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Financial Contingency Planning of the Operation and Maintenance in Global Urban Railway: A Narrative Review

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Abstract
Purpose: This study seeks to provide a thorough examination of financial contingency planning for operation and maintenance in urban railroads worldwide. The emphasis will be on developing solutions to address the specific issues encountered by authorities and operators.
Design/methodology/approach: This study compiles current research from Scopus and Web of Science databases, specifically examining financial risk assessment and mitigation measures in urban train systems. The research employs several optimization models, predictive maintenance methodologies, and risk assessment frameworks to measure the financial resilience and operational efficiency of railway infrastructure management systematically.
Findings: The financial risks associated with operating and maintaining urban railways are diverse, including factors such as fluctuating income, the need for capital investments, and the expenses of complying with regulations. The research highlights the significance of a strong risk assessment methodology for identifying hazards, proactive tactics for reducing consequences, and ongoing monitoring systems for adaptive management. Practical examples and proven methods from real-life situations are combined to provide policymakers, industry stakeholders, and academics with practical and useful knowledge.

Research limitations: The review mostly focuses on existing literature and case studies, which may have limits in terms of their applicability to all worldwide situations owing to differences in regulatory frameworks and operational conditions.
Research implications: This research adds to the existing body of knowledge by emphasizing the need to include financial contingency planning in the management of urban railway risks to achieve successful outcomes. The statement emphasizes the significance of implementing adaptive methods and adhering to regulatory requirements to strengthen the financial stability and operational safety of urban railway networks.
Practical implications: Policymakers and industry practitioners may use the results to create customized financial risk management methods that guarantee the sustainable growth of infrastructure and operational effectiveness in urban railway systems.
Keywords: Urban railway, Management, risk management, Financial contingency planning, Narrative review

Introduction

Urban railway systems play a crucial role in facilitating transportation efficiency and sustainable urban development. In Malaysia, as in many rapidly growing economies, the operation and maintenance of urban railways pose significant financial risks to both authorities and operators. (V. Singh et al., 2023). The effective management of these risks is paramount to ensuring the reliability, safety, and long-term viability of such critical infrastructure (Kadri et al., 2014) . This paper aims to provide a narrative review of Financial Contingency Planning for the Operation and Maintenance of global urban railway, offering mitigation strategies tailored to the specific challenges faced by authorities and operators in the country. The financial risks inherent in urban railway operation and maintenance are multifaceted (Di Graziano & Marchetta, 2021). The study encompasses revenue volatility due to fluctuating ridership levels and capital expenditure requirements for infrastructure upgrades and maintenance. To address these challenges, a holistic approach to financial risk management is necessary. (Appoh & Yunusa-Kaltungo, 2022)This involves implementing robust risk assessment methodologies to identify and quantify potential risks, developing proactive mitigation strategies to reduce their impact, and establishing mechanisms for continuous monitoring and adaptation. By synthesizing theoretical frameworks with real-world examples and best practices, this paper aims to equip policymakers, industry stakeholders, and researchers with actionable insights to enhance the financial resilience of urban railway systems in Malaysia. Ultimately, the successful implementation of effective financial risk management strategies will not only safeguard investments in urban transportation infrastructure but also contribute to the sustainable development of Malaysian cities in the years to come.

Objective of the Study

This paper aims to determine the role of financial contingency planning in the operation and maintenance of global urban railways. The objective that could be extracted from the scope theme of this paper;

- RO-1: To determine strategies for enhancing resilience in urban railway systems
- RO-2: To determine methods for optimizing cost efficiency and budgeting in railway infrastructure management
- RO-3: To determine financial risk assessment and mitigation strategies in global urban railway projects

Literature Review

Ensuring maximum performance and safety of global urban railway networks involves careful financial contingency planning that balances maintenance costs and operating efficiency (Maulana & Gunawan, 2023). To attain this equilibrium, it is crucial to use diverse optimization models that tackle distinct facets of railway operations, including line planning, timetabling, rolling stock allocation, and track maintenance (Zhou & Oldache, 2021). These optimization models take into account aspects such as passengers' travel needs, infrastructural limits, and the requirement for cost-effective maintenance procedures to improve the overall performance of the railway system (Sasidharan & Torbaghan, 2021). Furthermore, the maintenance planning for railway infrastructure is essential for guaranteeing the dependability and safety of operations while lowering expenses (Sedghi et al., 2022). Infrastructure managers may enhance the effectiveness of maintenance interventions by using data-driven methods and predictive maintenance tactics. This can result in enhanced safety, availability, and cost-efficiency. Furthermore, it is crucial to use risk-informed sustainable asset management strategies to tackle the difficulties presented by deteriorating infrastructure and constrained financial resources in the maintenance of railway lines (Sasidharan & Torbaghan, 2021).

Moreover, when it comes to running urban railways, it is crucial to identify the most important parts of the trains to save maintenance expenses and guarantee dependable operation (Seyedan Oskouei et al., 2024). dependability-centered maintenance (RCM) methods are crucial for reaching this objective by prioritizing essential components that have a substantial influence on the overall dependability of rolling stock. Similarly, the maintenance decision support models that include aspects such as cost, dependability, and availability are crucial for optimizing maintenance planning for railway track geometry (Kasraei & Zakeri, 2022). Railway operations are vulnerable to interruptions, highlighting the need to implement contingency measures to efficiently handle unforeseen incidents (Umar et al., 2023). Efficiently adjusting train platforming and routing plans during interruptions is crucial to minimize the effect on operations and maintain uninterrupted service delivery. Moreover, the incorporation of digital technologies, such as digital twins and Building Information Modeling (BIM), may improve the effectiveness of maintenance management and infrastructure operations in urban railway systems (Wu & Zhang, 2022). However, scheduling maintenance for railway tracks in busy railway systems is a challenging undertaking, particularly when there is a need to maximize operating time and minimize downtime caused by repair activities (Dao et al., 2018). Efficient maintenance activities and continuous training operations rely on the implementation of integrated planning methods that take into account resource allocation, crew scheduling, and maintenance windows (Lidén et al., 2018). In addition, using network-based approaches for advanced maintenance planning of Electric Multiple Unit (EMU) trains may effectively reduce expenses and enhance operational efficiency (Wu et al., 2017).

Similarly, ensuring operational efficiency and safety in high-speed railway systems requires the proper maintenance of railway tracks, including components such as point machines (Bian et al., 2019). Identifying defects in crucial parts and executing prompt maintenance schedules are crucial tactics to avoid operating interruptions and improve the overall dependability of railway infrastructure. Furthermore, implementing effective age-usage maintenance procedures for railway tracks is crucial in minimizing the hazards linked to faults and derailments, thereby improving the safety of railway traffic (Shafiee et al., 2014). Financial contingency planning for global urban railway systems necessitates a comprehensive strategy that incorporates optimization models, data-driven maintenance plans, risk-informed asset management approaches, and digital technology. Finally, urban railway system managers may ensure the smooth running of their systems and successfully manage their finances by giving

priority to dependability, safety, and cost-efficiency while planning maintenance for railway infrastructure.

Methodology

Journal Selection

For this analysis, the papers pertinent from the Scopus and Web of Science (WoS) databases that specifically addressed financial risk assessment and solutions for reducing it. A methodical search was performed using specific keywords such as "financial risk assessment," "risk mitigation strategies," and related phrases to locate appropriate material. The inclusion criteria were centred on peer-reviewed publications published after 2020, guaranteeing the relevance and up-to-dateness of the evaluated literature. A total of 80 publications were gathered for the current study project at the initial phase of the narrative review procedure from both databases.

Data collection

The data-collecting approach included obtaining and extracting whole articles from the chosen publications. The articles were evaluated by examining their abstracts and determining their relevance to the following themes: (1) Enhancing resilience and operational safety in urban railway systems, (2) Optimizing cost efficiency and budgeting in railway infrastructure management and (3) Financial risk assessment and mitigation strategies. The extracted key material encompasses the applied approaches, investigated case studies, and conclusions about risk assessment and mitigation solutions in several settings, including transportation, infrastructure, and environmental management.

Results and Findings

Theme 1: Enhancing Resilience and Operational Safety in Urban Railway Systems

Urban railway operation and maintenance need a comprehensive strategy for financial contingency planning to effectively manage various risks and obstacles. It is essential to analyze the regulatory environment in Malaysia to comprehend and handle the financial risks associated with urban railway operations. This analysis highlights the significance of adhering to regulations and the negative impact on costs that might result from non-compliance. China's implementation of the public-private partnership (PPP) funding model for urban rail transit (URT) projects emphasizes the need for a strong information integration framework to efficiently manage risks and rewards. This framework might potentially be used as a model for other nations (Huang et al., 2022). Hence, it is crucial to maintain important components such as Switches and Crossings (S&C) because they have a high likelihood of failing and may cause large disruptions to traffic. This requires making educated choices about asset management based on maintenance and failure data (Litherland & Andrews, 2023). Furthermore, the susceptibility of railway systems to natural calamities such as floods, as shown in China, emphasizes the need for simulation frameworks in evaluating risks and enhancing the durability of railway infrastructure against such occurrences (Zhu et al., 2022).

Additionally, the functional safety of railway tracks includes aligning track components to specified operating circumstances to ensure effective usage throughout their entire lifespan. This is achieved by employing the theory of elastic waves to optimize deformability parameters (Bondarenko et al., 2023). A reliability-based decision-making approach that combines Structural Health Monitoring (SHM) data with Principal Component Analysis (PCA) is used for railway bridge maintenance. This technique helps to minimize inspection and intervention

costs while guaranteeing the structural integrity and cost efficiency of the bridge (Lajevardi et al., 2023). Mega railway construction projects (MRCPs) encounter substantial environmental and technical obstacles, requiring strong institutional resilience to effectively respond to emergencies. The resilience of the construction management system is influenced by several factors, including the institutional environment, implementation, oversight, guarantee, and feedback systems. These elements work together to improve the system's flexibility and efficiency (Zhao et al., 2023). Moreover, a risk assessment model for the China Railway Express, based on Bayesian networks, emphasizes the significance of managing risks across many areas to guarantee safety, effectiveness, and long-term growth. This approach employs sophisticated risk management theories and sensitivity analysis to identify and alleviate significant risk variables, including political stability, infrastructural problems, and operational difficulties (Feng et al., 2022).

In the same way, this paradigm facilitates the efficient distribution of maintenance expenditures across crucial operational systems, such as railway tracks and signals, to achieve optimum performance, even when governments confront budget limitations (Hamshary et al., 2022). Furthermore, the incorporation of risk scenario awareness and safety decision-making is crucial, particularly for unmanned trains. Real-time risk assessment may be enhanced by monitoring scenario parameters and applying a Dynamic Bayesian Network (DBN) topology, therefore improving the autonomy and safety of train operations (Niu & You, 2022). Moreover, precise prediction of risk paths in urban rail transportation is crucial to avert delays and ensure safety. A probabilistic deep learning system that analyzes many sources of data, such as social media and passenger movement, has the potential to enhance forecasting accuracy and reduce the impact of cascading failures (Xue et al., 2023). Therefore, it is important to manage certain operating hazards, such as malfunctions in the braking system and occurrences of landslides. The safety and resilience of railway operations may be greatly improved by creating a model that calculates the minimum distances needed to avoid collisions for trains with brake faults, as well as by deploying early detection systems for probable landslides (Zhang et al., 2023; Zhu et al., 2023)

Meanwhile, early identification of landslides is crucial to guarantee the safety of high-speed railroads. By using satellite imaging and sophisticated analytic techniques, it is feasible to detect future landslides along railway tracks, thereby facilitating proactive management of hazards and mitigation of risks (Zhu et al., 2023). Moreover, the incorporation of servitization into asset management offers substantial prospects for original equipment makers. Manufacturers may strengthen their decision-making processes and solve technical problems by connecting asset management with product-service systems. This can be achieved by using advanced technologies like reliability analysis and multi-objective optimization (Erguido et al., 2022). In addition, the use of virtual coupling technology, which establishes a connection between many trains to form a virtually coupled train set (VCTS), necessitates the implementation of strong control systems to guarantee stability and safety. The use of a dual-mode robust model predictive control (DRMPC) strategy effectively deals with the uncertainties in train dynamics and guarantees the required performance of VCTS operations (Luo et al., 2023). Furthermore, the URRAN system in Russian railway transport serves as a prime example of using big data and artificial intelligence to effectively oversee the dependability, security, and resources of transportation infrastructure. This system allows instantaneous evaluation of potential hazards and the subsequent process of making informed choices, such as automated control of fire risks. Consequently, it guarantees the uninterrupted safety and effectiveness of railway operations (Shubinskiy, 2022).

However, to successfully analyze and increase the safety resilience of tunnels, an assessment framework may be constructed. This framework would be based on traits such as resistance,

adaptability, and resilience. Methods such as information fusion and improved fuzzy matter-element models can be used in this process (Dong et al., 2023). On the other hand, reliability engineering specifically aims to comprehend the mechanisms of failure in railway infrastructure to enhance investment decisions and maintenance planning. By using formal fault-tree modeling and probabilistic model verification, one may accurately evaluate and confirm the service reliability of railway systems during the design stage. This is especially important for essential components like switches and crossings (Weik et al., 2022). In particular, cybersecurity has become a vital element, particularly for subsystems that heavily rely on communication, such as signaling in Communication-based Train Control (CBTC) systems. The CENELEC TS 50701 standard offers a structured approach to handling cybersecurity risks, and its implementation aids in reducing the likelihood of system safety being compromised by possible cyber attacks. The approach is supported by experimental testing and high-fidelity simulations, which emphasize the significance of strong cybersecurity measures in ensuring the integrity and dependability of railway operations (Soderi et al., 2023).

Henceforth, operational safety is of utmost importance in the fields of passenger transportation and urban planning. A complete evaluation technique has been devised to analyze URT systems, taking into account uncertainty in important influencing variables and the risk preferences of decision-makers. The Vensim program is used for system dynamics modeling, evaluating the impacts on passengers, administration, equipment, environment, and elements related to disasters. The system utilizes the IVTF-TOPSIS and IVTF-AHP-entropy algorithms to compute decision-maker weights and indicator priorities in situations of uncertainty. The Changsha subway network is used as a case study to verify and improve its operations (Chai et al., 2022). Finally, the Beijing Subway employs a mixed-integer nonlinear programming (MINLP) method to optimize the control of trains and the management of passenger flow. This method enhances punctuality, reduces waiting durations, and manages platform overcrowding during peak periods of demand. Research conducted on simplified and real networks has shown substantial advantages in following schedules, decreasing waiting times, and managing platform congestion risks. These findings emphasize the viability of using this approach for real-time applications and operational enhancements. (Yuan et al., 2022).

Theme 2: Optimizing Cost Efficiency and Budgeting in Railway Infrastructure Management

This theme examines the issue of cost reduction and budgeting in urban railway operation and maintenance. It explores several tactics and models that try to optimize financial resources and ensure sustainability. Techniques include predictive maintenance, asset lifecycle management, and cost-benefit analysis to reduce financial risks. The creation of performance assessment models for road and railway tunnels emphasizes the significance of evaluating facility performance to direct maintenance plans in the face of deteriorating infrastructure. This technique employs Delphi and AHP analyses to identify crucial assessment parameters and perform cost-effectiveness studies, hence improving the practical applicability (Kim et al., 2022). The suggested technique aims to optimize preventive maintenance scheduling by reducing expenditures. Also, the research on railway lines has shown that making adjustments to maintenance budgets may lead to large gains in capacity. Additionally, case studies have emphasized the need to include production costs when assessing operational efficiency (Bakhtiary et al., 2022). The research focuses on assessing several techniques for tamping and highlights the need for long-term maintenance strategies in order to maintain track quality and operating dependability. It aims to strike a balance between short-term cost savings and long-term durability of the infrastructure (Marschnig et al., 2022). An iterated greedy matheuristic is presented as a solution for scheduling stochastic railway network development. This approach aims to optimize project profitability while considering budget and resource limitations. This

strategy guarantees the successful completion of the project by organizing construction stages in a way that meets the growing needs of passengers and efficiently manages operating expenses (Canca & Laporte, 2022).

On top of that, the study conducted in Belgium examined 36 transportation infrastructure projects and found that there were large increases in costs, especially at the stage before contracts were awarded for road construction. These cost overruns had a negative influence on the overall efficiency of infrastructure investments (Molinari et al., 2023). On the other hand, a study conducted in North America investigates the electrification of rail networks while considering budget limitations. The study utilizes a genetic algorithm to optimize routes by taking into account operational costs and changes in demand. The study highlights the economic advantages of establishing extensive connectivity and electrification in densely populated regions and mountainous landscapes (Patil et al., 2022). Similarly, another researcher suggests that the expansion of Hong Kong's Mass Transit Railway (MTR) between 2001 and 2006 resulted in gentrification, with higher-educated residents moving in and low-income households being displaced. This indicates the need for policy interventions to address housing needs (Liang et al., 2022).

To put it in another way, the methodology combines Monte Carlo simulation and fuzzy reasoning to handle uncertainty and improve maintenance methods on mainline lines in the UK, therefore improving the efficacy of asset management (Sasidharan et al., 2022). Social cost-benefit analysis and dynamic pricing are examined to maximize the allocation of resources while meeting the demands of both commercial and public transportation (Broman et al., 2022). As a result, this can lead to cost optimization in design and improve the longevity of railway infrastructure (Alzabeebee, 2023). Genetic algorithms are used for optimizing crack detection and maintenance tactics in tunnel maintenance. These algorithms help balance the extension of service life and cost efficiency by implementing proactive maintenance procedures. This ensures that railway operations are both safe and cost-effective (D. Wang et al., 2023).

In order to achieve that, one approach involves applying advanced algorithms to reduce electromagnetic interference costs during railway construction, demonstrating up to a 28.55% reduction in operational costs through activity-based costing (ABC) versus traditional methods (Chanpermpoonpol & Kirawanich, 2023). For multimodal transportation systems, a mathematical model integrates air and high-speed rail (HSR) networks in China to minimize passenger travel and recovery costs during disruptions, showcasing efficient recovery strategies within computational constraints (Xu et al., 2023a). Not only in China, but in Norway, a study on frost heave in crushed rock aggregates highlights cost-effective methods using soil index properties to predict frost susceptibility, essential for budget-constrained road construction projects (Loranger et al., 2022). Moreover, a multi-objective optimization model allocates resources among railway level crossings in Florida, balancing safety improvements with minimized traffic delays, crucial for optimizing countermeasure effectiveness within budget limits (Singh et al., 2022). Similarly, in West Africa, an optimization model for transportation network design integrates railway construction, port capacity expansion, and shipping network operations under budget constraints, supporting China's infrastructure investments with decision-making tools (Xin et al., 2022). Meanwhile, cost-effective design and construction strategies for railway tracks are explored, emphasizing sub-grade service life prediction and cost optimization, essential for long-term railway development in various contexts (Setiawan, 2022). Lastly, advancements in urban rail transit construction technologies, particularly in challenging environments like wet loess, underscore the importance of efficient project management and quality control to ensure cost-effective and safe subway development (Wang et al., 2022).

As a result, the researcher underscores the importance of condition monitoring in switches and crossings (S&C), emphasizing the connection between sensor data and S&C failures to

improve maintenance efficiency (Shih et al., 2022). A model is used to combine investment stages and extension plans for transit line expansion, taking into account budget restrictions, demand elasticity, and geographical distribution. The goal is to maximize the net present value (NPV) of the project (Wu & Schonfeld, 2022). Efficient train operations in high-speed rail systems rely on optimizing depending on passenger demand patterns and departure timings. This involves using flexible pricing and sophisticated scheduling models to maximize revenue and decrease trip costs (Wang et al., 2023). Predictive maintenance is a revolutionary method that systematically improves railway maintenance by using sophisticated algorithms to detect important component faults. This leads to enhanced safety and operational availability (Binder et al., 2023). Finally, the integration of rolling stock allocation and train timetables (RATT) in urban transit networks has shown substantial enhancements in service quality and cost efficiency. This is achieved through the use of bi-objective linear programming and Benders decomposition algorithms, specifically designed for complex multi-line metro networks (Yin et al., 2023a).

Theme 3: Financial Risk Assessment and Mitigation Strategies

Studies in the field of financial risk assessment and mitigation techniques for global urban trains consistently emphasize the need to adopt comprehensive and multifaceted approaches. Railway operators in Bulgaria use a system that combines SWOT criteria and the SIMUS method to evaluate policy options and strategic planning. This approach involves multi-criteria analysis to establish the most effective operational strategy. Ultimately, this process aids in making informed choices (Stoilova & Munier, 2021). Geological evaluations are used to create landslide susceptibility maps in the southern Tibetan Plateau. These maps help identify safer railway lines and reduce the dangers associated with difficult terrain (Wu et al., 2020). In both Sweden and Australia, sustainable asset management for railway tracks involves the use of Monte Carlo simulations to effectively balance maintenance costs with safety and environmental factors (Sasidharan & Torbaghan, 2021). Similarly, an enhanced projection pursuit model, using quantum particle swarm optimization (QPSO), is used to assess the resilience of subway stations in the face of waterlogging catastrophes. This model emphasizes crucial variables such as emergency procedures and recovery operations (Liu et al., 2020). A fuzzy preference programming framework is used to prioritize subway network rehabilitation in Canada. This paradigm integrates financial, social, and operational viewpoints to successfully manage limited money (Abouhamad & Zayed, 2020). The Interval Type-2 Fuzzy Logic FMEA framework in Serbia provides a strong method for detecting and prioritizing risk events in railway infrastructure projects. It highlights the need for comprehensive risk management across the whole lifespan of the project (Macura et al., 2022). Too, the implementation of high-speed railroads in China has had both positive and negative effects on spatial equality. A hybrid approach using fuzzy calibration and optimization models helps design safer railway transportation networks for hazardous materials in North China (Zhang et al., 2022)
On a national scale, it has improved accessibility. In the same way, in Sri Lanka, a spatial planning tool is used to balance environmental and socioeconomic implications while building linear infrastructure routes. This tool aims to promote sustainable development (Wu & Li, 2022). Like, to protect intact forest landscapes from the harmful impact of extractive industries, it is essential to conduct strategic environmental assessments and implement mitigation measures on a worldwide scale (Grantham et al., 2021). In the case of the sustainable assessment indicator system for railway tunnels in China, places significant emphasis on the ecological restoration and everyday maintenance aspects of sustainable construction (Qiu et al., 2020). ForestGALES, a hybrid-mechanistic model, provides reliable predictions of tree fall hazards onto railway lines in Germany. This model offers useful insights for implementing preventative

measures and improving storm readiness (Gardiner et al., 2024). These studies emphasize the significance of combining strategic planning, risk assessment, and sustainable practices to reduce financial risks in urban railway operations (Papathanasiou & Adey, 2021). Thus, an evaluation of the potential for river flooding and earthquakes to cause damage to the railway assets along the Belt and Road indicates a considerable level of vulnerability. The bulk of the estimated annual damage (EAD) is attributed to floods, particularly affecting China, Laos, and Cambodia the most (Wang et al., 2021). Similarly, flood risk assessments using damage-probability curves and improved land use plans are crucial for mitigating economic damages in flood-prone railway sections (Tincu et al., 2020). Additionally, another research analysis was conducted on flood risk and resilience in urban areas, which revealed intricate connections between these characteristics and their reliance on land use. This analysis aids in the identification of flood hotspots for specific interventions (Wang et al., 2023).

However, it has also worsened regional differences, highlighting the need for integrated planning strategies to address spatial inequity (Huang & Zong, 2021). A novel rail condition assessment model using ultrasonic methods boosts the precision of rail quality forecasts and improves track safety by detecting internal rail problems (Sadeghi et al., 2020). The use of a novel risk assessment method in real-time train scheduling, including unpredictable stay lengths, aims to limit the spread of delays and improve operational resilience (Meloni et al., 2021). Next, the economic assessments of particulate matter pollution in Seoul's subway emphasize the significant financial costs associated with health consequences, emphasizing the need to implement effective preventive measures (Thangavel et al., 2023). Moreover, a meticulous evaluation of the increase in property prices and value capture exposes weaknesses in the belief that there is a direct link between zoning and development. This highlights the need for transparent and well-informed planning methods (Sheehan et al., 2021). Finally, a refined subsidy approach for multimodal transportation in Shanghai, taking into account carrier pricing and shipping resilience, seeks to improve competitiveness and decrease carbon emissions, offering a quantitative foundation for policy development (Chen et al., 2023).

Due to the fact that, use ergonomic measures are used to tackle work-related injuries and musculoskeletal diseases among Indian railway track maintainers. This emphasizes the significance of safety measures, adequate training, and job rotation (Das, 2020). Eventually, the resilience of complex urban public spaces (CUPSs) like multi-floor rail transit stations is critical for public safety and sustainable development, requiring a six-level resilience indicator system to be established and validated, as seen in Shenzhen and Guangzhou stations (Xu et al., 2022). However, the assessment of rockfall hazards for railways in Sicily highlights the need for varied qualitative and quantitative risk methodologies to optimize territorial planning (Mineo, 2020). Biomarker validation in the ROBoCoP project addresses health risks for subway workers exposed to particulate matter, demonstrating the need for biomonitoring in polluted urban transport environments (Guseva Canu et al., 2021). Lastly, evaluating hazardous material transport modes using fault tree analysis and decision-making techniques helps rank critical transportation risks, emphasizing the need for integrated risk assessments in highway, marine, airway, and railway modes (Derse et al., 2022) These techniques allow for accurate risk assessments and the formulation of effective preventative solutions (Pei, 2022).

Next, the serviceability and long-term management of TBM tunnels are improved by using digital methods and AI algorithms for flaw segmentation. This approach enhances maintenance practices and leads to cost reduction (Foria et al., 2023). However, other researchers conducted studies on level crossings introduced a multi-objective approach that aims to effectively allocate resources by considering both the severity of hazards and the impact on traffic delays (Singh et al., 2022b). Furthermore, the importance of reducing passenger travel and mode recovery costs during interruptions was emphasized in the integrated recovery of multimodal

transportation systems in China (Xu et al., 2023b). A study was conducted in Norway to evaluate the susceptibility of crushed rock aggregates to frost heave. The researchers found a strong connection between the laboratory data and the estimated data, which may be used to assist in road building design, even with different budget constraints (Loranger et al., 2022).

Finally, urban rail transit has been a successful method for reducing urban stress by easing traffic congestion, reducing accidents, and limiting environmental pollution. Stable schedules, sufficient finances, and professional management people are essential for the construction and quality management of rail transportation, especially in difficult situations such as wet loess (Wang et al., 2022). Equally important, a novel framework was developed to address financial limitations in the maintenance of public transportation systems. This framework aims to optimize performance and allocate money efficiently across subway systems. Its effectiveness was shown via a real-world case study (El Hamshary et al., 2022). In the past, the optimization of train schedules for high-speed rail networks required a careful balance between meeting passenger expectations and maximizing company advantages. This may be achieved via the use of tactics such as flexible pricing and accommodating departure time preferences, which can enhance both efficiency and revenue generation (Wang et al., 2023). Last but not least, the integration of rolling stock allocation and train schedules in urban rail networks, as seen in Beijing, may greatly enhance service quality and cost-effectiveness by using sophisticated mathematical modeling and solution algorithms (Yin et al., 2023).

Conclusion

Overall, the research on financial contingency planning for urban railway operation and maintenance emphasizes the need for comprehensive plans to guarantee the long-term viability, security, and effectiveness of these essential assets. The key results emphasize the need to implement strong risk assessment techniques and data-driven maintenance plans to improve the dependability and durability of urban railway systems. Predictive maintenance models use historical data and sophisticated analytics to effectively minimize downtime and maintenance expenses by proactively identifying possible faults and scheduling appropriate treatments. The predictive maintenance skills are further enhanced by digital technologies, such as the Internet of Things (IoT) and artificial intelligence (AI). Operators may achieve enhanced operating efficiency and cost reduction by using real-time monitoring and analysis of railway components, which allows for the exact detection of abnormalities and the prediction of breakdowns.

Nevertheless, the report admits some constraints. First and foremost, there is a scarcity of comprehensive and high-quality data that is specifically relevant to Malaysia's urban railway system. Insufficient or contradictory data may compromise the efficacy of predictive maintenance models. Subsequent investigations should prioritize enhancing the process of gathering and verifying data to guarantee the effectiveness and dependability of maintenance techniques. Furthermore, a comprehensive strategy to financial risk management is required. Integrating risk assessment and predictive maintenance procedures with larger financial risk management frameworks, such as budgeting, cost efficiency, and financial contingency planning, is vital. Implementing a thorough strategy allows operators to effectively mitigate financial risks and guarantee long-term viability.

Given the results and constraints identified, policymakers and industry stakeholders may offer many suggestions. Effective cooperation among government agencies, railway operators, and technology suppliers is essential. To improve the overall efficiency of urban railway systems, it is crucial to establish standardized procedures for data gathering and exchange, as well as legal frameworks that facilitate the use of sophisticated technology. Prioritizing investments in digital technologies and infrastructure that provide predictive maintenance and real-time

monitoring is crucial. By using IoT sensors, AI algorithms, and advanced data analytics platforms, the maintenance capabilities of urban trains may be significantly enhanced, resulting in improved reliability and efficiency. It is crucial to cultivate a culture of ongoing development and innovation in the urban railway industry. To guarantee the continued effectiveness and relevance of maintenance techniques in the face of increasing issues, it is crucial to promote research and development efforts and provide training opportunities for railway staff. Further investigation is required to examine the use of artificial intelligence and machine learning algorithms in the field of predictive maintenance. These technologies have the potential to greatly improve the precision and dependability of maintenance models, enabling operators to accurately forecast and avoid breakdowns. In addition, it is crucial for research to prioritize the development of infrastructure that can better withstand natural catastrophes and other emerging risks. This may be achieved by using modern materials and building processes, as well as including climate resilience measures into railway design and planning.

Moreover, it is recommended that future studies explore the use of big data and sophisticated analytics to enhance maintenance procedures. By analyzing extensive amounts of data from several sources, one may get profound insights into the aspects that impact railway operation and create more efficient maintenance models. This entails using machine learning algorithms to detect patterns and trends, as well as creating predictive analytics tools that provide immediate insights on the status and performance of railways. To summarize, the research highlights the significance of thorough and evidence-based approaches in financial contingency planning for the operation and maintenance of urban railways. Although there have been notable improvements, it is crucial to focus on data quality and embrace a comprehensive strategy for managing financial risk. By engaging in cooperation, making investments in cutting-edge technology, and promoting innovation, urban railway systems may attain enduring sustainability and efficiency while maintaining their status as dependable and effective transportation options for communities throughout the globe.

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