiness (Breznická et al. 2023). Hence, this review goes beyond evaluating the system reliability factors to establish the method's reliability further. A development factor was identified across all publications, mainly through the process of developing the method: mathematical equation (Madushani et al. 2024), framework (Chen, 2023), flowchart (Philip & AlJassmi, 2023), and process (Naseri et al. 2024). Some publications include a dependability factor, which is mainly related to the speed of the optimization process supported by programming tools and software (Naseri et al. 2024). The factors of maintainability and repairability were not identified in the reviewed publications. Given the importance of these factors for system sustainability, it is suggested that they be considered in the design of future methods to enhance overall reliability.

CONCLUSION

In conclusion, this literature review identifies the essential domains of technology acceptance and system reliability for road maintenance budget optimization methods that utilize technology. The integration of several studies has illuminated major themes and trends, shedding light on the field's varied difficulties and potential. The literature review emphasized the significance of technology acceptance factors in increasing technology adoption, particularly in the public sector. The findings also highlighted the importance of system reliability factors, particularly in enhancing system reliability. It was discovered that most previous studies emphasized budget constraints in road maintenance, prompting a revisit to financial planning by developing optimization methods that leverage technology to maximize benefits and minimize costs. It was found that most publications have included technology acceptance factors such as localization, standardization, compatibility, return on investment, and model popularity. At the same time, some focus on organizational workflow and traditional ways of thinking. However, other important factors were still underrepresented, such as experts and technicians, national policy requirements, and management support. In terms of reliability, all publications included the factor of development, while some focused-on dependability, and none on maintainability and repairability.

FUTURE PROSPECT

Moving forward, policymakers, practitioners, and researchers are encouraged to implement and advance these road maintenance optimization methods that utilize technology to preserve the durability and resilience of global road networks. This comprehensive assessment lays the groundwork for future research and practical initiatives aimed at optimizing budgetary solutions for continuous, and sustainable road infrastructure maintenance. Additionally, this study recommends that further research focus on developing a strategic model to assess the acceptance of technology-based budget optimization methods for road maintenance, to optimize financial resources and achieve maintenance goals. Furthermore, given that policies serve as essential guidelines for the public sector in meeting its goals, it was also suggested that future research on policy improvement consider technology acceptance and reliability factors, which influence both the adoption and effectiveness of technology-based optimization methods.

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DECLARATION OF COMPETING INTEREST

None.

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