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A Strategic Framework for Urban Infrastructure Asset Management: Enhancing Longevity, Resilience, and Service Quality in City Assets

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Abstract:

Introduction: Urban areas have increasing demands to sustain infrastructure in the context of deteriorating assets and expanding populations. Accordingly, Infrastructure Asset Management (IAM) offers a systematic methodology to enhance planning, budgeting, and performance. This research presents a versatile IAM framework designed for urban environments to promote sustainable development.

Methods: A ten-stage framework was developed, starting with a preliminary report and ending with an infrastructure report card. SWOT analysis is carried out at every phase to assist decision-making and fulfill the city's requirements. A hypothetical case study illustrates the implementation of a budget allocation model with respect to the physical condition assessment using AHP and Lingo software.

Results: The case study measures the infrastructure GPA for urban areas and regions in Saudi Arabia. A mathematical model improves budget allocation by considering infrastructure sector implications, condition assessment ratings, and required costs. City X had a GPA of 2.69 (D+), demonstrating the need for further investment in the specific infrastructure sector.

Discussion: The developed model enables required financing, allocating available resources to critical areas such as wastewater management for the hypothetical case study. Budget limits result in planned cuts in lower-priority areas, affecting service quality. Continuing success requires strategic anticipation, regular evaluation, and varied financing flows.

Conclusion: The framework provides a logical model for urban Asset Management, considering lifespan cost, risk assessment, and level of service analysis. It enables data-driven decision-making and aids cities to tailor the framework to their location and resources. Extensive implementation may improve infrastructure sustainability, resilience, and consistency with national development goals.

Keywords: Infrastructure asset management, City policy, SWOT, Decision-making, Life-cycle cost, Risk management, Level of service, Infrastructure report card, Budget allocation, Condition assessment.

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1. INTRODUCTION

As urban areas expand and infrastructure ages, cities face growing pressure to maintain and improve critical assets, such as roads, water networks, and public facilities, to ensure service quality, sustainability, and resilience. Effective infrastructure asset management (IAM) has emerged as an essential practice to manage the life cycles of these assets. IAM involves a systematic approach to planning, budgeting, risk assessment, and resource allocation, all aimed at optimizing asset performance over time. However, cities often encounter challenges in implementing IAM due to factors like limited budgets, logistical complexities, and evolving service demands. Without a structured framework, cities struggle to sustain infrastructure quality and align asset management with policy objectives and community needs. This study introduces a strategic IAM framework tailored for urban environments, enabling cities to incrementally adopt IAM practices that suit their specific conditions and constraints. The framework provides a structured roadmap that prioritizes data-driven decisions, risk and cost management, and alignment with both short-term and long-term goals. Using this framework, cities can improve resource efficiency, boost infrastructure performance, and create a foundation for sustainable growth. The framework also accommodates cities at different stages of IAM development, offering a flexible, scalable approach that aligns with existing policies, budget limits, and operational needs. This adaptability is key to helping cities progressively advance their IAM capabilities and respond proactively to future infrastructure demands.

2. LITERATURE REVIEW

2.1. Historical Background

Effective IAM is increasingly seen as vital in urban areas where population growth, aging infrastructure, and resource constraints challenge service maintenance and economic resilience [1]. IAM principles emerged as an integrated approach to managing infrastructure assets sustainably by optimizing their lifecycle, assessing risks, and aligning with budgetary constraints. IAM concepts were first developed to address the maintenance backlog created during the global infrastructure expansion of the 20th century. In the 1980s, the rise of IAM in countries like the United States, Canada, Australia, and the United Kingdom reflected a paradigm shift from reactive maintenance to a proactive approach focused on lifecycle management and sustainability [2]. IAM focuses on balancing the costs, risks, and performance of assets, a strategy pioneered in these countries through extensive research and practice guidelines, such as the PAS 55 standard developed in the UK, which has since evolved into ISO 55000 [3]. IAM frameworks typically involve key stages such as data collection, asset condition assessment, lifecycle cost analysis, and establishing service-level agreements. Recent studies [4, 5] outline step-by-step IAM processes that cities can adopt. This approach involves setting measurable goals, establishing key performance indicators (KPIs), and conducting regular performance reviews to ensure alignment with municipal goals. A review by authors emphasizes the importance of aligning IAM with broader urban planning objectives to promote cross-departmental collaboration and resource optimization [6]. Several case studies highlight the best practices in IAM, particularly in regions that have formalized IAM principles at the municipal level. Australia and New Zealand serve as exemplary cases where IAM has been institutionalized in local governments through regulatory mandates. New Zealand's Local Government Act of 2002, for example, requires councils to produce long-term infrastructure plans, a model that has been widely studied [2]. Similarly, Canada's Ontario province legislated the creation of asset management plans for municipal infrastructure in 2012, resulting in systematic resource allocation improvements [7]. Both examples underscore the importance of regulatory frameworks in facilitating IAM adoption at the local level. In the U.S., IAM adoption is growing, but its application is often limited by funding and regulatory variability. A 2018 report by the American Society of Civil Engineers (ASCE) rated U.S. infrastructure at a D+ level [8]. Barriers like budget constraints, inconsistent data standards, and technical skill gaps hinder local governments from fully implementing IAM [9-12].

2.2. Current Applications and Practices

With the expansion of technologies, infrastructure practices become increasingly the target of the decision-makers at different levels, countries, provinces, cities, and organizations. A study proposed a digital infrastructure for road networks with the aid of hundreds of literature and questionnaire surveys [13]. The application scenarios cover design and construction, maintenance, operation, and highway administration. A data integration approach using master data identification, correlation matrices, and a data relationship model ensures interoperability. Developing a robust backup system was conducted with respect to data redundancy, encryption, and role-based access control [14]; smart contracts were proposed by Villa *et al*. for the infrastructure maintenance and management activities according to blockchain networks to ensure transparency, security, and automation without the need for intermediaries [15]. Another infrastructure framework was suggested using the Internet of Things coupled with the health index of an asset [16], this application was useful in enhancing the infrastructure maintenance activities according to the consequence of asset failure. Railway infrastructure was selected to study the onboard monitoring applications, mainly focused on track geometry quality to assess the condition and forecast the requirements [17]. The integrated digital twin and BIM/GIS have been utilized to optimize port asset management in Spain [18]. The proposed system utilizes real-time data acquisition, predictive maintenance, and resource optimization to tackle key challenges in Sapin's port. Aragón *et al*. compared the utilization of digital twins in the construction and infrastructure sectors with other sectors [19]. The difficulties in recording, storing, and accessing both static and dynamic data are examined. Al-Oun *et al*. established an infrastructure framework for sustainable energy in Jordan [20]. This study examines the relationship between policy and infrastructure in solar energy adoption, highlighting tariff structures as a key determinant. Deep learning models were developed for highway infrastructure in Alberta, Canada [21] with implications spanning autonomous driving, crash environment reproduction, highway safety, big data analysis, maintenance planning, and asset management. Mirali *et al*. introduced Artificial Intelligence

(AI) as a new tool that rapidly merged into the infrastructure sector using a systematic review [22]. Several questions have been raised regarding how and what this merger can be utilized to improve the process of infrastructure asset management. According to the previous studies, no study has captured the infrastructure asset management process within the county scale, which is the aim of the current study.

2.3. Theoretical Foundations

Managing city infrastructure requires balancing several key functions [23]. The primary functions include Level of Service (LoS), Risk, Condition and Performance, and Budget. Decision makers should carefully consider three potential scenarios (more, less, or the exact available budget is required) to prevent any deficit in these areas. The objective of Infrastructure Asset Management is to operate assets in alignment with LoS expectations, maintain minimal risk, and stay within budget by effectively monitoring and managing the asset's condition and performance throughout its lifecycle. This process can help a decision maker to allocate the required funds to continue effectively managing the infrastructure assets of the city [24-26].

2.4. LoS

The LoS explores the concept as a crucial component in asset management frameworks, particularly for urban infrastructure systems. LoS reflects the performance standards expected by users and municipalities, incorporating aspects such as reliability, accessibility, quality, and safety across different asset types [2]. Early LoS studies focused on developing metrics to quantify service levels, particularly in transportation and utility networks. As IAM frameworks evolved, researchers have worked to standardize LoS metrics to facilitate asset evaluation, budget planning, and policy development. Chasey *et al*. provided a comprehensive LoS for civil infrastructure systems based on capacity in terms of availability and maintenance in terms of operations, using a 2X2 matrix to help the decision maker for the best investment in transportation projects [27]. In addition, Sharma *et al*. [28] developed a framework for assessing the aggregate level of service (ALOS) in municipal infrastructure using the analytical hierarchy process (AHP) to model and combine service levels for various road users, considering factors like safety and aesthetics. This framework was applied to urban roads to balance LoS for vehicles, bicycles, and pedestrians. Moreover, Han *et al*. assessed the LoS from a customer perspective. This helps decision-makers allocate resources effectively to enhance service quality [29].

2.5. Life Cycle Assessment

Lifecycle management has become a cornerstone of IAM frameworks, aiming to minimize long-term costs while ensuring asset functionality. Glick and Guggemos provided a case study in Northern Colorado that used both life-cycle cost (LCC) and environmental life-cycle assessment to illustrate how achieving sustainability goals can also yield environmental benefits [30]. Yuan *et al*. proposed a life cycle method for data collected during construction to asset management information systems, which can eliminate waste from redundant data collection and enhance data collector safety [31]. Liu *et al*; [32] emphasized that decisions should prioritize life-cycle evaluations and costs, ideally made early in a transportation system's development. Early assessments profoundly influence a facility's lifespan and determine its overall cost to the public. The life-cycle critical success factors (CSF) framework was identified with integrated "learning mechanisms" to provide both public and private sector stakeholders with a deeper understanding of the key factors necessary (for successfully implementing a public-private partnership (PPP) contract strategy). During the life cycle of an infrastructure asset, condition and performance assessments are performed to understand the behavior of the assets and aid the decision maker in making a reliable decision(s). Salman *et al*. [33] developed a mathematical model to assess the condition assessment for residential roads with respect to structure, construction, environment, and miscellaneous categories. Authors in a study obtained a performance index for a water main network by integrating reliability and criticality index [34]. Reliability is based on the number of failures, while the criticality index is based on economic, operational, social, and environmental. Mohseni *et al*. [35] reviewed techniques for monitoring the condition of buildings and introduced a risk-based methodology for aggregating the conditions of individual elements. This approach enhances decision-making accuracy for the strategic management of buildings by providing a higher-level analysis of inspected elements.

2.6. Risk Assessment

Risk assessment for an infrastructure asset is necessary to identify the associated risk during the asset operation. The following research studies address risk analysis from various perspectives. Abourizk *et al*. outlined a systematic approach for evaluating the risks associated with potential infrastructure failures [36]. Its innovative aspect lies in modeling infrastructure deterioration at a broader level of detail, which enhances the practicality and feasibility of the application for real-world use. Yu *et al*. prioritized maintenance tasks based on risk with respect to the necessary resources of large of a large facility [37]. Zahran and Ezeldin outlined a risk assessment framework designed to assist governments in navigating the risk evaluation process for programs funded through results-based mechanisms [38]. Shahata and Zayed introduced a methodology and framework that supports decision-making in corridor rehabilitation project planning [39]. It focuses on a risk-based approach to integrate repair and renewal of roadworks assets, using a combination of the Delphi method and the AHP for developing a risk model.

2.7. Optimum Budget Allocation

Billions of dollars are required to maintain the operation of the infrastructure assets during their useful life. Au-Yon *et al*. illustrated a method for prioritizing facility maintenance in high-rise residential buildings in Peninsular Malaysia [40]. With increasing importance in the building maintenance industry, maintenance prioritization helps ensure effective management and upkeep of these facilities. Xu *et al*. considered employing a resource allocation model to evaluate investment strategies in financial services firms aimed at minimizing losses related to operational risks [41]. Markov Chain was employed to obtain an optimal budget allocation for educational maintenance activities [23]. Wooldridge *et al*. highlighted that relying on cash-basis accounting, line-item budgeting, and inadequate cost accounting hinders decision-makers from effectively managing local government capital allocations [42].

Based on historical data and previous studies, managing infrastructure is one of the most challenging tasks, requiring vast resources such as billions of dollars, skilled experts, and various tools and machinery of different types and sizes. However, these resources alone are insufficient without a clear process and roadmap, such as a dynamic and flexible framework, which is the focus of this paper.

3. METHODOLOGY

Fig. (**1**) depicts a proposed framework of a city infrastructure asset management; it includes ten stages, starting with a preliminary report and ending up issuing an infrastructure report card.

3.1. Stage (1): Preliminary Report

The objective of the preliminary report is to study the current practices and accordingly identify the required strategies, plans, and resources to perform the upcoming stages. The report is prepared by consultant specialists with extensive experience in infrastructure asset management. The preliminary report should not be limited to the following items: an overview of the need for infrastructure asset management, benefits for city planning, budgeting, and long-term maintenance, and the current state of city infrastructure, which includes current infrastructure assets (rods, water systems, bridges, *etc*.), and challenges in operation, maintenance, funding, management, and the existing asset management processes, identifying the requirements and resources with the applicability of implementing the next stages. The required time frame and cost should be established according to the city's vision and mission. The SWOT analysis of the preliminary report is shown in Table **1**.

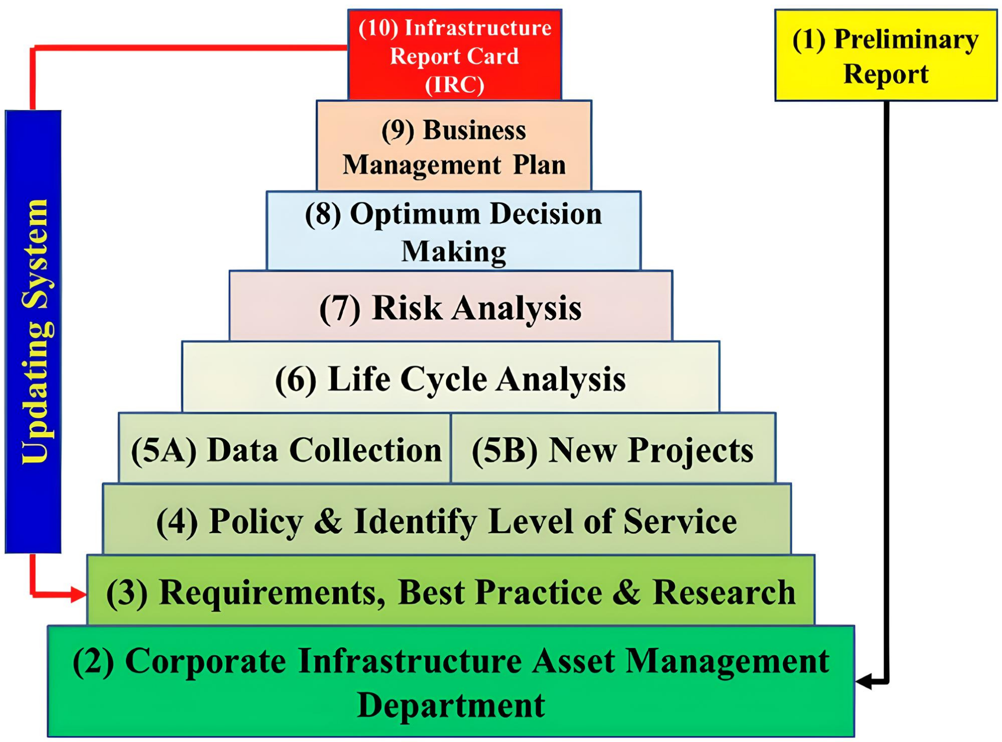


Fig. (1). Proposed infrastructure asset management formwork.

Table 1. SWOT analysis of stage 1 (preliminary report).

Strengths	Weaknesses
• Expert participation guarantees consistent, informed analysis. • Strategic planning is supported by a thorough study approach. • Address important requirements for the enhancement of city infrastructure.	• Great reliance on external advisors could raise expenses. • Possibly a long evaluation process prior to intervention.
Opportunities	**Threats**
• Improved municipal planning, financial control, and maintenance results. • Better long-term infrastructure resilience resource allocation.	• Funding restrictions could restrict the application of recommendations. • Aligning with the city's vision and goal requires public and political support.

Fig. (2). Infrastructure asset management formwork.

3.2. Stage (2): Corporate Infrastructure Asset Management Department

Establishing or reestablishing a specific department of infrastructure asset management is the key success of the whole process. Without such a department, applying the upcoming stages is a big challenge if not impossible. A central department is necessary to manage the city assets according to the required level of services within the available budget and risk control. Fig. (**2**) shows the required specialists that are required to establish a corporate infrastructure asset management department.

Each member(s) of the team plays an important part in managing the city assets. The major role of the head of the department is to make the required decisions with the city authors, according to the department reports. The department requires engineers in different fields (civil, mechanical, electrical, *etc*.) to perform the technical work and finalize the final reports. Inspector teams are responsible for the daily operation and maintenance of assets and for collaborating directly with external contractors involved in related infrastructure projects. The size of the team varies based on the department's vision and mission. It might be very big to include many technicians to limit the involvement of the external contractors, very limited to allocating the required projects to the external contractors, or between. However, trained inspectors and technicians are required to carry out the daily operation and maintenance for the long term. An accountant in the infrastructure asset department manages financial records, budgets, and funding allocation for asset maintenance and improvements. They analyze costs, prepare financial reports, and ensure compliance with financial policies, providing insights to guide asset investment decisions. This role is essential for maintaining fiscal responsibility in long-term infrastructure asset management and sustainability. Computer-aided design (CAD) specialists are responsible for creating detailed technical drawings and digital models using CAD software. They support engineers and architects by translating project specifications into accurate plans, diagrams, and 3D representations. Programmers in the infrastructure asset department design and maintain software applications that track asset data, support maintenance scheduling, and optimize asset management processes. They use data analytics tools to assess infrastructure health and develop systems for predictive maintenance. This role enhances data-driven decision-making and improves operational efficiency in managing the city's infrastructure assets. GIS Specialists in the department manage geospatial data and mapping tools to support asset tracking, condition monitoring, and maintenance planning. They analyze spatial data to help assess the locations and statuses of assets like water mains, roads, and utilities, providing essential insights for decision-making. By integrating GIS with other asset management systems, they enable more efficient management and visualization of infrastructure data across the city. Lawyers in the department ensure legal compliance in asset acquisition, management, and disposal processes. They review contracts, handle regulatory issues, and address potential liabilities associated with infrastructure projects. Additionally, they provide legal guidance on public-private partnerships, property rights, and environmental laws, safeguarding the department against legal risks and preparing and finalizing the department's policy. Finally, the involvement of external contractors and consultants is essential to support the department in achieving its objectives. The strengths, weaknesses, opportunities, and threats (SWOT) analysis of the established department are shown in Table **2**.

Table 2. SWOT analysis of stage 2 (corporate infrastructure asset management dep.).

Strengths	Weaknesses
• The department can facilitate and coordinate asset management across the city or the organization. • Multidisciplinary skills among team members ensure technical, legal, and financial integrity support. • Efficient decision-making and resource allocation can be achieved through clear roles and well-structured management.	• Trained staff and specialists required a very high initial cost. • Depending too much on external contractors for some technical tasks may raise costs.
Opportunities	**Threats**
• Improved data-driven asset management lowers long-term expenses and maximizes upkeep. • Ability to achieve key city goals and enhance infrastructure sustainability by means of coordinated actions.	• Budgetary restrictions and constraints could affect staffing or required tools, therefore influencing operational performance. • Legal and compliance issues, particularly in public-private partnerships and contract management with external contractors.

Table 3. SWOT analysis of stage 3 (requirements, best practices and research).

Strengths	Weaknesses
• Access to established international best practices provides proven strategies to emulate. • Academic research integration promotes ongoing improvement in sustainability, efficiency, and service levels. • Collaborative workspace and team resources support streamlined operations and strategic alignment.	• High variability in logistic requirements across cities may complicate standardization efforts. • Reliance on external research might require significant adaptation to local contexts.
Opportunities	**Threats**
• Adopting the best practices can expedite development and reduce the learning curve for asset management. • Research-driven practices offer continuous opportunities for innovation in cost, time, and service enhancements.	• Changes in global standards or practices may lead to costly adjustments. • Potential resource constraints could limit the ability to conduct or utilize academic research fully.

3.3. Stage (3): Requirements, Best Practices and Research

With all logistical requirements in place—such as office space and workstations, which may vary from one city to another—the team should begin by collecting and researching up-to-date best practices from around the world. Several developed countries such as Australia, New Zealand, UK, USA, and Canada started the same process decades ago, and therefore, it is necessary to adopt the possible and applicable practices. Additionally, academic research plays a crucial role in supporting and validating best practice knowledge. Research about enhancing infrastructure sustainability, increasing the level of service, reducing cost and time and others are necessary for the continuous improvement of the required tasks of the department. The SWOT analysis of the stage is shown in Table **3**.

3.4. Stage (4): Policy and Identify LoS

Preparing a policy for an Infrastructure Asset Management Department involves defining clear objectives for managing assets effectively, including guidelines on maintenance, data management, and resource allocation. It should establish roles and responsibilities, outline compliance standards, and specify procedures for risk management and sustainability practices. Additionally, the policy must address asset valuation methods, performance monitoring metrics, and reporting frameworks to ensure accountability and continuous improvement. This foundation helps maintain asset value and ensures efficient, sustainable infrastructure management across the organization. Simultaneously, the policy must define the required level of service. To establish a LoS framework for an Infrastructure Asset Management Department, it's essential to define performance standards that meet community needs while balancing budget and resource constraints. The LOS should identify KPIs for infrastructure quality, such as reliability, availability, and safety. By setting benchmarks and periodically assessing the department's performance against these metrics, the team can ensure that services are maintained at optimal levels, enabling informed decisions on resource allocation and asset maintenance. However, the policy and the indicated level of service must be updated for several reasons, including shifts in community interests, new technology, and new budget allocations. The SWOT analysis of this stage is shown in Table **4**.

3.5. Stage (5): Data Collection and New Projects

Data collection for infrastructure Asset Management Department involves systematically classifications of the available infrastructure assets and gathering information on all these assets, such as age, condition, location, maintenance history, and operational status. This data provides a foundational understanding of the assets' current state and assists in prioritizing maintenance, budget planning, and future asset renewal needs, as required for the next stages. Employing methods like GIS mapping, remote sensing, and on-site inspections ensures that data is accurate, up-to-date, and accessible, ultimately supporting informed decision-making and efficient asset management. In addition, data on new infrastructure projects should be integrated with the existing infrastructure. In fact, this is the big challenge stage, collecting data from different sources including man-

Table 4. SWOT analysis of stage 4 (policy and identify level of services).

Strengths	Weaknesses
• Clearly defined policies enhance accountability, risk management, and sustainable practices. • Establishing LoS ensures infrastructure performance aligns with community needs and department goals. • Performance monitoring enables efficient decision-making and resource allocation.	• Updating policies and LoS can be resource-intensive, especially with evolving community needs and technologies. • Balancing service quality with budget constraints may limit flexibility.
Opportunities	**Threats**
• New technologies can streamline LOS tracking, improving maintenance efficiency. • Community engagement allows the department to refine policies to match emerging priorities.	• Changes in funding or technology could disrupt established LOS or require major policy adjustments. • Variations in community expectations might create challenges in meeting diverse needs within limited budgets.

Table 5. SWOT analysis of stage 5 (data collection and new projects).

Strengths	Weaknesses
• Comprehensive data collection enables informed decision-making and prioritization of asset maintenance. • Tools like GIS mapping improve data accuracy and accessibility for efficient asset management. • Systematic classification helps in developing a reliable database for all city assets.	• Integration of data from varied sources, especially manual entries, can lead to inconsistencies. • Time-intensive processes for establishing a robust and complete database can delay further stages.
Opportunities	**Threats**
• Advanced technologies (*e.g.*, remote sensing) offer opportunities to enhance data precision. • Collaboration with consultants and contractors improves data quality and knowledge sharing.	• Lengthy data collection may increase resource demand and budget pressures. • Potential for data mismanagement or delays in data integration could impair project timelines.

Table 6. SWOT analysis of stage 6 (life cycle analysis).

Strengths	Weaknesses
• LCA provides a comprehensive understanding of the asset's full lifespan, promoting long-term cost and resource optimization. • Informed decision-making through performance assessments can help maximize asset efficiency and sustainability. • Enhanced ability to assess environmental impacts, reducing ecological footprints during the asset lifecycle.	• LCA requires extensive data and accurate inspection tools, which may be costly and time-consuming to implement. • Complex mathematical models for performance evaluation may introduce technical challenges and require expertise.
Opportunities	**Threats**
• Integration of advanced inspection technologies can improve the accuracy of condition assessments. • LCA can drive improvements in sustainable practices, reducing long-term operational costs.	• Inconsistent or incomplete data could compromise the effectiveness of the analysis and decision-making. • High initial investment in inspection tools and systems may strain budgets, especially for large infrastructure projects.

ual data and arranging them in a unique database is a very hard task. Furthermore, the time required to create such a database and populate it with reliable data may take months, involving all available resources, including decision-makers, external consultants, and contractors. The SWOT analysis of this stage is shown in Table **5**.

3.6. Stage (6): Life Cycle Analysis

After creating a reliable database, data is utilized to perform the required analysis and can be performed to support the decision-making process. The first analysis is to understand nature and performance of the utilized infrastructure assets by performing the life cycle analysis (LCA). This task of the infrastructure Asset Management Department involves evaluating the entire lifespan of infrastructure assets, from design and construction to operation, maintenance, and eventual disposal or replacement. This analysis helps assess long-term costs, environmental impact, and resource requirements at each stage of an asset's life. By incorporating LCA, the department can make informed decisions that optimize asset performance, reduce costs, and enhance sustainability, ultimately supporting efficient infrastructure management. Condition and performance assessments are highlighted in this stage based on inspection reports and mathematical models. According to the infrastructure type, several inspections tools such as visual, small to big devices, simple to complicated technology are utilized to finalize the inspections reports. A grading system is necessary to implement the final grade of the condition and performance of the utilized infrastructure assets. The SWOT analysis of this stage is shown in Table **6**.

Table 7. SWOT analysis of stage 7 (risk analysis).

Strengths	Weaknesses
• Provides proactive measures to safeguard infrastructure assets by identifying and mitigating risks early. • Enhances asset reliability and longevity, supporting uninterrupted service levels and public safety. • Allows prioritization of assets based on risk levels, optimizing resource allocation for high-risk areas.	• Dependence on accurate data from Life Cycle Analysis; incomplete data may limit risk assessment accuracy. • Implementing advanced tools like GIS mapping and risk matrices may require significant technical and financial resources.
Opportunities	**Threats**
• Enables targeted investments in high-risk assets, potentially reducing future maintenance costs and unexpected failures. • Risk analysis can guide policy adjustments to improve resilience against environmental and operational risks.	• New or unforeseen risks may emerge, requiring continual updates to the risk assessment models and strategies. • Budget limitations could hinder the department's ability to fully implement risk mitigation strategies across all assets.

3.7. Stage (7): Risk Analysis

The risk analysis is an advanced analysis that is built based on the life cycle analysis. The Risk Analysis task of infrastructure Asset Management Department focuses on identifying, assessing, and mitigating potential risks that could impact infrastructure assets, including those related to aging, environmental factors, and operational failures. This task involves prioritizing assets based on their risk levels and developing response strategies to ensure asset longevity and resilience. By proactively managing risks, the department helps maintain reliable service levels and safeguards both public safety and the financial investment in infrastructure. The risk levels of utilized infrastructure assets should be identified using risk matrices, GIS mapping, dashboards, and other tools. The SWOT analysis of this stage is shown in Table **7**.

It is important to emphasize that managing infrastructure assets necessitates a thorough understanding of the risks associated with their use. Most practitioners and researchers assess the risk for operation and maintenance budgeting. Simply identifying the probability of failure and the consequences of failure, which are the two dimensions of risk, can lead to the implementation of the three necessary plans: operational, tactical, and strategic. The probability of failure is determined by several factors, including age, number of failures, material types, forms, and sizes. On the other hand, the consequences of failure are determined by crucial elements such as location, capacity, and asset value. If both dimensions are considered two random events, the risk value will be calculated using the likelihood of failure multiplied by the consequence of failure. Furthermore, the estimated losses due to the risk are equal to the probability of failure multiplied by the value of the consequence of failure, which represents the loss value. The main problem in this matter is to collect the necessary associated components and data, which specialists can obtain utilizing various methods and techniques. Furthermore, without a clear procedure for data collection, storage, maintenance, and training, it will be difficult to provide trustworthy conclusions on the associated risks [23, 33, 34].

3.8. Stage (8): Optimum Decision Making

The "Optimum Decision Making" stage in the infrastructure asset management department involves analyzing various maintenance, repair, and replacement options to select the most cost-effective and sustainable solutions. This process includes evaluating life cycle costs, potential risks, and service impact to maximize asset longevity and performance. Advanced modeling tools and data analytics help forecast outcomes, supporting decisions that align with the department's strategic goals and resource constraints. Regular assessments and updates to decision-making criteria ensure the department adapts to evolving infrastructure needs. The SWOT analysis of this stage is shown in Table **8**.

3.9. Stage (9): Business Management Plan

The "Business Management Plan" stage for the infrastructure asset management department forms the foundational strategy and operational goals for managing infrastructure assets. This includes defining objectives, budgeting, resource allocation, and key performance indicators

Table 8. SWOT analysis of stage 8 (optimum decision making).

Strengths	Weaknesses
• Promotes cost-effective and sustainable decisions that maximize asset longevity and performance. • Utilizes advanced modeling and data analytics for accurate outcome forecasting, aligning decisions with strategic goals. • Enhances adaptability to infrastructure needs by updating criteria based on ongoing assessments.	• Dependence on high-quality data for accurate modeling; poor data can compromise decision-making quality. • Initial setup and maintenance of advanced tools may require substantial investment and technical expertise.
Opportunities	**Threats**
• Enables long-term budget optimization by selecting the most efficient maintenance and repair solutions. • Supports strategic planning aligned with evolving infrastructure requirements and resource constraints.	• External factors, such as budget cuts, may impact the feasibility of ideal maintenance and repair decisions. • Rapid technological changes may require frequent updates to decision-making tools, increasing operational costs.

Table 9. SWOT analysis of stage 9 (business management plan).

Strengths	Weaknesses
• Provides a strategic foundation for effective asset management, aligning with organizational goals. • Ensures clear accountability with defined objectives, budgets, and KPIs. • Streamline operations with established workflows and role definitions, boosting efficiency.	• Developing a comprehensive plan can be resource-intensive and time-consuming. • The plan's effectiveness is limited by the accuracy of the initial budget and resource projections.
Opportunities	**Threats**
• Enhance transparency and measurable progress, supporting informed decision-making. • Aligns service levels with city policies and budgets, optimizing long-term sustainability.	• External budget fluctuations may disrupt the plan's goals and timelines. • Shifts in city policy or leadership can impact alignment and resource availability.

Table 10. SWOT analysis of stage 10 (infrastructure report card).

Strengths	Weaknesses
• Provides a clear assessment of infrastructure health, guiding policy and funding decisions. • Enhances transparency by communicating asset conditions to stakeholders and the public. • Prioritizes maintenance and investment needs, supporting proactive infrastructure planning.	• Time-intensive data collection and grading processes may limit report frequency. • Limited by the accuracy and scope of available data, which may affect reliability.
Opportunities	**Threats**
• Increases public awareness of infrastructure needs, potentially supporting funding initiatives. • Encourages long-term, data-driven strategies for asset improvement.	• Insufficient funding or political support could hinder the implementation of prioritized actions. • Economic or environmental changes may impact projected infrastructure needs or risks.

to ensure sustainable and effective asset management. It also outlines roles, responsibilities, and workflows to streamline department activities. The plan acts as a guided document, aligning the department's efforts with broader organizational goals and ensuring accountability and measurable progress over time. One important report issued in this stage is the estimation of the optimum cost and time to perform the required level of service within acceptable risks according to the city policy and budget. The SWOT analysis of this stage is shown in Table **9**.

3.10. Stage (10): Infrastructure Report Card

This is the final step, which is required by the department to issue the infrastructure report card. It is a summary of the current condition and performance of critical infrastructure assets, such as roads, bridges, water systems, and public facilities. This report assesses assets on various criteria like structural health, safety, service level, and required maintenance. Grades are assigned to each category, helping to communicate the infrastructure's status to policymakers and the public. The report card also highlights investment needs up to the next cycle, prioritizes maintenance tasks, and promotes informed decisions to improve infrastructure longevity and service quality. The next cycle may occur in approximately five years, depending on the city's policy, starting directly from stage 2, which evaluates the structure of the infrastructure department and the required resources to start the second cycle. The SWOT analysis of this stage is shown in Table **10**.

4. RESULTS

In this section, a hypothetical case study is presented to partially illustrate the developed framework. Saudi Arabia has been selected to issue an infrastructure report card based on condition assessments, with the assumption that grades for all infrastructure assets are available and ready for analysis. Fig. (**3**) shows the geographical map of Saudi Arabia with the proposed infrastructure hierarchy classifications; it is divided into five regions and 46 cities [43]. Eq. (**1**) is developed to apply numerical values from the case study.

$$\boldsymbol{GPA} = \sum_{\boldsymbol{n}=\mathbf{1}}^{\boldsymbol{N}} (\boldsymbol{S}.\boldsymbol{W})_{\boldsymbol{n}} \quad \textbf{(1)}$$

The variable "S" represents the grade score of each division, based on a numerical scale where "1" corresponds to a very poor condition (grade "F"), and "5" represents an excellent condition (grade "A"). For instance, the S value for the water sector is "4" because its grade is "B." The variable "W" denotes the weight of each sector relative to others, which can be determined using a decision-making method, such as the AHP [23, 44, 45]. This approach is suitable as it aligns with the hierarchical structure of the developed model.

Assuming that City (X) has reported the condition assessment for each infrastructure sector, as shown in Fig. (**4**). The water sector is graded (B), wastewater (D), roads (C),

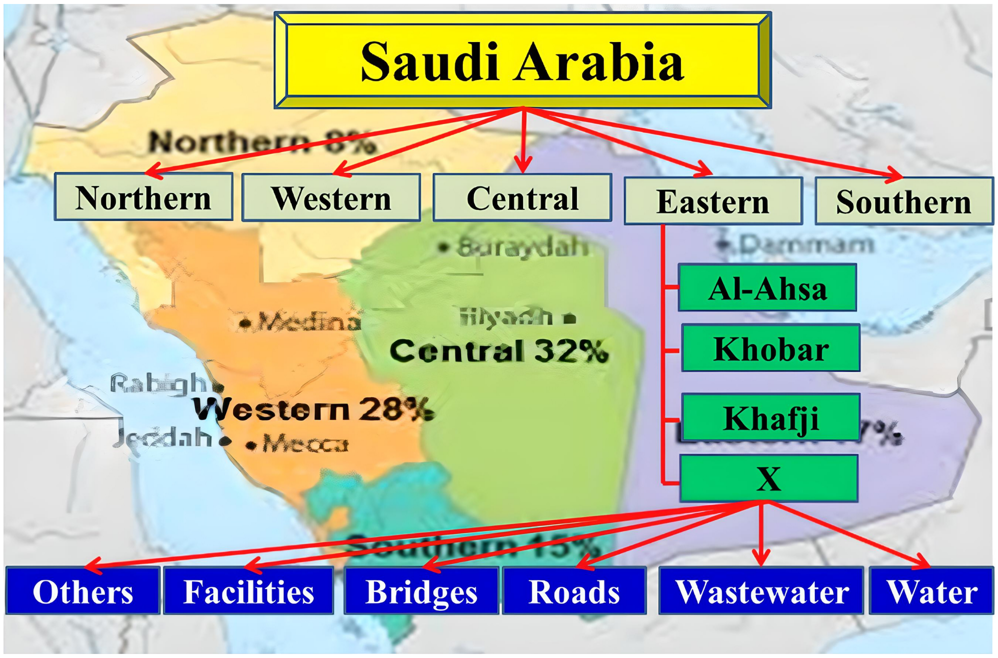


Fig. (3). Saudia Arabia hierarchy.

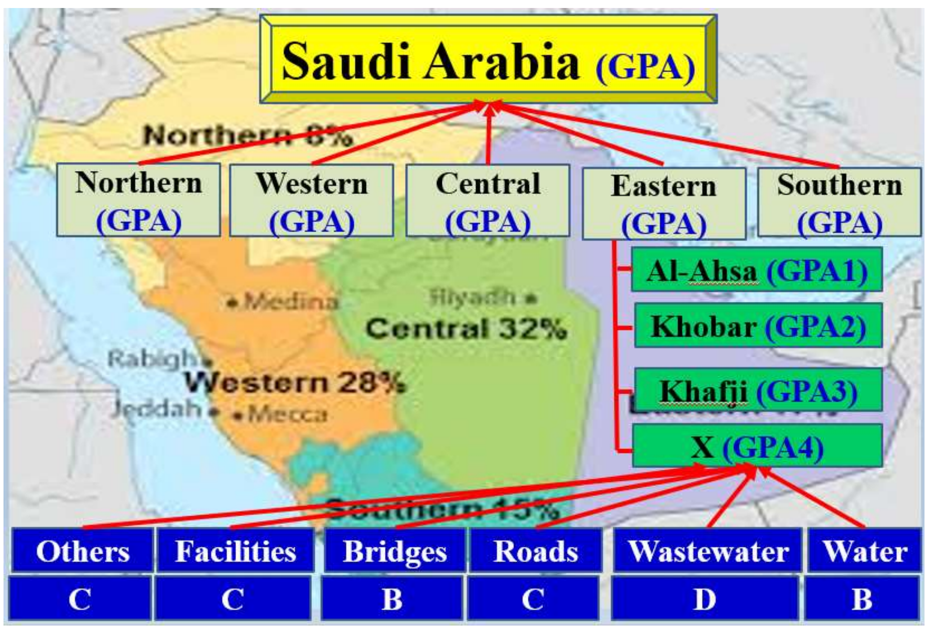


Fig. (4). GPA of infrastructure Saudia Arabia.

etc. To determine the GPA of City X, a mathematical model can be applied. For example, the weighted average model is simple and easy to use, as demonstrated in Eq. (**1**).

Decision-makers can determine each division's importance based on factors such as required service levels, customer numbers, tax revenue, or other relevant criteria. The variable "N" represents the total number of infrastructure divisions. Accordingly, the GPA of City X, along with other cities in the same region, is determined. Moving to the regional level, the Eastern region, in this case, Eq. 1 can be applied, where "S" represents the GPA of each city, and "W" reflects the city's importance. The importance can be assessed based on factors such as population, tax revenue, strategic planning priorities, or other criteria. The variable "N" represents the number of cities in the region. Similarly, the GPA of the entire country can be calculated by applying the same principle, using regions instead of cities. The required funding for the next cycle is another critical data point to be included in the report card. This figure should be based on thorough analysis to generate business management reports that consider various factors influencing the current condition of each sector, such as the expected level of service and risk. Additionally, it should align with the country's vision for infrastructure funding. An optimal budget allocation model is needed, structured from the top down through the country's hierarchy, as illustrated in Fig. (**5**).

At the regional level, budget allocation can be developed based on the region's GPA and other factors, such as population, tax revenue, and the regional strategy for existing and new infrastructure projects, as determined by decision-makers. Similarly, the budget allocation model at the city level can follow the same approach as the regional model. Finally, the optimal budget allocation model at the sector level must account for infrastructure functions, including risk, condition assessment, performance, and level of service. Based on the primary functions [23], the required mathematical model can focus on selecting one or more functions as objectives while treating the remaining infrastructure functions as constraints. Additional constraints, such as the number of customers and strategic goals of decision-makers, can also be incorporated into the model. The following numerical example illustrates the budget allocation model across the sectors of City X. Assume the city's available budget is 100 (unit cost), and the available data for the sectors in City X is shown in Table **11**.

The data provided by City X indicates the required cost for downgrading or upgrading one grade, as well as for maintaining the same condition assessment (j). Downgrading the condition assessment of a sector is likely to increase the associated risk. Therefore, the allocated budget should be carefully managed, with a focus on operation and maintenance activities to mitigate the resulting risks. The developed model requires the relative weights for the six sectors, according to Eq. (**1**). Table **12** shows the proposed data (provided by the author) along with the results of the AHP process.

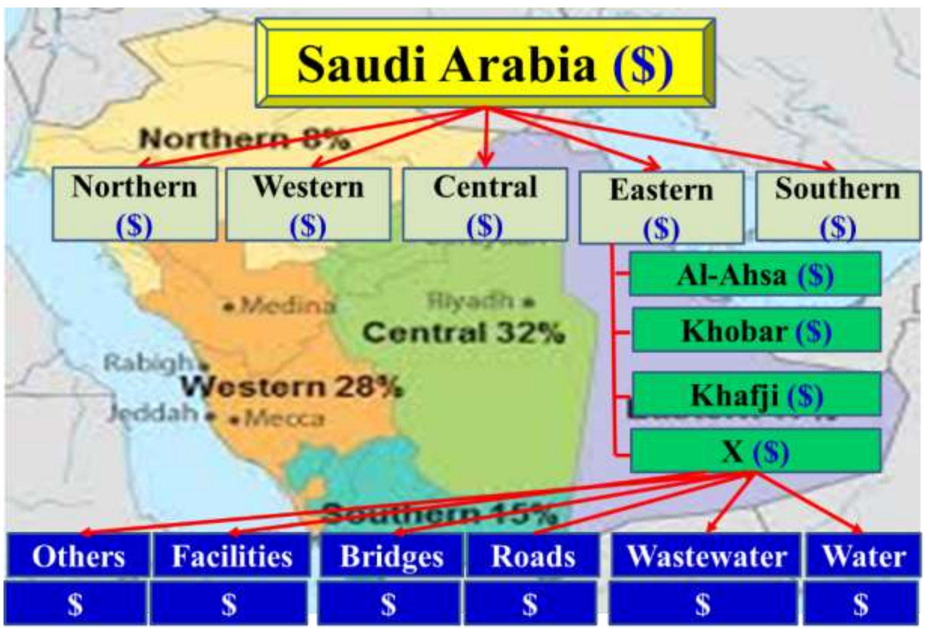


Fig. (5). Proposed budget allocation model to fund the Saudi infrastructure.

Table 11. Available data of city X for the next cycle.

Sector	CA	CA (Value)	Required Cost for the Next Cycle (unit cost)		
-	-	-	Downgrading (1 Grade)	Current	Upgrading (1 Grade)
Water	B	4	4	12	20
Wastewater	D	2	2	15	25
Roads	C	3	12	30	35
Bridges	B	4	3	7	25
Facilities	C	3	6	8	40
Others	C	3	40	75	105

Table 12. AHP results.

-	Water	Wastewater	Roads	Bridges	Facilities	Others	Weight
Water	1.00	0.33	0.50	1.00	2.00	0.50	0.11
Wastewater	3.00	1.00	2.00	2.00	4.00	1.00	0.28
Roads	2.00	0.50	1.00	1.00	2.00	0.50	0.15
Bridges	1.00	0.50	1.00	1.00	2.00	0.33	0.12
Facilities	0.50	0.25	0.50	0.50	1.00	0.25	0.06
Others	2.00	1.00	2.00	3.00	4.00	1.00	0.28

The relative weights of the six sectors are listed in the last column of Table **12**. The wastewater and other sectors have the highest weights (28%), while the facility sector has the lowest weight (6%). The consistency ratio (CR) of this process is 1.26%, which is below the 10% threshold. Therefore, the sector weights can be used for the optimal budget allocation model. The proposed mathematical model below aims to achieve optimal budget allocation across the sectors (i) of City X, based on the available budget. The objective of the model is to achieve the maximum GPA for the city within the available budget, which should be allocated across the six sectors using Lingo software [46], as shown in Fig. (**6**).

$Max = GPA$ "Objective: Maximize the GPA of City X"

$GPA = \sum_{i=1}^{6}\sum_{j=1}^{3} W_i . CA_{ij};$ "GPA of city X;i:sector;j:the new condition assessment"

$TRC = \sum_{i=1}^{6}\sum_{j=1}^{3} C_{ij} . X_{ij};$ *"Total Required Cost"*

$\sum_{j=1}^{3} X_{ij} = 1$ *"Selecting One Condition Assessment/Sector"*

$AB \leq TRC$; "Available Budget"

@BIN(X_{ij}*)*; "Action/ No Action"

Cost Data … … … … … … .;

Condition Assessment Data … … … … … … .;

Sector Weight Data (AHP Output) … … … … … … .;

5. DISCUSSION

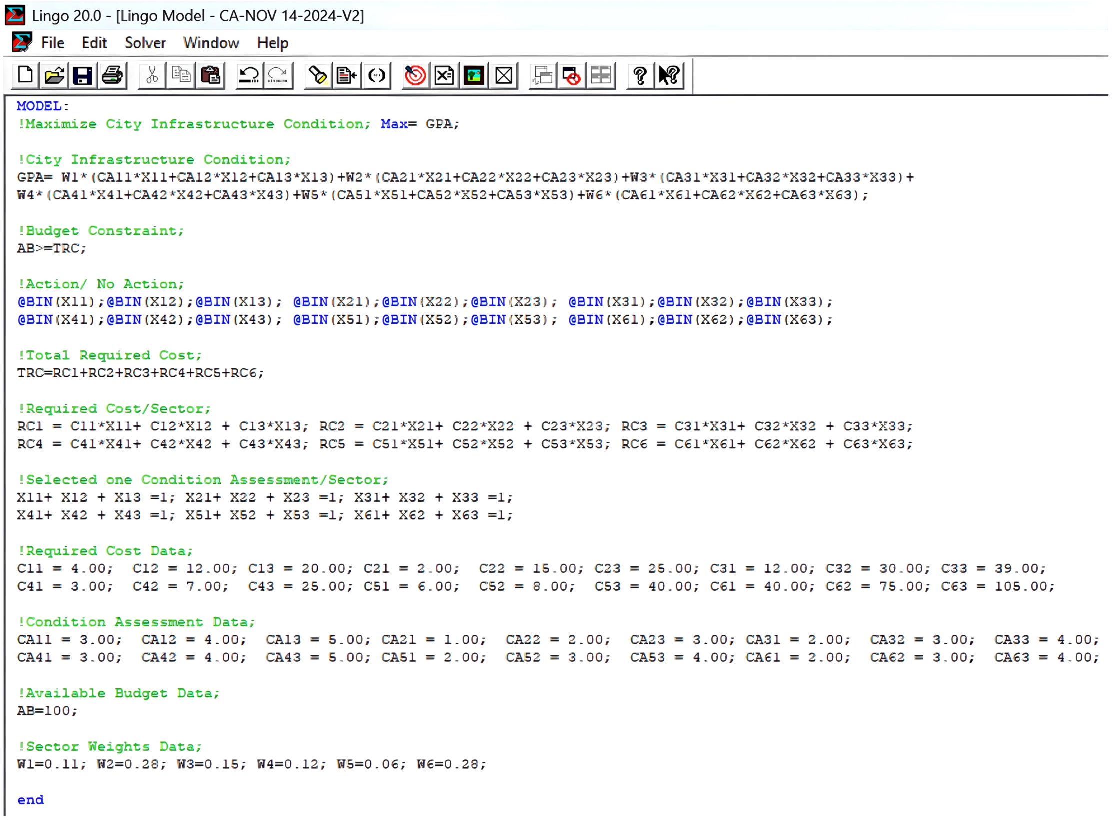
The output from running the software is shown in Fig. (**7**). The available budget of 100 (unit cost) is allocated among the six sectors as follows: 4 (unit cost) to the water sector, 25 (unit cost) to the wastewater sector, 12 (unit cost) to the roads sector, 7 (unit cost) to the bridges sector, 8 (unit cost) to the facilities sector, and 40 (unit cost) to other sectors. This result indicates that, according to the available budget for the next cycle, the condition assessments of the water, roads, and other sectors will be downgraded, while the condition of the bridges and facilities sectors will remain unchanged, and the wastewater sector will be upgraded. The allocation of funds highlights the prioritization of the wastewater sector, which may be due to its critical role in public health and environmental sustainability. The significant allocation to other sectors suggests a broader focus on miscellaneous infrastructure elements that require immediate attention. Conversely, the lower allocation to the water and road sectors could indicate a strategic decision to defer their maintenance, potentially leading to increased deterioration over time. Higher budgets would yield better outcomes, allowing for more comprehensive maintenance and improvements across all sectors. Conversely, lower budgets may lead to less favorable results, increasing the likelihood of infrastructure failures and higher long-term costs. The decision-making process should, therefore, consider future budget forecasts, potential funding sources, and long-term infrastructure sustainability goals. Additionally, the GPA of City X is 2.69, which corresponds to a D+ grade on a scale of 1 to 5. This suggests that City X needs additional funding to improve its GPA. A low GPA indicates that the city's infrastructure is operating at a suboptimal level, posing risks to public safety, economic activities, and quality of life. Without adequate investment, the infrastructure will continue to degrade, potentially leading to costly emergency repairs and reduced service levels. Furthermore, the results emphasize the need for a proactive asset management approach that aligns budget allocations with sector-specific needs and risk assessments. Decision-makers should explore alternative funding mechanisms such as public-private partnerships, grants, and optimized resource allocation strategies to bridge the funding gap. Periodic reassessment of infrastructure conditions and funding priorities will be crucial in ensuring the long-term sustainability and resilience of City X's infrastructure. In conclusion, while the current budget allocation provides some improvements, it is evident that a more substantial financial commitment is necessary to achieve a higher infrastructure GPA and reduce associated risks. Stakeholders must collaborate to identify sustainable solutions that balance fiscal constraints with infrastructure performance goals.

6. FRAMEWORK SENSITIVITY AND ADAPTABILITY

The developed infrastructure framework can be adapted for different levels, from a small organization to a country's infrastructure. Consequently, the required resources and technologies differ to meet the needs of customers. The preliminary report, which is Stage 1 of the framework, must consider the adaptability of the framework to fit the organization's infrastructure. They might consider the following sensitive issues:

6.1. Country Stability and Security

This is the first filter to adapt the framework for any level. Without stability and security, it is impossible to implement any stage of the framework. Accordingly, this is an important step taken by governments after the war.




```
MODEL:
!Maximize City Infrastructure Condition; Max= GPA;

!City Infrastructure Condition;
GPA= W1*(CA11*X11+CA12*X12+CA13*X13)+W2*(CA21*X21+CA22*X22+CA23*X23)+W3*(CA31*X31+CA32*X32+CA33*X33)+
W4*(CA41*X41+CA42*X42+CA43*X43)+W5*(CA51*X51+CA52*X52+CA53*X53)+W6*(CA61*X61+CA62*X62+CA63*X63);

!Budget Constraint;
AB>=TRC;

!Action/ No Action;
@BIN(X11);@BIN(X12);@BIN(X13); @BIN(X21);@BIN(X22);@BIN(X23); @BIN(X31);@BIN(X32);@BIN(X33);
@BIN(X41);@BIN(X42);@BIN(X43); @BIN(X51);@BIN(X52);@BIN(X53); @BIN(X61);@BIN(X62);@BIN(X63);

!Total Required Cost;
TRC=RC1+RC2+RC3+RC4+RC5+RC6;

!Required Cost/Sector;
RC1 = C11*X11+ C12*X12 + C13*X13; RC2 = C21*X21+ C22*X22 + C23*X23; RC3 = C31*X31+ C32*X32 + C33*X33;
RC4 = C41*X41+ C42*X42 + C43*X43; RC5 = C51*X51+ C52*X52 + C53*X53; RC6 = C61*X61+ C62*X62 + C63*X63;

!Selected one Condition Assessment/Sector;
X11+ X12 + X13 =1; X21+ X22 + X23 =1; X31+ X32 + X33 =1;
X41+ X42 + X43 =1; X51+ X52 + X53 =1; X61+ X62 + X63 =1;

!Required Cost Data;
C11 = 4.00;  C12 = 12.00; C13 = 20.00; C21 = 2.00;  C22 = 15.00; C23 = 25.00; C31 = 12.00; C32 = 30.00; C33 = 39.00;
C41 = 3.00;  C42 = 7.00;  C43 = 25.00; C51 = 6.00;  C52 = 8.00;  C53 = 40.00; C61 = 40.00; C62 = 75.00; C63 = 105.00;

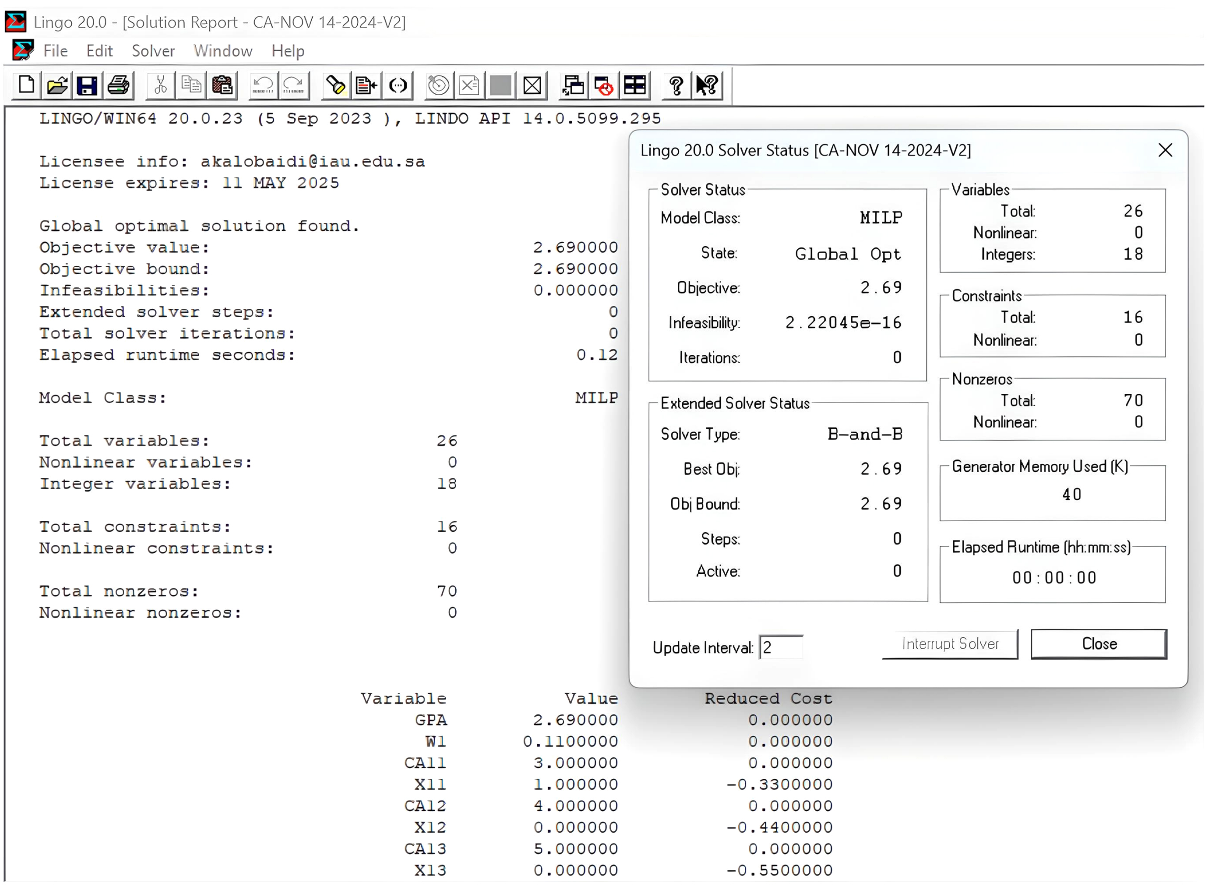
!Condition Assessment Data;
CA11 = 3.00;  CA12 = 4.00;  CA13 = 5.00; CA21 = 1.00;  CA22 = 2.00;  CA23 = 3.00; CA31 = 2.00;  CA32 = 3.00;  CA33 = 4.00;
CA41 = 3.00;  CA42 = 4.00;  CA43 = 5.00; CA51 = 2.00;  CA52 = 3.00;  CA53 = 4.00; CA61 = 2.00;  CA62 = 3.00;  CA63 = 4.00;

!Available Budget Data;
AB=100;

!Sector Weights Data;
W1=0.11; W2=0.28; W3=0.15; W4=0.12; W5=0.06; W6=0.28;

end
```

Fig. (6). The input of the budget allocation model using lingo [46].

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LINGO/WIN64 20.0.23 (5 Sep 2023 ), LINDO API 14.0.5099.295

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License expires: 11 MAY 2025

Global optimal solution found.
Objective value:                              2.690000
Objective bound:                              2.690000
Infeasibilities:                              0.000000
Extended solver steps:                               0
Total solver iterations:                             0
Elapsed runtime seconds:                          0.12

Model Class:                                      MILP

Total variables:                   26
Nonlinear variables:                0
Integer variables:                 18

Total constraints:                 16
Nonlinear constraints:              0

Total nonzeros:                    70
Nonlinear nonzeros:                 0

                    Variable           Value        Reduced Cost
                         GPA        2.690000            0.000000
                          W1       0.1100000            0.000000
                        CA11        3.000000            0.000000
                         X11        1.000000          -0.3300000
                        CA12        4.000000            0.000000
                         X12        0.000000          -0.4400000
                        CA13        5.000000            0.000000
                         X13        0.000000          -0.5500000
```

Fig. 7 contd.....

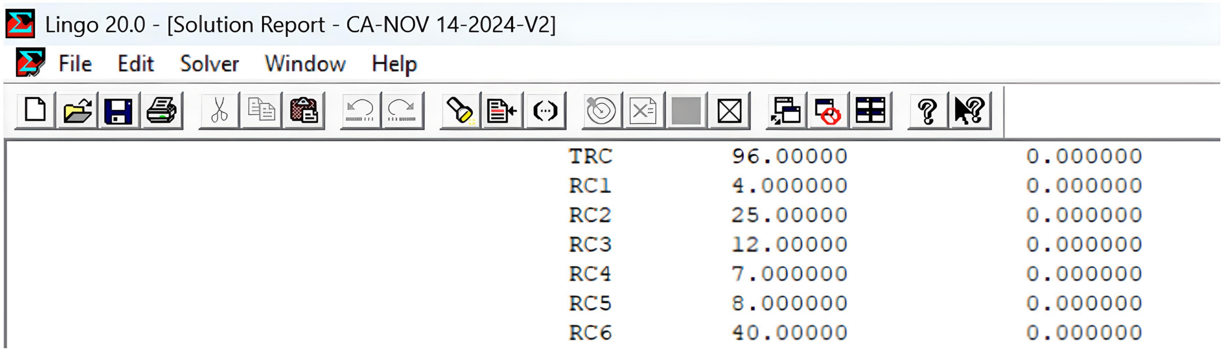

Fig. (7). The output of the budget allocation model using lingo [46].

6.2. Regulatory and Policy Constraints

The newly developed policy of infrastructure asset management should align with the country's regulations and policy constraints. Traditions and other national habits might be abided by the policy.

6.3. Economic and Funding Availability

Adapting the framework requires millions to trillions of US dollars. The most important questions are: who will fund it? When will the funds be available? What is the inflation rate? And more questions might be initiated during the preparation of the preliminary report.

6.4. Technological Advancements

Trained specialists need to use suitable new tools, software, and equipment for inspections, maintenance, collecting and storing data, and others related to the required plans and research. Therefore, updating the technologies is crucial for the successful implementation of the farmwork stages.

6.5. Climate and Environmental Conditions

The developed framework should consider the external environment that affects the operation of the infrastructure assets. For instance, the depth of the water main network in Canada differs from the required depth in Saudi Arabia because of temperature. In Canada, when the temperature is extremely low, it will lead to frozen water in pipes unless the depth of these pipes is more than two meters to avoid this risk.

6.6. Urbanization and Population Growth

Understanding future urbanization and population growth is crucial to start implementing the infrastructure framework. Big cities' requirements are different than the requirements of small cities in terms of the budget, resources, locations, *etc*.

6.7. Interoperability with Existing Systems

The developed infrastructure framework should first study the existence of systems and practices to integrate them with the new practices. However, efforts are required to train the current staff in the new technologies and practices.

6.8. Workforce Skills and Training

The framework requires huge numbers of staff with different types of skills and knowledge to operate and manage the infrastructure assets. The big challenge in this issue is the required structure that facilitates the work of the individuals and teams to obtain the required outcome.

6.9. Public and Stakeholder Engagement

It is necessary to engage the public, who will utilize the infrastructure assets, at the early stage of preparing the organization's policy. The locals can be very useful to help identify the requirements and constraints. Furthermore, the local feedback about the assets' services is crucial to check and improve the quality and quantity of these services.

6.10. Resilience to Disruptions and Crises

Resilience to disruptions and crises can be improved through the life cycle of the infrastructure assets by developing and implementing risk assessments, which are always required to avoid and mitigate natural disasters, cyber threats, supply chain disruptions, and pandemic impacts.

6.11. Scalability and Modular Design

A well-designed infrastructure framework should be developed to meet the requirements. The stakeholders may alter these requirements to meet their needs, taking into account the available budget, service level, and associated risks. These requirements might be changed to fulfill the needs of the stakeholders with respect to the available budget, level of service, and associated risks. This flexibility can't be achieved without considering the previous points.

The author and his team will discuss the aforementioned points in their upcoming individual research. Therefore, the current research is limited to listing the adaptable points only without further discussion.

7. LIMITATIONS

The limitations of implementing a strategic framework for infrastructure asset management in urban environments may include:

7.1. Data Availability and Quality

Accurate, up-to-date data is essential but often challenging to obtain, especially in cities with limited data collection and management systems.

7.2. Resource Constraints

Funding, skilled personnel, and technological resources may be insufficient, impacting the framework's full implementation.

7.3. Stakeholder Alignment

Coordinating goals across departments and stakeholders can be complex, especially if priorities conflict.

7.4. Adaptability

Urban infrastructure needs to evolve, so the framework must be flexible enough to respond to technological, environmental, and population changes.

7.5. Time-Intensive Analysis

Activities like life cycle analysis and risk assessment are detailed and may require a long-term commitment to see significant benefits.

8. FUTURE WORK

The current study's future work could concentrate on the following areas:

i. Merging of new technology and applications such as artificial intelligence (AI). The utilization of AI in each stage of the developed framework, especially for maintenance, enhances predictive maintenance to avoid failure with its consequences, which include optimum use of resources and is time-consuming. Research can focus on the following topics:

1) Autonomous inspection systems: To save time and cost of the required resources.

2) Integration with the internet of things (IoT): To enhance predictive accuracy by real-time monitoring.

3) Analytical real-time data: To advance infrastructure maintenance response time for emergency cases.

4) Cloud-based data storage: To access the required data by all stakeholders.

5) Climate-resilient infrastructure: To design a maintenance strategy for extreme weather conditions.

6) Digital twin technology: To simulate the real infrastructure with different conditions.

7) Automated crack and defect detection: To identify defects through imaging recognition.

ii. Framework adaptability according to city or organization conditions. Future research might consider the economic conditions, country stability and security, available resources and technologies, traditions, *etc*.

iii. Case studies from diverse cities could help refine the framework's adaptability to different urban environments and funding structures. However, the country's legislation may make this task sensitive.

CONCLUSION

In conclusion, this study presents a strategic framework for implementing IAM tailored for urban settings aimed at optimizing the maintenance, operation, and longevity of critical infrastructure assets such as roads, water systems, and public facilities. The framework uses a systematic approach involving life-cycle cost analysis, risk management, and service level assessments to build a robust foundation for sustainable urban planning. By providing structured stages, from initial planning to issuing an infrastructure report card, the framework supports cities in making data-driven decisions, achieving efficient resource allocation, and prioritizing essential infrastructure investments. Additionally, the use of SWOT analysis at each stage enables cities to better understand and respond to both internal and external factors impacting IAM processes. This framework has practical implications: it offers flexibility to be fully or partially adopted by cities new to IAM principles, allowing them to integrate these methods incrementally. Cities can modify the framework to address unique challenges, policies, and budget constraints, ensuring adaptability across diverse urban settings. The study further emphasizes the importance of involving stakeholders and aligning IAM strategies with long-term urban growth and resilience goals. Different levels of organizations, cities, and countries can adopt the developed framework. Each level represents an individual organization, which is connected to the upper level and the lower level. A country-level represents the head of the hierarchy, which can be divided into regions; each region is divided into cities, and each city is divided into municipalities. Each organization requires its own resources and budget. This complexity can be managed effectively based on the country's legislation. Hence, the involvement of the country leaders is necessary to facilitate the process of managing the infrastructure of the country-wise. These best practices are already applied in a few developed countries, such as Australia, the USA, the UK, and Canada. These countries are spending trillions of US dollars yearly to manage their infrastructure. Accordingly, huge work is required to apply the best practices in other countries to avoid infrastructure aging and other associated risks to provide an acceptable level of service within the available budget.

AUTHORS' CONTRIBUTIONS

The author confirms sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

LIST OF ABBREVIATIONS

AHP	=	Analytical Hierarchy Process
ALOS	=	Aggregate Level of Service
LOS	=	Level of Service
IAM	=	Infrastructure Asset Management

CONSENT FOR PUBLICATION

Not applicable.

AVAILABILITY OF DATA AND MATERIALS

The data and supportive information are available within the article.

FUNDING

None.

CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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