

Computational Assessment of Municipal Infrastructure Asset Performance for Smart Operations and Maintenance

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Abstract. Smart Operations and Maintenance (O&M) requires infrastructure owners to move from reactive maintenance toward data-driven, risk-informed and financially sustainable asset management. This study examines whether current and planned asset investments are adequate to maintain service delivery, productive capacity, and long-term financial sustainability in Municipality X, and to develop asset management objectives. Computational asset management indicators were applied to assess the performance and long-term sustainability of six infrastructure asset portfolios, namely water, sanitation, solid waste, community facilities and operational buildings, roads and stormwater, and electricity. The rationale for the study is that Municipal infrastructure systems are exposed to ageing, funding constraints, service-delivery pressures, and rising maintenance backlogs. The study adopted a quantitative asset management assessment approach guided by SANS 55001, the Maintenance Monitoring and Evaluation Protocol, and principles of infrastructure asset management planning. Five SMART asset management objectives were formulated and linked to measurable indicators. The study found deterioration of the Asset Consumption Ratio (AM1), deficits in the Asset Sustainability Ratio (AM2) in selected portfolios, the Revenue-Generating Asset Ratio (AM3) improvement from 48.5% to 55%, and the Asset Renewal Funding Ratio (AM5) trajectory of 89%, 92%, and 96%. The study concludes that Municipality X is not operating optimally across several asset portfolios. It is recommended that Municipality X should implement an integrated digital asset management platform supported by condition monitoring, predictive maintenance analytics, lifecycle costing and risk-based prioritisation.

1. Introduction

Infrastructure is foundational to development as it supports production, household welfare and broader economic activity [1]. Calderón and Servén [2] similarly show that infrastructure development is connected to economic growth and income distribution, although the strength of the relationship depends on infrastructure quality, access and institutional context. Asset management standards define asset management as a coordinated organizational activity intended to realise value from assets, with value shaped by the balance among performance, cost, and risk across the asset life cycle [3, 4]. In the context of municipal infrastructure, value is realised through service performance rather than ownership alone. Roads, stormwater systems, water networks, sanitation assets, electricity networks, solid waste facilities and public buildings only create public value when they remain available, reliable, safe and financially sustainable. The OECD argues that infrastructure governance affects whether infrastructure investment delivers time, cost and service-delivery outcomes, meaning that institutional capacity is as important as technical infrastructure provision [5]. This is consistent with the UN infrastructure asset-

management handbook, which frames public infrastructure assets as systems that local and national governments must manage to support resilience, sustainability, accessibility and development outcomes [6].

Municipal infrastructure management faces asset ageing, deferred renewal, incomplete asset information, constrained budgets, and service-delivery expectations. The literature on infrastructure assets reveals that there are different dimensions to value. The World Bank [7] perceives infrastructure asset value as development, growth and service access; the OECD emphasizes institutional decision-making, transparency and accountability, while the UN asset management guidance stresses sustainability, resilience and local government capacity [1, 5, 6]. Coordinated work processes are identified as central requirements for proactive municipal infrastructure management [8, 9].

Within this context, Smart Operations and Maintenance (Smart O&M) offers a technology-enabled approach to infrastructure management. In this study, Smart O&M refers to the integration of asset data, condition monitoring, lifecycle costing, predictive analytics, risk prioritisation, and digital decision-support systems into maintenance and renewal planning. This interpretation is consistent with the condition-based maintenance literature, which links diagnostics, prognostics, and data processing to maintenance decision-making [10], and with the risk-based maintenance literature, which emphasises the integration of risk estimation, risk evaluation, and maintenance planning [11].

The study identifies Municipality X's purpose as developing local economies and providing infrastructure and services, and it links asset management objectives to financial health and sustainability policy directives. A multi-method simulation approach developed within the AnyLogic software framework was used to present a quantitative assessment of six infrastructure asset portfolios in the municipality using asset management performance indicators. The aim of the paper is to assess whether current and planned asset investments are adequate to maintain service delivery, productive capacity and long-term financial sustainability in Municipality X, and to develop a Smart O&M-oriented interpretation of the results.

2. Literature Review

2.1. Infrastructure Asset Management

Infrastructure asset management provides a systematic basis for aligning asset decisions with organisational objectives, service levels, lifecycle costs and risk. ISO 55000 describes the principles and terminology of asset management and identifies it as applicable to all types of assets and organisations [3]. ISO 55001 specifies requirements for establishing, implementing, maintaining and improving an asset management system [4]. The Institute of Asset Management presents asset management as an integrated discipline concerned with achieving value through coordinated decisions over acquisition, operation, maintenance, renewal and disposal [12].

In municipal settings, asset management requires particular attention to the relationship between infrastructure performance and community outcomes. The International Infrastructure Management Manual positions infrastructure asset management as a stewardship function in which public organisations manage infrastructure investment on behalf of communities and customers [13]. A recurring problem in municipal asset management is fragmented information. Vanier [8] argues that the construction and infrastructure sectors require decision-support tools for asset management, while Halfawy [9] identifies data integration, process coordination, and shared information environments as major challenges in municipal infrastructure asset management.

2.2. Asset Lifecycle Management and Sustainability

Lifecycle asset management requires that decisions about maintenance, renewal, replacement, and disposal be made with reference to whole-life performance rather than short-term expenditure alone. The World Bank [7] links resilient infrastructure to preventive maintenance and lifecycle management, while IPWEA [13] emphasises that infrastructure owners should manage assets in relation to service levels, risk and lifecycle costs. For water infrastructure, Alegre et al. [14] define infrastructure asset

management as a set of processes intended to ensure that infrastructure performance corresponds to service targets over time, risks are managed, and lifecycle costs are minimised.

2.3. Smart Operations and Maintenance

Smart O&M represents a progression from reactive and schedule-based maintenance toward condition-based, predictive and risk-informed maintenance. Jardine, Lin and Banjevic [10] define condition-based maintenance research as diagnostics and prognostics that use condition-monitoring data to support maintenance decision-making. Carnero [15] shows that the implementation of predictive maintenance can be supported by decision tools that combine operational research, decision rules, and probabilistic reasoning. More recent digital twin literature extends these ideas by connecting physical assets with virtual representations, sensor data and analytics for monitoring and optimisation [16, 17]. In the built environment, digital twins and asset information models have been proposed as mechanisms for integrating static asset data with dynamic operational information. Boje et al. [18] argue that construction digital twins require semantic completeness and integration of dynamic data, while Lu et al. [19] propose digital twin-enabled anomaly detection for built-asset monitoring.

2.4. Condition Monitoring, Predictive Maintenance and Asset Performance

Condition monitoring provides evidence on asset health and deterioration. In maintenance theory, condition-based and predictive maintenance rely on collecting and analysing data to determine when maintenance should be undertaken, rather than relying only on failure events or fixed intervals [10, 15]. This logic is important when studying municipal infrastructure because asset failure can disrupt essential services, create emergency expenditure and reduce public confidence. Performance indicators such as asset consumption, sustainability ratios and maintenance expenditure ratios therefore provide an initial computational layer, but their explanatory power improves when integrated with asset-level condition and failure data.

2.5. Risk-Based Asset Management

Risk-based asset management recognises that not all assets have equal consequences of failure. ISO 31000 provides a general risk management process for identifying, analysing, evaluating, treating, monitoring, and communicating risk [20]. Khan and Haddara [11] present risk-based maintenance as a quantitative method that connects risk estimation, risk evaluation and maintenance planning. Asset-level assessments of failure likelihood and consequence-based criticality provide greater clarity regarding organisational risk exposure and support more defensible maintenance and renewal priorities [21].

2.6. Digital transformation

Digital transformation in infrastructure asset management involves the use of asset information systems, geographic information systems, sensors, digital twins, analytics and dashboards to support decision-making. Halfawy [9] emphasises the need for integrated municipal infrastructure management environments, while digital twin research shows how physical and virtual asset information can be connected for monitoring, simulation and optimisation [16, 17]. Municipal portfolio-level indicators should be treated as an initial diagnostic and prioritisation mechanism rather than the final basis for intervention. Specific maintenance and renewal decisions require subsequent tactical and operational assessment of asset condition, performance, criticality, risk and lifecycle cost [22].

2.7. Conceptual Framework

Asset-management governance and lifecycle principles provide the theoretical foundation; asset and financial data are transformed into five AM1–AM5 indicators; these are interpreted through service delivery, risk, and financial sustainability; lifecycle decisions then determine maintenance, renewal, or replacement needs; and Smart O&M technologies provide monitoring, predictive analytics, and decision support. The paper's methodology adds a scenario-simulation layer in which baseline and Smart O&M scenarios are compared across six municipal infrastructure portfolios.

The conceptual framework is shown in Figure 1.

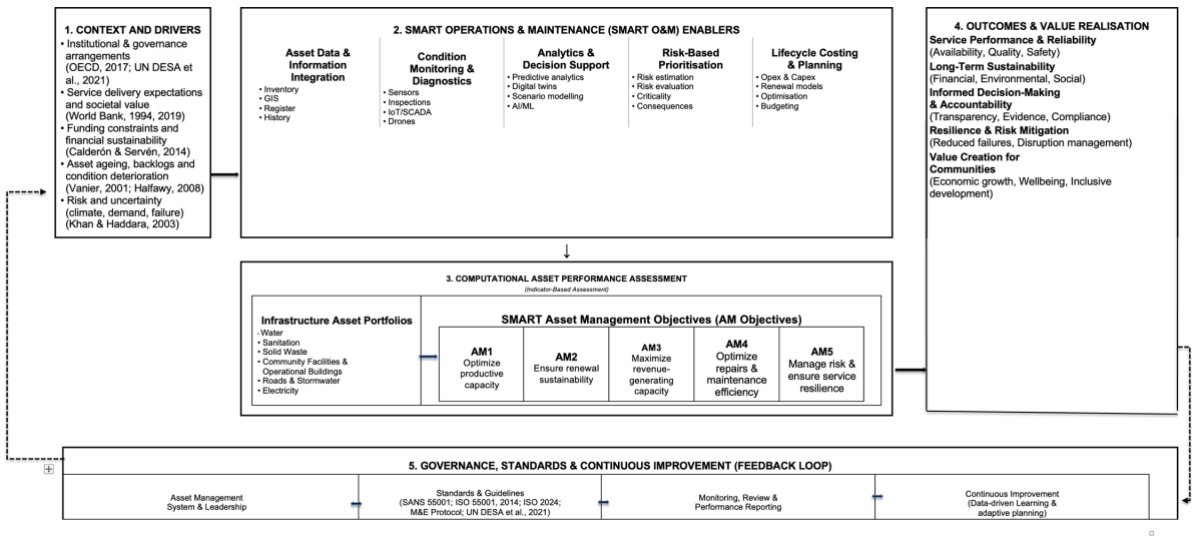


Figure 1. Conceptual framework of the study.

The conceptual framework adopted in this paper links asset data to organisational decision-making through five analytical layers: asset data, performance indicators, risk interpretation, lifecycle planning and Smart O&M decision support. At the first layer, asset registers and financial data provide information on current replacement cost, depreciated replacement cost, depreciation, planned capital expenditure and operational expenditure. At the second layer, performance indicators convert these data into measures of asset consumption, sustainability, revenue generation, maintenance, and renewal funding. At the third layer, the indicators are interpreted in relation to risk, service delivery and financial sustainability. At the fourth layer, lifecycle planning determines whether maintenance, renewal or replacement is required. At the final layer, Smart O&M technologies support continuous monitoring, predictive analytics and decision dashboards.

3. Research Methodology

3.1. Research Design

The study adopted a quantitative secondary-analysis design supported by scenario-based simulation. The purpose of the methodology was to assess whether reported and planned infrastructure asset investments in Municipality X are adequate to sustain productive capacity, service delivery and long-term financial sustainability across six municipal infrastructure portfolios. The analysis was structured around five asset-management indicators: Asset Consumption Ratio (AM1), Asset Sustainability Ratio (AM2), Revenue-Generating Asset Ratio (AM3), Repairs and Maintenance Expenditure as a Percentage of Current Replacement Cost (AM4), and Asset Renewal Funding Ratio (AM5). The design was guided by SANS 55001 [23], the Maintenance Monitoring and Evaluation Protocol [24] and principles of infrastructure asset management planning [25].

3.2. Data Integration and Database Architecture

Municipality X is treated as an anonymised municipal case. The municipality is assessed as a public infrastructure owner responsible for providing infrastructure and services while maintaining the productive capacity and financial sustainability of its asset base. The analysis covers six infrastructure asset portfolios: 1. Water infrastructure; 2. Sanitation infrastructure; 3. Solid-waste infrastructure; 4. Electricity infrastructure; 5. Roads and stormwater infrastructure; 6. Community facilities and operational buildings. These portfolios were selected because they represent core municipal

infrastructure systems with different service-delivery, maintenance, renewal and revenue-generation characteristics. Water, sanitation, and electricity are treated as revenue-linked infrastructure portfolios, while roads, stormwater, community facilities, and parts of the solid-waste portfolio are treated as essential public-service assets that may not generate direct revenue but remain critical to municipal performance.

3.3. Data sources and preparation

The empirical basis of the study consists of verified Municipality X financials and asset management data these were used as inputs for the asset management calculations and scenario assessment. The data is used for academic purposes, and the anonymisation of Municipality X prevents disclosure of identifiable municipal information. The original dataset provides the asset-management objectives, current asset-performance values and 30-year planning-period indicators. The data is organized into baseline, simulated post-intervention and financial-appraisal outputs. The following data categories were used: current replacement cost (CRC); depreciated replacement cost; accumulated depreciation; annual depreciation; repairs and maintenance or AM4-classified expenditure; renewal expenditure; revenue-generating asset values; AM1–AM5 indicator values; 30-year planning-period values; and simulated Smart O&M intervention costs.

Data preparation comprises transcription of the reported schedules, unit standardisation, alignment of reporting periods and checks of arithmetic and consistency between tables. Total operating expenditure is not treated as maintenance-only expenditure, and reported AM5 values are not considered independently reproduced without the underlying renewal cash flows and discount assumptions. Model inputs will therefore distinguish reported data, independently recalculated values and explicit assumptions, with unresolved discrepancies documented before scenario analysis

3.4. Any-Logic supported simulation approach

A deterministic, discrete-time model is proposed in AnyLogic to assess asset-value and financial changes across Municipality X's six infrastructure portfolios over 30 years. Annual calculations will be aggregated into three ten-year reporting periods. Each portfolio will contain asset cohorts with defined replacement values, remaining useful lives and renewal schedules. Inputs will include current replacement cost (CRC), depreciated replacement cost (DRC), depreciation, renewal and growth expenditure, and available funding. The initial model will use constant prices and zero residual values, consistent with the assignment assumptions.

Annual updates will account for depreciation, asset retirement and commissioned renewal and growth assets using the equations below. Here, i denotes the portfolio, t the year, Dep annual depreciation, CRC_{ret} and DRC_{ret} retired asset values, and A_{ren} and A_{growth} the replacement values of commissioned renewal and growth assets. Retired DRC will be measured after applicable depreciation, and replaced assets will be removed before their replacements are added. New assets will begin depreciation in the year following commissioning.

$$\begin{aligned} CRC_{i,t} &= CRC_{i,t-1} - CRC_{i,t}^{ret} + A_{i,t}^{ren} + A_{i,t}^{growth} \\ DRC_{i,t} &= DRC_{i,t-1} - Dep_{i,t} - DRC_{i,t}^{ret} + A_{i,t}^{ren} + A_{i,t}^{growth} \end{aligned}$$

The model will compare the baseline with digital information support and renewal reprioritisation under an unchanged renewal budget. AM1–AM5 will be calculated from the resulting asset values and expenditure streams, without imposing percentage improvements. AM3 will change only through asset composition or valuation; AM4 will require maintenance-only expenditure; and AM5 will require matched planned and required renewal cash flows. Verification will use independent spreadsheet calculations and asset-balance checks, while sensitivity analysis will test expenditure timing, implementation costs and intervention assumptions. Outputs will represent conditional financial and

asset-value projections, not demonstrated improvements in service delivery, physical condition or risk reduction..

3.5. Scenario and Financial assessment

The simulation assessment compared the reported baseline position with a Smart O&M intervention scenario and related financial sensitivity scenarios. The baseline scenario reflects the reported current and planning-period asset-performance values. The Smart O&M scenario represents simulated post-intervention performance values for AM1–AM5 and associated financial implications. These values are used to assess whether Smart O&M could improve asset performance trajectories, maintenance alignment, renewal sustainability, and financial planning.

The proposed appraisal would calculate incremental NPV = $-C_0 + \sum [(B_t - C_t)/(1 + r)^t]$, for years $t = 1$ to T , where C_0 is initial investment, B_t incremental benefits, C_t recurring incremental costs, r the discount rate and T the appraisal horizon. Capital and operating costs must be separated, terminal value justified, and overlapping benefits excluded. The price base, real or nominal treatment, discount rate, adoption lag and sensitivity ranges require evidence; none is silently assigned here.

3.6. Indicators and study assessment

Table 1. Asset-management indicators, study definitions, benchmarks and interpretive cautions.

Indicator	Study definition	Benchmark	Interpretive caution
AM1	Asset consumption / remaining productive capacity	>50%	Portfolio-level averages can conceal critical assets.
AM2	Asset sustainability ratio: renewal expenditure ÷ depreciation	>95%	High short-term renewal does not guarantee well-timed renewal.
AM3	Revenue-generating immovable assets ÷ total immovable-asset CRC	>60%	Portfolio mix is partly a policy choice, not a condition measure.
AM4	Repairs and maintenance expenditure ÷ CRC	1.8–2.2% p.a.	Supplied numerator is total OPEX, not verified R&M-only spend.
AM5	Funding of projected renewal expenditure	>90%	Uniform values across portfolios limit asset-level discrimination.

CRC = current replacement cost; OPEX = operating expenditure; R&M = repairs and maintenance. Benchmarks are policy thresholds.

3.7. Validation Controls and Limitations

The baseline, calculated, and simulated values were distinguished throughout the analysis. The benchmark interpretation was also separated from financial appraisal. The data is anonymised and therefore cannot be treated as audited municipal performance. The AM4 indicator was limited by uncertainty about whether the numerator represents only repairs and maintenance expenditure or broader operating expenditure. Finally, the simulation outputs depend on the assumptions embedded in the AnyLogic parameters and should therefore be interpreted as planning evidence rather than confirmed real-world performance. The model was not validated against observed post-intervention outcomes because Smart O&M interventions had not been implemented and followed over the study horizon. Validation was therefore limited to comparing modelled baseline states with reported Municipality X values and conducting consistency checks against the source asset-management records.

4. Results

4.1. AM1: Asset Consumption Ratio

Current AM1 values indicate that water (45%), sanitation (39%), solid waste (49%) and electricity (40%) are below the >50% study benchmark; roads and stormwater (55%) and community facilities (52%) are above it. The long-horizon trajectory is more severe (Figure 2). Solid waste is the only portfolio above the benchmark in both 2019–2028 (66%) and 2029–2038 (63%). By 2039–2048, all six portfolios fall below the benchmark: water 11%, sanitation 37%, solid waste 41%, electricity 41%, and both roads and stormwater and community facilities 0%. The zero values should be interpreted as terminal scenario outputs requiring model and asset-level validation, not literal proof that every asset has no remaining capacity.

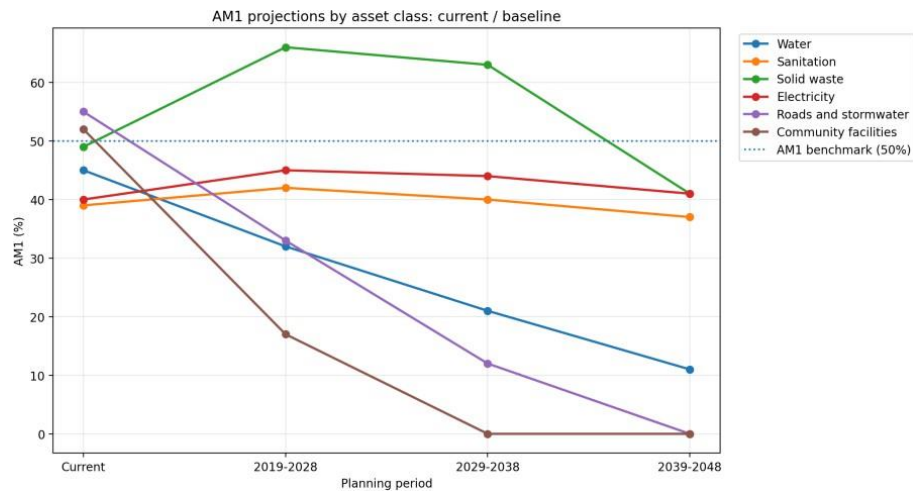


Figure 2. Current AM1 trajectory by portfolio. The dashed line marks the >50% policy benchmark.

The current AM1 trajectories show a general deterioration in productive asset capacity against the 50% benchmark. Water declines from 45% to 11%, roads and stormwater from 55% to 0%, and community facilities from 52% to 0% by 2039–2048, indicating a substantial long-term risk of asset consumption. Sanitation and electricity remain below benchmark throughout, while solid waste performs comparatively better in the first two planning periods but falls to 41% in the final period.

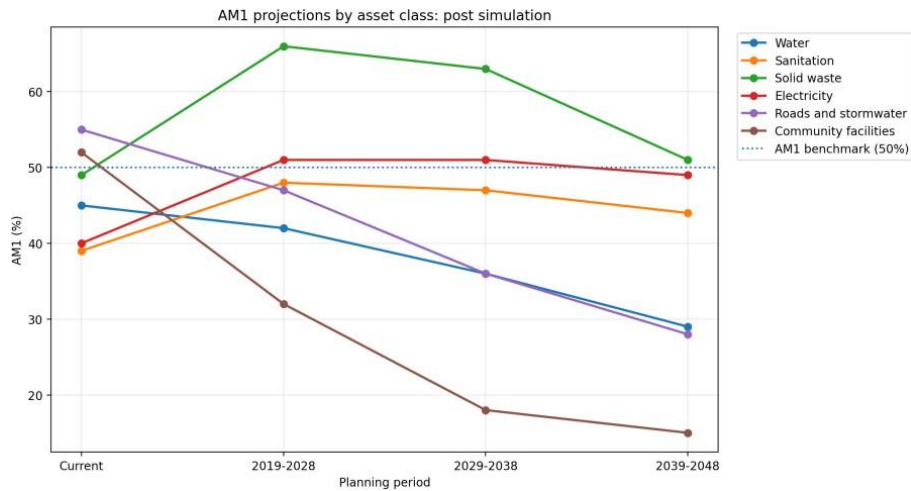


Figure 3. Post Simulation AM1 trajectory by portfolio. The dashed line marks the >50% policy benchmark.

The post-simulation trajectories show improvement across all portfolios, but the gains are uneven. Solid waste reaches 51% in 2039–2048, and electricity improves to around benchmark level in the first two future periods, but water, sanitation, roads and stormwater, and community facilities remain below 50%. Therefore, the simulated Smart O&M interventions improve long-term asset sustainability, but do not fully restore benchmark compliance. The results imply continued need for targeted renewal investment, condition-based maintenance planning and service-delivery risk prioritisation.

4.2. AM2: Renewal Sustainability

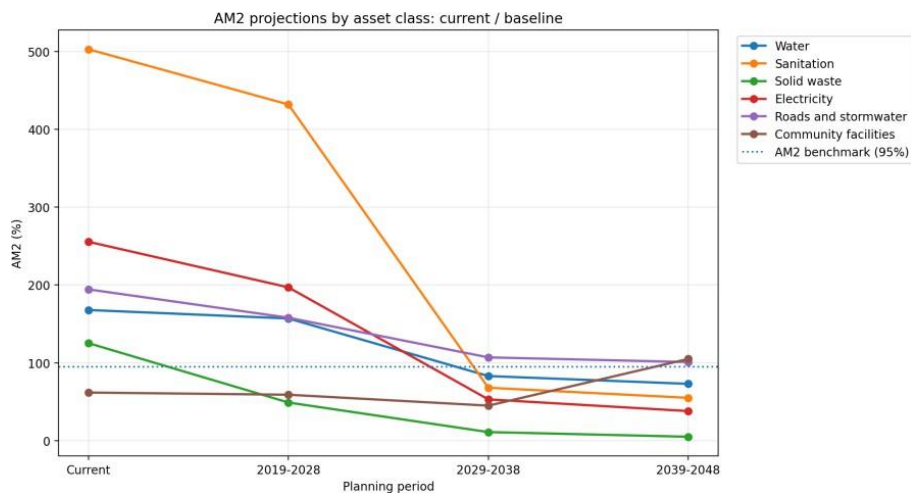


Figure 4. Current AM2 trajectory by portfolio. The dashed line marks the >95% policy benchmark.

The AM2 trajectories indicate mixed long-term sustainability performance against the 95% benchmark. Under the current/baseline trajectory, sanitation and electricity begin far above the benchmark but deteriorate sharply in later periods, suggesting that strong current renewal performance does not translate into sustained long-term asset sustainability. Solid waste shows the weakest trajectory, falling well below the benchmark throughout the projection period. Water levels decline below the benchmark in later periods, while roads and stormwater remain above it. Community facilities improve by the final period.

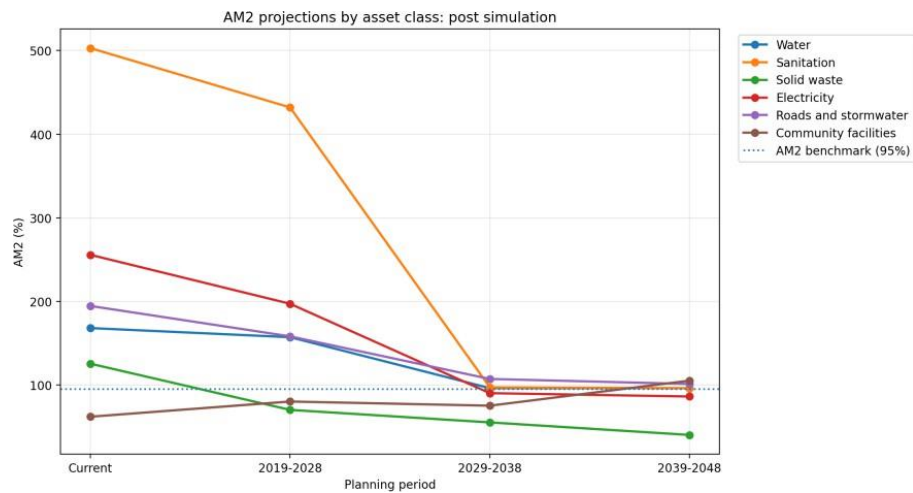


Figure 5. Post-simulation AM2 trajectory by portfolio. The dashed line marks the >95% policy benchmark.

The post-simulation trajectory shows clear improvement in water, sanitation, electricity, solid waste and community facilities. Water and sanitation recover to benchmark level by 2039–2048, while electricity improves substantially but remains below 95%. Solid waste has improved but remains materially below the benchmark, indicating a persistent renewal risk. Under the specified Smart O&M scenario assumptions, the model projects improved long-term asset performance trajectories, but these do not fully resolve renewal-investment gaps or service-delivery risk across all portfolios.

4.3. AM3: Revenue Generating Asset Ratio

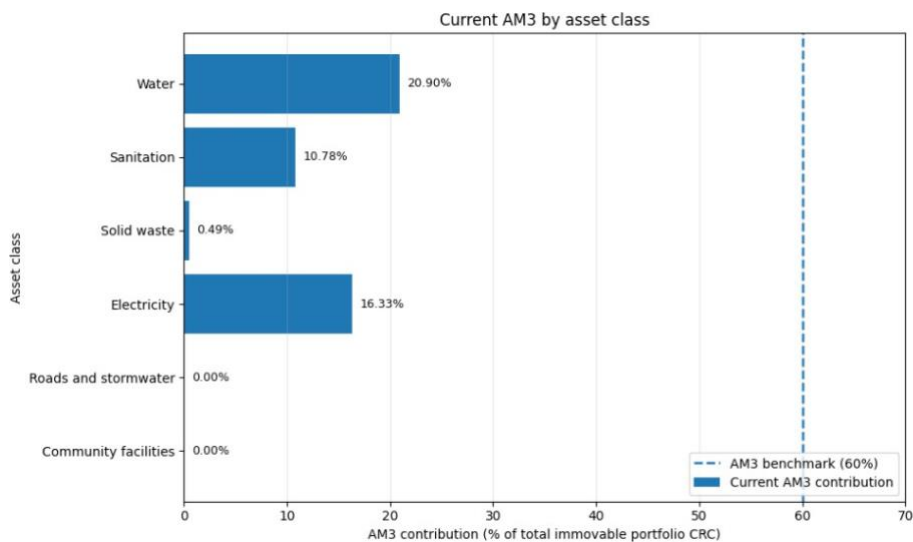


Figure 6. Current AM3 trajectory by portfolio. The dashed line marks the >60% policy benchmark.

The current AM3 graph shows that revenue-generating capacity is concentrated in water, electricity, and sanitation, with contributions of 20.90%, 16.33%, and 10.78%, respectively. Solid waste contributes marginally at 0.49%, while roads and stormwater and community facilities contribute 0%.

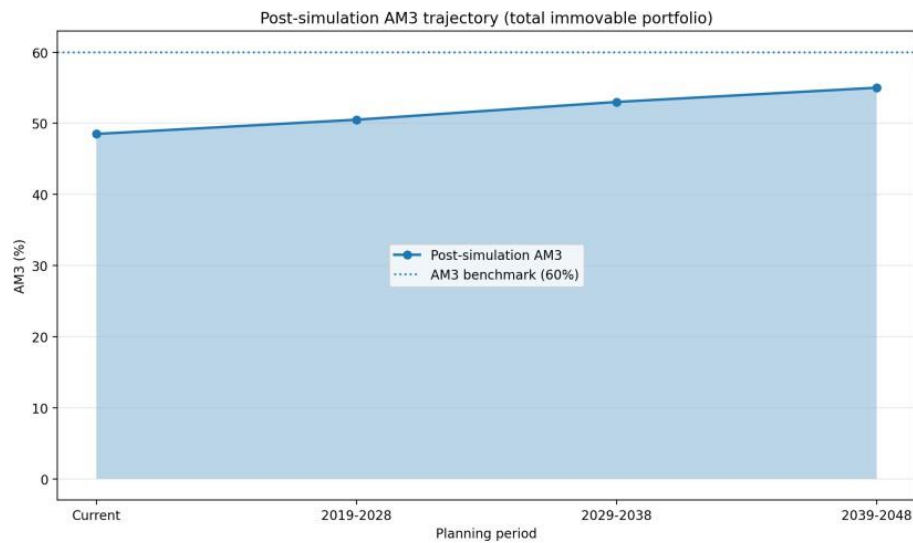


Figure 7. Post-simulation AM3 trajectory by portfolio. The dashed line marks the >60% policy benchmark.

The post-simulation AM3 trajectory shows improvement at total portfolio level, rising from 48.5% currently to 55% by 2039–2048. This indicates that the simulated Smart O&M interventions improve the portfolio's revenue-generating performance but do not meet the 60% benchmark.

4.4. AM4: Repairs and Maintenance as a Percentage of Current Replacement Cost

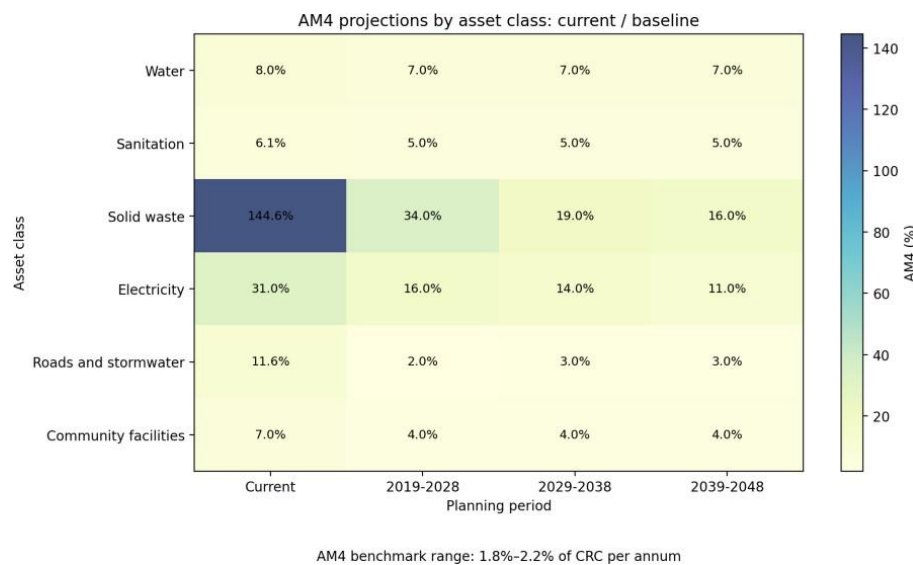


Figure 8. Current AM4 trajectory by portfolio.

The AM4 graphs show that current repairs and maintenance expenditure is generally above the 1.8%–2.2% benchmark across most asset classes. Solid waste is the most extreme outlier, declining from the current 144.6% to 16.0% by 2039–2048, while electricity remains high, declining from 31.0% to 11.0%. Water, sanitation and community facilities also remain above benchmark, although at lower levels. Roads and stormwater are closest to the benchmark, recording 2.0% in 2019–2028 but rising slightly above the range thereafter. Because the available source data did not permit independent verification that the AM4 numerator represented only repairs and maintenance expenditure, AM4 is treated as a

proxy maintenance-cost indicator in this study. Consequently, conclusions regarding maintenance expenditure efficiency are interpreted cautiously and are not used independently to establish excessive or inadequate maintenance spending.

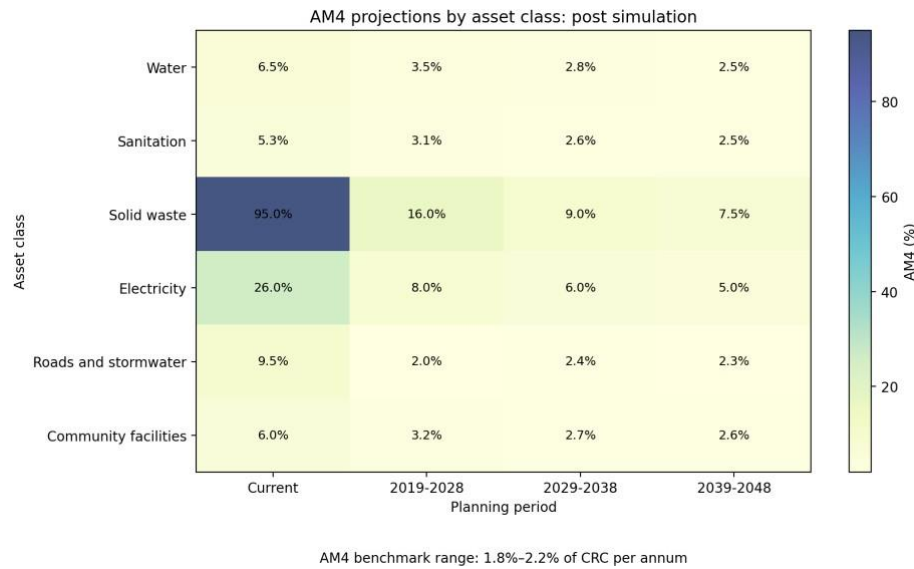


Figure 9. Post-simulation AM4 trajectory by portfolio.

4.5. AM5: Asset Renewal Funding Ratio

AM5 aims to maintain future renewal needs and planned expenditure in relation to future needs. The asset renewal funding ratio is not reported as applicable in the current position but is assessed over the 30-year planning horizon. The assignment reports values of 89%, 92% and 96% across the three successive 10-year planning periods for all portfolios.

5. Discussion

The results indicate that Municipality X's current and planned asset investments are not uniformly adequate to sustain productive capacity, renewal sustainability, maintenance efficiency and long-term financial resilience across the six infrastructure portfolios. AM1 results are worth noting, where the current asset-consumption trajectories show substantial long-term deterioration. Water, sanitation and electricity are already below the 50% benchmark in the current position, while roads, stormwater and community facilities decline sharply over the planning horizon despite initially exceeding the benchmark. The simulated Smart O&M results improve AM1 across all portfolios, but only partially. Solid waste reaches the benchmark in the final period, and electricity improves to around benchmark level in the earlier future periods, but water, sanitation, roads and stormwater, and community facilities remain below 50%. This suggests that Smart O&M can improve asset-performance trajectories, but cannot substitute for sufficient renewal investment where asset-consumption risk is structurally high.

AM2 further demonstrates that strong current renewal performance does not necessarily indicate long-term sustainability. Sanitation and electricity exceed the 95% benchmark but deteriorate sharply under the baseline trajectory, while solid waste remains materially below the benchmark throughout the projection period. Post-simulation results show improved renewal sustainability, particularly for water and sanitation, but persistent gaps remain in solid waste and electricity. This supports the lifecycle-management argument that renewal decisions should be based on long-term asset condition, risk and service requirements rather than current-period expenditure alone [13, 14].

AM3 shows that revenue-generating capacity is concentrated in water, sanitation, and electricity, while roads, stormwater, and community facilities do not contribute directly to the revenue-generating asset ratio. This should be interpreted with caution, given the nature of assets in municipal portfolios, as

non-revenue-generating infrastructure remains essential for public service delivery, accessibility, drainage, safety, and institutional functioning. The post-simulation AM3 trajectory improves at total portfolio level but remains below the 60% benchmark. Therefore, Smart O&M may improve revenue assurance and the performance of tariff-linked assets, but it does not fully resolve the municipality's portfolio-level revenue-generation gap.

AM4 indicates that expenditure classified as repairs and maintenance is generally above the 1.8%–2.2% benchmark, with solid waste and electricity showing the highest values. The post-simulation trajectory reduces AM4 across all portfolios, suggesting improved alignment with maintenance planning objectives. However, most portfolios remain above the benchmark, and the interpretation is constrained by the study's caution that the numerator may reflect broader OPEX rather than verified repairs-and-maintenance-only expenditure. The AM4 results should therefore be treated as a cost-classification and maintenance-planning signal rather than definitive proof of excessive maintenance expenditure.

AM5 shows the most stable performance. The baseline trajectory is slightly below the benchmark in the first period, then improves to above the 90% target in later periods. The simulated trajectory improves the first-period result and maintains later-period compliance. However, because the AM5 values are uniform across all portfolios, they provide limited asset-class-specific insight. This confirms the need to interpret portfolio-level indicators alongside asset-level evidence on condition, criticality, and lifecycle cost.

The findings support Smart O&M as a decision-support mechanism rather than a guaranteed solution. Condition monitoring, predictive analytics, risk-based prioritisation and digital asset information systems can strengthen maintenance and renewal planning by improving the quality and timing of decisions [10, 11, 15]. The simulated improvements remain projections and should not be interpreted as verified implementation outcomes. The scenario analysis indicates that Smart O&M, under the assumptions specified in the model, has the potential to improve selected long-term portfolio performance indicators; however, the magnitude and persistence of these improvements remain contingent on the validity of the intervention assumptions, adequate renewal funding, reliable asset information, and asset-level risk assessment.

6. Conclusion and Recommendations

This study assessed how current and planned infrastructure asset investments in Municipality X can contribute towards productive capacity, service delivery and long-term financial sustainability. The study applied five asset-management indicators across six municipal infrastructure portfolios and compared current or baseline trajectories with simulated Smart O&M projections.

The study contributes to areas where municipal asset management intervention is needed. It demonstrates how computational indicators and AnyLogic-supported scenario analysis can be used to compare baseline and simulated infrastructure performance. Scholarly, it contributes to Smart O&M literature by showing that digital maintenance approaches should be understood as planning and decision-support tools rather than automatic solutions to asset deterioration or funding gaps.

It is recommended that Municipality X prioritise asset-condition verification, AM4 cost-classification review, and targeted renewal planning for portfolios with persistent AM1 and AM2 underperformance. Water, sanitation, and electricity should be prioritised for condition monitoring, predictive maintenance, and revenue-assurance interventions, while roads, stormwater, and community facilities require lifecycle renewal planning despite their limited direct revenue contribution. The municipality should also strengthen asset registers, develop asset-level criticality ratings, and use Smart O&M dashboards to link performance indicators with maintenance, renewal and budget decisions.

The study is limited by its reliance on an anonymised dataset and simulated post-intervention projections. Future research should therefore incorporate asset-level condition data, failure records, verified maintenance expenditure, service-level indicators and observed post-implementation outcomes to test whether the simulated Smart O&M benefits can be achieved in practice.

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