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The Efficiency of Integrated Facilities Maintenance Contracts (FMC) for Public Buildings: The Impact of Contractual and Physical Characteristics

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ABSTRACT

Public Facilities Maintenance Contracts (FMC) are critical for ensuring the functionality, cost-effectiveness, and long-term performance of government buildings. In recent years, integrated contract structures have gained prominence as they provide a single point of responsibility and promote better service coordination. However, inefficiencies remain, largely stemming from inadequate resource allocation and insufficient performance oversight within these arrangements. Despite their growing importance, limited research has investigated how contractual and physical characteristics influence maintenance contract efficiency. This study addresses this gap by evaluating the efficiency of integrated FMC in Malaysia using data from 45 government contracts. Each FMC efficiency was measured using a normalized per annum Present Value (PV) method and correlation analysis of key variables, including contractual characteristics (contract value and period) and physical characteristics (building size, number of storeys, number of blocks, and building age). The analysis reveals that efficiency decreases with higher contract values, extended contract periods, and buildings with multiple blocks, while taller buildings demonstrate marginal efficiency gains. Interestingly, building age does not significantly influence contract performance, highlighting the role of contract design in driving efficiency outcomes. The study emphasizes the importance of careful contract planning and well-structured agreements with explicit provisions for performance-based incentives to enhance maintenance efficiency. Aligning contractual frameworks with building attributes is, therefore, critical for optimizing resource allocation and improving public infrastructure maintenance practices.

Keywords: Facilities Maintenance Contracts (FMC); maintenance efficiency; contractual characteristics; physical attributes

INTRODUCTION

Public buildings form a vital component of national infrastructure, supporting economic, administrative, educational, and social activities. Ensuring these facilities remain functional, safe, and cost-effective throughout their life cycle requires continuous and efficient maintenance management. Across the globe, governments allocate substantial budgets to building maintenance. However, persistent inefficiencies in contract execution often led to escalating costs, operational disruptions, and substandard service delivery (Esteve et al., 2024). For this reason, integrated Facilities Maintenance Contracts (FMC) have become essential for managing public infrastructure, offering structured mechanisms to allocate resources, monitor performance, and ensure accountability.

Despite these arrangements, research indicates that inefficiencies exist in developed and developing contexts. For example, integrated facility management models are widely adopted in the United Kingdom and other advanced economies, yet challenges such as unclear performance metrics and complacency still undermine efficiency (Sherratt et al., 2020). Similarly, in Asia and other emerging regions, constraints such as inadequate monitoring systems, weak regulatory enforcement, and limited adoption of digital tools continue to affect maintenance performance outcomes (Cao et al., 2022). These global trends highlight that improving FMC efficiency is also a local concern and a shared challenge many governments face.

In Malaysia, many public facilities are primarily managed through integrated FMC overseen by federal agencies (Jabatan Kerja Raya Malaysia, 2020). Although these frameworks aim to provide structured procurement and resource management, inefficiencies remain. Issues such as misallocating maintenance budgets, a lack of periodic contract evaluations, and inadequate performance-based incentives have been frequently reported. In some cases, high-value contracts do not translate into improved service quality, while long-term agreements without systematic reviews lead to reduced contractor accountability. Moreover, the absence of digital monitoring systems such as Building Information Modelling (BIM) in many government contracts exacerbates these challenges (Cao et al., 2022). These inefficiencies raise concerns about the sustainability of public infrastructure and the value obtained from government expenditure.

The major challenge in public facilities maintenance contracts lies in resource management and performance accountability. Globally, large-scale contracts frequently face resource misallocation, contractor complacency, and insufficient performance monitoring, undermining cost efficiency and service quality (Esteve et al., 2024; Sherratt et al., 2020). In Malaysia, despite the structured framework of integrated facilities maintenance contracts under public departments, inefficiencies persist due to budget misallocation, a lack of periodic evaluations, and limited adoption of digital monitoring systems such as BIM (Cao et al., 2022). These challenges are reflected in specific contract features: while higher contract values theoretically provide better services, they often suffer from bureaucratic complexity and ineffective resource distribution in practice. Similarly, longer contract durations may offer stability but frequently lead to inefficiency when performance is not periodically reviewed. On the physical side, building characteristics such as multi-block layouts or large Gross Floor Areas (GFA) introduce logistical difficulties that reduce efficiency. In contrast, factors such as building age or number of storeys have revealed inconsistent impacts on performance. These unresolved inefficiencies demonstrate the urgent need for a systematic evaluation of how contractual and physical characteristics shape maintenance efficiency outcomes.

In the Malaysian context, Hauashdh, Jailani, and Rahman (2020) systematically reviewed national building maintenance practices and identified persistent inefficiencies in management, financial allocation, and technical execution, particularly in the public sector. More recently, Olanrewaju, Wong, and Lim (2023) analyzed 139 public hospitals and revealed that maintenance demand was driven less by building age and more by poor quality, ineffective reporting, and inadequate spare parts. These studies highlight the lack of integrated analysis of contractual and physical factors, underscoring the need for the present study to address this research gap.

Although many studies have examined Facilities Maintenance (FM) from the contractual perspective, very few have investigated how these factors influence maintenance efficiency empirically. Existing research often isolates one dimension and overlooks its combined effect on contract outcomes, particularly in the context of public buildings. Furthermore, while international studies have increasingly emphasized performance-based approaches, empirical research in Malaysia that evaluates integrated facilities maintenance contracts by considering both contractual and physical characteristics remains scarce (Grącki & Plebankiewicz, 2024). This absence of integrated studies limits the ability of policymakers and facility managers to design evidence-based strategies for improving efficiency. Addressing this research gap, the present study examines the relationship between efficiency and FMC attributes, offering a more comprehensive understanding of the determinants of efficiency in public facilities maintenance contracts.

This study aims to evaluate the efficiency of public facilities maintenance contracts by examining contractual characteristics (such as contract value and period) and physical building attributes (such as GFA, number of storeys, number of blocks, and building age). The study provides empirical evidence on how these factors influence maintenance efficiency by applying a normalized Present Value (PV) approach and correlation analysis to data from public government contracts in Malaysia. The findings are expected to contribute to both theory and practice by filling the research gap on the integrated impact of contractual and physical characteristics. From a practical standpoint, the study offers actionable insights for policymakers and facility managers to optimize contract structures, improve accountability, and allocate resources more effectively, thereby ensuring sustainable and cost-efficient management of public infrastructure.

LITERATURE REVIEW

CONTRACT STRUCTURES AND MAINTENANCE EFFICIENCY

Facility management contracts can be categorized into three primary models: Single FM, Bundled FM, and Integrated FM. Each contract offers different levels of service integration and operational efficiency. Single FM involves outsourcing individual services to different service providers, such as cleaning, security, or Heating, Ventilation, and Air Conditioning (HVAC) maintenance. This model allows for flexibility in selecting specialized vendors. However, it can lead to higher administrative complexity, inconsistent service levels, and potential inefficiencies due to a lack of coordination between multiple providers (Lok et al., 2021).

To address these inefficiencies, departments may opt for Bundled FM. Here, multiple facility management services, such as cleaning and security, are outsourced to a single provider. This approach reduces operational complexity, enhances service coordination, and allows for cost savings through economies of scale. However, while Bundled FM streamlines operations compared to Single FM, it still does not offer a fully integrated solution, as each service within the bundle may still operate independently (Ismaeil, 2024).

Integrated FM consolidates all facility management services under one provider for a more holistic and strategic approach, ensuring a seamless and centralized operation. FM providers can leverage advanced technologies to optimize cost efficiency, risk management, and service quality. This model is particularly beneficial for large organizations and government institutions that require a structured, long-term approach to facility management. Integrated FM offers the highest level of efficiency and strategic alignment, but it requires strong contract management and enforcement to oversee all FM operations (Lok et al., 2021).

Integrated FM has been infused with Performance-Based Contracts (PBCs), which are an alternative to traditional maintenance contracts. PBCs are linking payments to contractor performance metrics such as downtime reduction and service quality (Tseng & Yang, 2024). Their studies suggest that incorporating Key Performance Indicators (KPIs) into maintenance contracts improves contractor accountability and service reliability. Additionally, research highlights that PBCs promote proactive maintenance, reducing the occurrence of emergency repairs and extending asset lifespan. A study by Calahorra-Jimenez and Poythress (2024) emphasized incentive-driven models. In this case, contractors are rewarded for exceeding benchmarks, leading to enhanced service efficiency and cost savings. However, challenges in PBC implementation include contract complexity, monitoring difficulties, and contractor resistance to change, necessitating robust regulatory frameworks and monitoring mechanisms.

Recent evidence highlights the importance of aligning contract structures with performance outcomes. Tseng and Yang (2024) demonstrated that PBCs in infrastructure maintenance achieved a benefit-cost ratio exceeding 5.0, confirming their economic viability and superior efficiency compared to traditional contracts. Similarly, in Malaysia, Wong et al. (2021) emphasized that hospital facilities under concession contracts still underperform unless value-based practices such as responsiveness, innovation, and user-focused service delivery are embedded in the contract framework. These studies argued that contractual design and incentive structures are crucial determinants of FM efficiency.

Furthermore, contract duration plays a crucial role in maintenance efficiency. While long-term contracts provide stability and continuous service, they can also lead to complacency and reduced contractor motivation. Short-term contracts, on the other hand, promote competitive pricing and encourage performance improvement but may lead to frequent service provider turnover, affecting consistency and institutional knowledge retention (MacKay, 2020). Hybrid models that combine long-term contracts with periodic performance reviews and renegotiation clauses are gaining traction in facility management as a balanced approach to ensure sustained maintenance efficiency.

IMPACT OF PHYSICAL CHARACTERISTICS ON MAINTENANCE

Physical attributes such as building size, height, and layout significantly influence maintenance performance. Larger and more complex buildings often require more resource-intensive maintenance strategies, contributing to cost escalation (Ferreira et al., 2022). Research by Ramanathan and Rathore (2024) highlighted that multi-block buildings tend to have lower efficiency levels due to coordination challenges and inefficiencies in resource allocation.

Physical characteristics of buildings also exert a measurable influence on maintenance performance. Ferreira et al. (2022) revealed that building height significantly affects façade degradation, with upper levels experiencing faster deterioration due to solar exposure and wind-driven rain, while lower levels face heavier pollution loads. In addition, Rathod (2023) reported that as building space per occupant increases, both janitorial and maintenance costs rise, indicating that floor area and density directly affect operational efficiency. These findings demonstrate that factors such as height, floor area, and spatial complexity must be considered when evaluating contract efficiency.

The accessibility of building components also plays a vital role in determining maintenance efficiency. Facilities with integrated maintenance-friendly design elements, such as centralized mechanical and electrical systems and modular infrastructure, often experience lower maintenance costs and improved response times (Arditi & Nawakorawit, 1999). Conversely, buildings with dispersed systems, poorly designed service corridors, and limited accessibility increase maintenance difficulty, leading to prolonged downtime and increased labor costs.

Another critical factor influencing maintenance efficiency is the type of construction materials used. Buildings constructed with durable, low-maintenance materials, such as composite panels, fiber-reinforced polymers, and self-cleaning surfaces, exhibit lower long-term maintenance costs compared to traditional materials like concrete and wood (Riahinezhad et al., 2021). Adopting green materials and energy-efficient systems also aligns with sustainability initiatives, reducing operational costs and environmental impact in public facility management.

Finally, research suggests that a building's functional use affects its maintenance demands. Due to higher wear and tear, high-traffic buildings such as hospitals, schools, and transportation hubs require more frequent maintenance than administrative offices (Olanrewaju & Abdul-Aziz, 2023). Implementing predictive maintenance strategies, sensor-based monitoring, and tailored maintenance scheduling for different building types can optimize resource allocation and enhance overall maintenance efficiency.

CHALLENGES AND BEST PRACTICES IN MAINTENANCE MANAGEMENT

Maintenance management is complex because it requires balancing multiple, often conflicting objectives: cost efficiency, service quality, and long-term asset sustainability. For example, reducing short-term costs through reactive maintenance can lead to asset deterioration and higher lifecycle expenses (Durán et al., 2020). Conversely, prioritizing service quality may require larger budgets, which challenges government agencies facing fiscal constraints (Esteve et al., 2024). In addition, sustainability objectives, such as using green materials or energy-efficient systems, often increase upfront costs but reduce long-term environmental and operational impacts (Larsson & Larsson, 2020).

This multi-dimensional nature of maintenance decisions underscores why it is a complex management task, demanding structured policies, continuous monitoring, and integrated performance frameworks (Olanrewaju & Abdul-Aziz, 2023). One key importance in maintenance management is the availability of standardized procedures for contract execution and monitoring. Without well-defined performance indicators, assessing contractor performance and ensuring accountability becomes difficult (Asadabadi and Sharpe, 2019).

Best practices in maintenance management include using structured contract management frameworks that incorporate periodic performance reviews and benchmarking against industry standards. Developing clear maintenance policies and guidelines, training facility managers, and ensuring proactive planning rather than reactive maintenance can significantly enhance efficiency (Olanrewaju & Abdul-Aziz, 2022).

Another challenge is resource allocation, where inefficient budgeting leads to underfunding or excessive maintenance expenditures. Governments and facility managers need to implement lifecycle cost analysis and prioritize preventive maintenance to reduce long-term repair costs (Durán et al., 2020). Furthermore, engaging stakeholders through transparent communication and structured reporting mechanisms helps optimize maintenance strategies.

CONTRACTOR PERFORMANCE AND ACCOUNTABILITY IN MAINTENANCE CONTRACTS

The performance of contractors in maintenance projects is a critical determinant of efficiency. Poor contractor performance is often linked to insufficient oversight, lack of experience, and misalignment of contract incentives. Studies indicate that clearly defined performance metrics, penalties for non-compliance, and incentives for exceeding targets can significantly improve contractor accountability (Tseng and Yang, 2024).

A performance-based approach that ties contractor payments to key outcomes, such as reduced downtime, adherence to maintenance schedules, and service quality, ensures a higher level of commitment from service providers. Additionally, regular audits, site inspections, and transparent reporting mechanisms can enhance contractor accountability and improve maintenance outcomes (Esteve et al., 2024).

Collaborative contracting, where contractors and facility managers work together in a partnership-based approach rather than a transactional model, has also been revealed to improve efficiency. This approach fosters innovation, cost-sharing strategies, and continuous improvements in maintenance service delivery (Larsson & Larsson, 2020). By integrating these best practices and ensuring contractor accountability, maintenance management can be significantly improved, leading to cost savings, enhanced asset longevity, and better service delivery in public infrastructure maintenance.

ECONOMIC AND POLICY OF FACILITIES MAINTENANCE

Economic and policy factors shape maintenance management strategies and influence contract efficiency. Government budget constraints often lead to deferred maintenance, resulting in infrastructure deterioration and higher long-term costs (Tseng and Yang, 2024). To mitigate these financial challenges, Public-Private Partnerships (PPPs) have been increasingly utilized to finance and manage public FM. PPPs leverage private sector investment to enhance efficiency, introduce innovation, and share financial risks between government agencies and private entities.

Incentive-based contracting is another approach that is gaining traction in maintenance policy frameworks. PBCs that reward contractors for achieving efficiency targets and penalize non-compliance have been revealed to enhance accountability and service quality (Sherratt et al., 2020). Additionally, outcome-based maintenance policies prioritizing cost-effectiveness over rigid budget allocations allow for more flexible resource distribution, ensuring optimal utilization of maintenance funds (Durán et al., 2020).

Sustainability considerations have also shaped maintenance policies, with an increasing emphasis on green infrastructure initiatives. Government regulations now require energy-efficient FM strategies, including adopting renewable energy sources, energy-efficient lighting, and water conservation measures (Larsson & Larsson, 2020). Maintenance contracts incorporate sustainability metrics such as carbon footprint reduction and lifecycle cost analysis to align with environmental targets. Policy incentives, including tax credits and grants, are being introduced to encourage green maintenance practices in public infrastructure management.

The future of maintenance policy will likely focus on integrating digital innovations, refining procurement frameworks, and enhancing collaboration between public and private stakeholders. Governments must establish standardized regulations to ensure data security, promote equitable PPP agreements, and develop training programs to upskill maintenance professionals in digital tools and decision-making (Ma et al., 2023). These reforms will be crucial in sustaining efficient and cost-effective maintenance management in public buildings.

THEORETICAL FRAMEWORK

This study adopts Production Efficiency as its theoretical foundation, where efficiency is viewed as the optimal use of resources with minimal waste (Alaffi et al., 2024). There are many ways to measure efficiency. In this study, a simple efficiency measurement is being used, i.e., FM outputs divided by inputs – refer to equations (1) and (2), where the highest value indicates higher efficiency. In addition, efficiency is influenced by input–output relationships and by facilities' structural and contextual factors. Accordingly, contractual variables (contract value and duration) and physical variables (GFA, number of storeys, number of blocks, and building age) are treated as factors that may shape efficiency outcomes. This framework underpins the analysis of how these variables influence the efficiency of public facilities maintenance contracts.

METHODS

This study employs a quantitative research approach to analyze the efficiency of public facilities using integrated FMC in Malaysia. The methodology consists of multiple stages, including data collection, variable selection, statistical analysis, and validation of findings. The research is designed to provide empirical insights into how contractual and physical characteristics influence maintenance efficiency. Figure 1 presents the flowchart of the study.

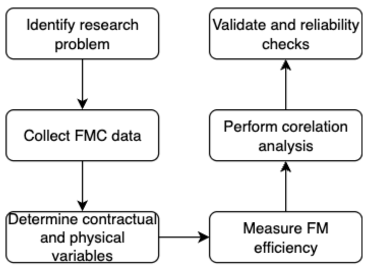

FIGURE 1. Research flowchart

DATA COLLECTION

The dataset in Table 1 consists of 45 integrated FMC managed by a federal government department in Klang Valley, Malaysia. The dataset includes Government Offices, Religious Buildings (Mosques), Commercial and Mixed-

Use Government Buildings, Law Enforcement and defense Buildings, and Green and high-performance Buildings. This study relies entirely on secondary data sourced from integrated FMC and official reports maintained by the department. Data consistency and accuracy were verified through cross-referencing with publicly available government documents. The data collected includes:

TABLE 1. Data collected for the study

No	Data collected	Description	Mean	Min	Max
1	Area of Facilities Maintenance	Gross Floor Area (m2GFA)	123,061	14,777	563,416
2	Contract value	In MYR, converted to Present Value (PV)	93,798,233	4,078,688	1,893,724,178
3	Contract period	Year of maintenance contract	5.55	3.00	25.00
4	Number of storeys	Building height measured from the lower ground	18.18	2.00	45.00
5	Number of blocks	Number of buildings in the contract	3.00	1.00	15.00
6	Age of building	Current age of the building	17.91	5.00	21.00

MEASUREMENT OF EFFICIENCY

Efficiency in FMC is measured by assessing the ratio of maintenance output to input, as in equation (1). A high value indicates a more efficient maintenance contract. The area of the building typically represents the output. This study uses GFA instead of Net Floor Area (NFA) to consider the impact of whole-FM. The input, which is the contract values, consists of financial commitments allocated in FMC values, including capital, labor, energy, materials, and services. Equation (2) represents the developed efficiency calculation for the study. The efficiency calculation follows:

$$Efficiency = \frac{Output}{Input}, \quad (1)$$

$$FM\ efficiency = \log\left(\frac{Area\ of\ Facilities\ Maintenance}{\frac{(\text{Contract Value at PV})}{(Contract\ Period\ in\ Year)}}\right), \quad (2)$$

where to ensure consistency across contracts, maintenance contracts are normalized at the PV in 2023 with a 5% annual discount rate. This approach allows for meaningful comparisons of contracts with varying durations and contract values.

PRESENT VALUE (PV) CONVERSION

To standardize financial measurements and allow comparability across different maintenance contracts, PV conversion is applied using the following discounted cash flow equation (3):

$$PV = \sum_{t=1}^{n} \frac{C}{(1+r)^t}, \quad (3)$$

where is the annual payments, is the discount rate, represents the period, and is the number of periods (years). The 5% discount rate was selected based on estimated market interest rates, including future rates, to ensure accurate cost comparisons. A normalized per annum PV value was derived to assess maintenance efficiency objectively, minimizing biases introduced by contracts with different time spans and cost structures.

CORRELATION ANALYSIS

Pearson's correlation analysis evaluated the relationships between maintenance efficiency and the selected independent variables, including contract value, contract period, building size, number of storeys, number of blocks, and building age. This study's numerical variables were converted to log numbers to improve linearity. The Pearson correlation coefficient () was calculated to identify the strength and direction of these relationships, categorized in Table 2 as follows:

TABLE 2. Categorization of correlation strength based on coefficient range

Correlation Range	Strength
0.00–0.19	Very Weak
0.20–0.39	Weak
0.40–0.59	Moderate
0.60–0.79	Strong
0.80–1.00	Very Strong

A significance test statistic was applied to determine whether the observed correlations were statistically meaningful. Subsequently, scatter plots were used to visually assess trends and relationships between maintenance efficiency and various predictors. At the same time, linear coefficient lines were generated to display correlation matrices, aiding in understanding how different variables interact with each other. By focusing on correlation analysis, this study avoids assuming causality but instead highlights significant associations that can inform future policy decisions and contract structuring in public FM.

This methodological framework ensures a rigorous, data-driven evaluation of FM efficiency, providing insights that inform policy improvements and contract structuring strategies.

VALIDATION AND RELIABILITY

Conducting pilot testing of efficiency metrics before full-scale data analysis maintained internal consistency. Using normalized efficiency scores through PV conversion further enhances the robustness of the findings. This methodological framework provides a rigorous, data-driven approach for evaluating the efficiency of public facilities maintenance contracts, contributing to improved contract structuring and resource optimization.

RESULTS

FACILITIES MAINTENANCE EFFICIENCY

Figure 2 highlights the density of FM efficiency scores of 45 FMCs.

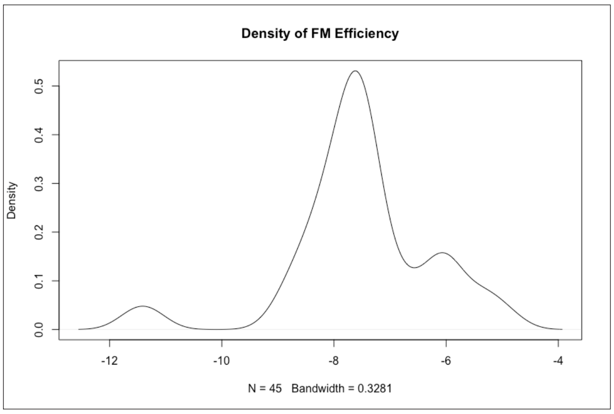

FIGURE 2. Density of Maintenance Efficiency

Table 3 indicates the descriptive statistics of FM efficiency scores. Table 4 describes the correlation analysis between contractual characteristics, physical attributes, and FM efficiency. The dataset of 45 FMC was assessed to identify patterns that affect efficiency performance.

CONTRACT CHARACTERISTICS

CONTRACT VALUE AND FM EFFICIENCY

A strong negative correlation was observed between contract value and maintenance efficiency ($r = -0.86$, $p < 0.01$). Higher-value contracts tended to exhibit lower efficiency scores, suggesting that larger budgets do not necessarily result in better maintenance outcomes because they involve higher inputs. This inefficiency may be attributed to higher administrative costs, ineffective budget allocation, or increased bureaucratic complexity associated with large-scale contracts, which can be managed during earlier project conception or using performance-based mechanisms for payment or allowing contract clauses for renegotiation.

TABLE 3. Descriptive statistics of FM efficiency scores

Mean	Range	SD	Quantile	IQR
-7.514	-11.571 (min), -4.911 (max)	1.265	-11.571 (0%), -8.056 (25%), -7.582 (50%), -7.010 (75%), -4.911 (100%)	1.045

TABLE 4. Pearson's Product-Moment Correlation analysis

Variables	Correlation Coefficient (r)	Significance (p-value)	Confidence Interval	Strength
FM Efficiency vs. Contract Value	-0.859	0.001	[-0.921, -0.757]	Very strong negative
FM Efficiency vs. Contract Period	-0.607	0.001	[-0.764, -0.382]	Strong negative

continue...

...cont.

FM Efficiency vs. GFA	0.094	0.535	[-0.204, 0.378]	Very weak positive
FM Efficiency vs. No of Storeys	0.330	0.027	[0.040, 0.568]	Weak positive
FM Efficiency vs. No of Blocks	-0.329	0.028	[-0.567, -0.039]	Weak negative
FM Efficiency vs. Age of Building	0.061	0.689	[-0.236, 0.349]	Very weak positive

CONTRACT PERIOD AND FM EFFICIENCY

A strong negative correlation was observed between contract duration and efficiency ($r = -0.61$, $p < 0.01$). More extended contract periods were associated with decreasing efficiency levels, implying that extended maintenance agreements might reduce contractor motivation and accountability. The absence of periodic evaluations and performance-based incentives in long-term contracts could contribute to this inefficiency. To mitigate this, shorter contract cycles with well-defined performance review mechanisms may be preferable.

PHYSICAL CHARACTERISTICS

GROSS FLOOR AREA (M^2GFA) AND FM EFFICIENCY

A non-significant positive correlation ($r = 0.0949$, $p > 0.05$) was observed between efficiency and GFA, suggesting that building size alone does not strongly impact maintenance efficiency. Hence, the anticipated economic benefits from economies of scale associated with building size did not materialize. Factors such as maintenance planning and technology adoption in the contract could be more critical in improving economies of scale.

NUMBER OF STOREY AND FM EFFICIENCY

A weak but statistically significant positive correlation ($r = 0.330$, $p < 0.05$) was revealed between the number of storeys and efficiency. This suggests that taller buildings benefit from centralized service coordination and more structured maintenance operations, potentially leading to marginally improved efficiency levels. Thus, the benefits of taller buildings may streamline operations and reduce duplication of effort. In this case, a small efficiency gain might come from economies of scale in vertical servicing.

NUMBER OF BLOCKS AND FM EFFICIENCY

A weak negative correlation ($r = -0.329$, $p < 0.05$) was identified, indicating that buildings with multiple blocks tend to have lower efficiency levels. This inefficiency is likely due to logistical challenges in resource distribution, travel time for maintenance personnel, and coordination difficulties across different sections of the building complex. Therefore, it highlights the need for contract provisions and maintenance strategies that address the challenges of servicing dispersed building clusters.

AGE OF BUILDING AND FM EFFICIENCY

No significant correlation ($r = 0.061$, $p > 0.05$) was identified between building age and efficiency, implying that older buildings do not necessarily experience lower maintenance efficiency. This indicates that efficiency is influenced more by maintenance practices and material durability than by chronological age. Buildings constructed with robust, low-maintenance materials tend to retain performance levels over time, while structures reliant on more fragile or high-maintenance materials may experience efficiency declines. These results highlight the importance of proactive maintenance strategies, targeted refurbishment investments, and the adoption of predictive technologies, alongside carefully selecting durable materials, in sustaining long-term building performance.

These findings highlight the need to refine contract structures, improve oversight mechanisms, and optimize maintenance planning to enhance efficiency in public FMC. The study provides evidence-based recommendations for policymakers to implement performance-driven contract frameworks that align with the operational realities of public infrastructure management.

VISUALIZATION OF RESULTS

The scatter plots provide further insight into these relationships. Figure 4 illustrates a scatter plot of contract value versus maintenance efficiency, which confirms a strong negative correlation, with higher contract values linked to lower efficiency. Contract period versus maintenance efficiency follows a similar but moderate trend, reinforcing that shorter contracts yield better results.

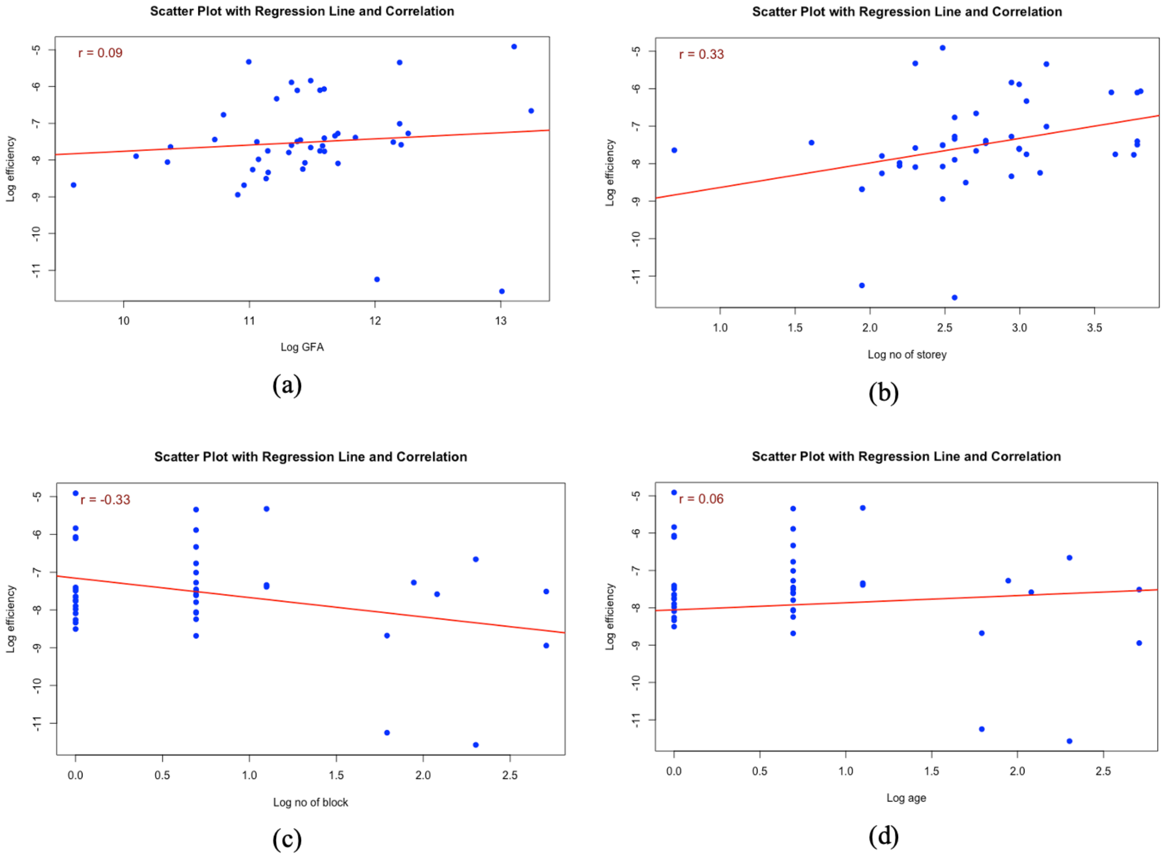

FIGURE 3. Physical characteristics: FM efficiency vs. GFA (a) and number of storeys (b), number of blocks (c), and building age (d)

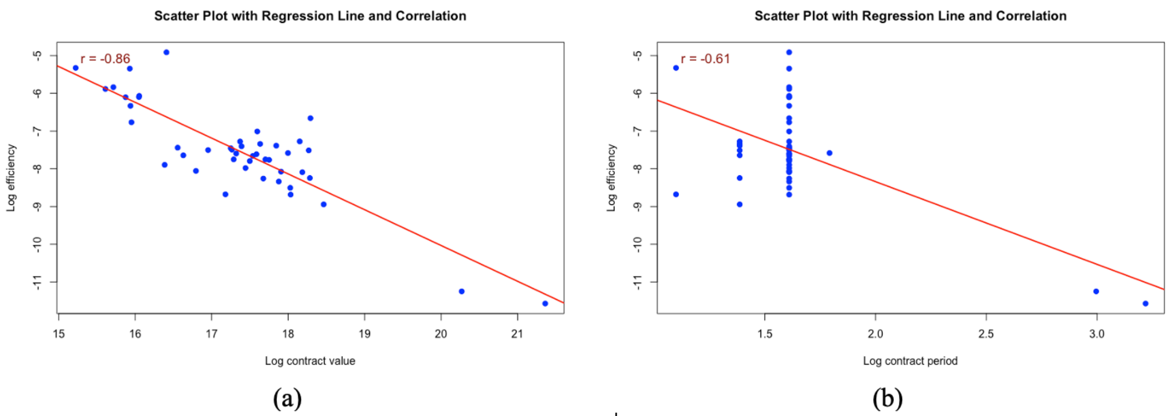

FIGURE 4. Contract characteristics: FM efficiency vs contract value (a) and contract period (b)

Conversely, Figure 4 indicates that building size and the number of storeys have moderate and weak positive correlations with maintenance efficiency, suggesting that taller buildings can contribute to efficiency. In contrast, the comparison of blocks versus maintenance efficiency reveals a weak negative trend, indicating that logistical challenges in multi-block buildings negatively impact efficiency. Lastly, the building age versus maintenance efficiency scatter plot demonstrates a weak positive correlation, reinforcing that well-maintained older buildings with better materials and construction can achieve efficiency levels as those of newer buildings.

These findings provide a data-driven understanding of maintenance efficiency in public buildings. The study indicates the need for well-structured contracts, improved contract oversight, and strategic maintenance planning to enhance efficiency and cost-effectiveness in government-managed infrastructure.

DISCUSSION

The findings of this study highlight inefficiencies in public FM, particularly regarding high-value contracts and multi-block buildings. The negative correlation between contract value and maintenance efficiency has demonstrated that larger maintenance budgets do not always translate into better efficiency but may instead contribute to resource misallocation (Esteve et al., 2024). This result is consistent with international evidence demonstrating that large-scale public contracts often face bureaucratic complexity and accountability gaps (Tseng & Yang, 2024; Wong et al., 2021). The efficiency could be improved by PBCs, which have been suggested as an effective strategy to address these inefficiencies, as it ties contractor compensation to KPIs such as system uptime and service quality (Malelak et al., 2019). Implementing such models could enhance accountability and reduce inefficiencies in high-value contracts. Based on the datasets, some long-term maintenance contracts were signed many years ago, before PBC was introduced systematically with the introduction of the standard form of contract.

The study also identified a negative correlation between contract period and maintenance efficiency. Similar findings by Sherratt et al. (2020) suggested that long-term contracts may foster complacency, reducing contractors' incentive to perform efficiently. This reinforces the argument that shorter contracts with periodic evaluations are more effective, as also noted by Hauashdh et al. (2020) in their review of Malaysian maintenance practices. To mitigate this issue, a shorter contract period and frequent performance reviews could maintain high service standards and operational efficiency. Implementing digital monitoring tools, such as BIM, has been proposed as an effective strategy for ensuring performance-based oversight (Surmann & Hirsch, 2016). Based on current practice, federal government departments have opted for 3 to 5-year maintenance contracts (Jabatan Kerja Raya Malaysia, 2020). However, legacy maintenance contracts of more than 5 years are still being implemented until the end of the contract period.

The weak correlation between building size and maintenance efficiency suggests that economies of scale do not automatically lead to better performance. Surprisingly, this result indicates that larger floor area alone is not a strong predictor of efficiency, which aligns with Gómez-Chaparro et al. (2019), who observed that larger hospitals were not always more efficient unless accompanied by strong planning and management, and with Rathod (2023), who reported that occupancy density and space allocation are stronger predictors of cost efficiency than size alone. In contrast, the negative correlation between the number of blocks and efficiency emphasizes the logistical difficulties in maintaining multi-block buildings, necessitating centralized maintenance strategies. This aligns with Ramanathan and Rathore (2024), who identified multi-block complexity as a key source of inefficiency in public building projects.

Finally, building age was not significantly correlated with efficiency, contradicting assumptions that older buildings require more maintenance effort. This surprising finding suggests that age alone is not a determinant of efficiency, and instead, factors such as quality, reporting systems, and predictive maintenance strategies play a more important role (Olanrewaju et al., 2023; Bouabdallaoui et al., 2021). This finding also supports the argument that strategic refurbishment and predictive maintenance can sustain the efficiency of aging buildings (Bouabdallaoui et al., 2021).

In terms of validity and reliability, the findings are supported by statistically significant correlation results ($p < 0.05$ for key variables), normalized PV conversion ensuring comparability across contracts, and pilot testing of efficiency metrics to confirm internal consistency. These measures enhance the robustness and reliability of the results.

In summary, the study highlights the need for improved contract structures, digital monitoring tools, and strategic maintenance planning to enhance the efficiency of public FM. These insights contribute to the broader discourse on infrastructure management and offer practical recommendations for policymakers and facility managers.

This study provides an in-depth analysis of public facilities maintenance contracts. The findings indicate that:

1. High-value contracts are less efficient, possibly due to resource misallocation and administrative inefficiency.
2. Longer contract durations correlate with decreased efficiency, highlighting the need for periodic performance evaluations and an acceptable contract period length.
3. Multi-block buildings experience higher inefficiencies, primarily due to logistical challenges in maintenance operations, which necessitate contract frameworks and maintenance approaches designed to overcome the logistical complexities of dispersed building clusters.
4. Taller buildings demonstrate marginal efficiency advantages, likely due to centralized systems and streamlined operations.
5. Building age does not significantly affect efficiency, emphasizing the importance of maintenance strategies and building quality over mere structural age.

CONCLUSION

This study contributes to the body of knowledge by providing empirical evidence on how different contractual and physical characteristics affect maintenance efficiency. This research enhances the existing literature on public FM efficiency by integrating productive efficiency modeling techniques to measure maintenance efficiency. The study also highlights the importance of PBCs and monitoring tools in improving maintenance outcomes.

From a practical standpoint, this research provides valuable recommendations for policymakers and facility managers. By considering contractual and physical characteristics, maintenance efficiency can be significantly improved through performance-structured incentives and accountability measures. Adopting digital tools, such as BIM, can further enhance monitoring and resource allocation. Furthermore, centralized maintenance strategies for multi-block buildings and structured contract management approaches can mitigate inefficiencies associated with fragmented maintenance efforts.

Future research should explore the long-term impact of predictive maintenance systems and their cost-effectiveness in public infrastructure management. Additionally, further studies could examine the role of policy interventions, such as financial incentives and regulatory frameworks, in enhancing maintenance efficiency across different building types.

In conclusion, this study offers critical insights into optimizing public FM efficiency by highlighting contractual and physical characteristics to enhance current FMC. It achieves this by tailoring future contracts with performance-based incentives and incorporating digital monitoring tools. By implementing these recommendations, policymakers and facility managers can ensure sustainable and cost-effective management of public infrastructure, contributing to improved service delivery and long-term use of efficient resources.

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DECLARATION OF COMPETING INTEREST

None.

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