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ENHANCING HOUSING AND COMMUNAL SERVICES DELIVERY IN UKRAINE: AN INTEGRATED FRAMEWORK FOR RISK, STAKEHOLDER, AND PROJECT PRIORITIZATION

Object of research – an integrated framework combining risk analysis, stakeholder engagement, and dynamic project prioritization within the BOS CIS ERP-BPMS platform at Mastergaz, a major HCS provider in Kyiv (Ukraine) serving over 750,000 subscribers. Problem, which is solved – housing and communal service providers in Ukraine face critical challenges from Soviet-era aging infrastructure, severely constrained budgets, and fragmented management, resulting in frequent service disruptions and low customer satisfaction rates. Methods used – a convergent mixed-methods single case study design combining quantitative operational data from BOS CIS platform with qualitative insights from surveys of 220 respondents and 10 semi-structured management interviews; multi-criteria decision analysis (MCDA) with knapsack-style budget allocation algorithm; statistical validation through paired t-tests and repeated-measures ANOVA. Main results – over a six-month pilot period, the integrated approach achieved 23% reduction in critical infrastructure downtime, 44.4% improvement in mean repair times, 42.9% faster response times, 12% increase in customer satisfaction, and 8% decrease in monthly heating expenses, all within existing budget constraints. Scope of practical use of results – the framework provides a replicable model for HCS providers in Ukraine and similar post-Soviet contexts, offering transparent, data-driven decision-making for optimizing limited resource allocation and enhancing community trust. Integrating real-time risk management, systematic stakeholder collaboration through monthly forums, and adaptive multi-criteria prioritization within a unified digital platform significantly enhances HCS delivery efficiency and strategic decision-making even under severe budgetary constraints.

***Keywords**: housing, infrastructure, risk, stakeholder, prioritization, Ukraine, budget, integration, digital, performance.*

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1. Introduction

Housing and communal services (HCS), which encompass water supply, sanitation, heating, waste management, and electricity distribution, are critical to urban well-being and societal stability [1, 2]. In Ukraine, the scale of this challenge has become particularly acute, with recent assessments revealing that damage to infrastructure has reached 170 billion USD, including 60 billion USD in the housing sector alone, affecting 236,000 residential buildings [3]. Moreover, the total reconstruction and recovery needs are estimated at 524 billion USD over the next decade, approximately 2.8 times Ukraine's estimated GDP for 2024 [4]. Major disruptions in these services can trigger severe socioeconomic and public health repercussions, from direct financial losses and eroded public trust to heightened vulnerability to hazardous conditions [5]. The challenges grow more acute in contexts characterized by limited financial resources, aging infrastructure, and tensions among diverse stakeholders who compete for constrained budgets [6, 7]. Ukraine has typified these issues. Much of its HCS infrastructure was developed under the Soviet system, featuring extensive but deteriorating networks that required frequent repairs and modernization within strict budgetary confines. Consequently, municipal authorities and service providers often face a stark choice: to invest in urgent short-term fixes or pursue more sustainable, longer-term improvements – an impasse that underscores the need for more robust and integrated decision-making approaches. This challenge is particularly significant in Ukraine's district heating sector, where 254 companies supply 26 million people, consuming 18% of the country's total gas consumption [8].

In response to these pressures, recent scholarship has shifted towards frameworks that integrate rigorous risk management, systematic stakeholder engagement, and dynamic project prioritization [9]. Traditional risk management in HCS often relies on formal protocols or registers that capture technical failures but rarely addresses the day-to-day improvisations of frontline personnel [10]. For instance, a technician who patches a minor leak on the spot may resolve an immediate hazard but leaves no formal trace of this intervention, depriving senior management of a deeper risk signal for future planning [1]. Although stakeholder engagement is widely acknowledged as vital, it tends to manifest itself as sporadic community meetings or isolated feedback surveys [11]. Without the continuous integration of local knowledge, such as recurrent seasonal drops in water pressure, key concerns can be overlooked when budgets are allocated or strategic objectives are set [12].

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Project prioritization in the HCS sector introduces a third layer of complexity into the problem. Faced with limited funds, utilities must determine which interventions, such as pipeline replacements, boiler overhauls, or insulation upgrades, most effectively mitigate risks and sustain high-quality services [13]. Despite growing awareness of broader evaluation criteria, many providers continue to rely on basic cost-benefit calculations or political imperatives, which can overlook factors such as safety risks, social impacts, or intangible consequences for organizational reputation [14, 15]. Recent advances in MCDA methodologies, particularly those addressing stakeholder participation and uncertainty management [16], and synthetic MCDA frameworks for participatory planning [17], offer promising solutions to these limitations. Multi-criteria decision analysis (MCDA) is a compelling alternative because it can compare projects across economic, technical, environmental, and social dimensions [18]. Nevertheless, many MCDA implementations remain static, being revisited only at scheduled intervals and rarely updated in real time; for example, when an extreme weather event dramatically shifts priorities [9]. Although sophisticated statistical tools, such as Monte Carlo simulations, can enhance risk estimates, their high data and expertise requirements can render them impractical for smaller or underfunded utilities [19].

Simultaneously, there has been increasing interest in leveraging enterprise resource planning (ERP) and business process management systems (BPMS) to facilitate real-time monitoring and interdepartmental coordination [20, 21]. ERP platforms typically centralize key organizational processes, such as finances, inventory, and human resources, whereas BPMS focus on modeling and automating complex workflows. In an ideal HCS setting, a unified ERP–BPMS platform can absorb operational data (e. g., technician logs and field sensor outputs) and stakeholder inputs (e. g., regulatory mandates and community complaints), continually updating a holistic risk and prioritization model. Recent research on the evolution of ERP and BPMS systems demonstrates that modern platforms can integrate workflow engines that combine advantages of both system types [22], while studies on maintenance management show promising results in risk mitigation through integrated approaches [23]. However, in reality, many utilities still maintain separate data repositories for risk registers, project cost estimates, and stakeholder feedback, thereby limiting the potential benefits of digital integration [6].

Despite growing scholarly attention to integrated HCS frameworks, several critical gaps persist in the literature. First, existing studies predominantly focus on either risk management [1] or stakeholder engagement [2] in isolation, with limited empirical evidence on how their integration affects operational outcomes in resource-constrained environments. While risk management frameworks provide structured approaches to identifying hazards [10], they often fail to incorporate real-time stakeholder feedback that could reveal emerging local issues. Conversely, stakeholder engagement studies [11] rarely connect community inputs directly to operational risk metrics or budget allocation decisions.

Second, although MCDA applications in infrastructure are well-documented [13, 15, 18], these implementations typically operate on periodic review cycles – quarterly or annually – missing critical real-time adaptation opportunities. Current MCDA models lack mechanisms for continuous recalibration based on sensor data, field reports, and stakeholder complaints, particularly in post-Soviet contexts where infrastructure degradation occurs unpredictably and political priorities shift frequently.

Third, the literature lacks comprehensive frameworks that simultaneously address technical (sensor-based monitoring), organizational (cross-departmental coordination), and social (community feedback) dimensions within a unified digital platform. Studies on ERP systems [20] focus primarily on internal process optimization, while BPMS research [21] emphasizes workflow automation without incorporating external stakeholder data. Most notably, no empirical studies demonstrate how ERP-BPMS integration can facilitate this multi-dimensional approach while operating under severe budgetary constraints typical of Ukrainian utilities, where capital expenditures are limited to essential repairs rather than comprehensive modernization.

Recent studies have shown promising results in applying participatory MCDA frameworks [16] and synthetic MCDA approaches [17], yet they predominantly focus on Western contexts with established digital infrastructure. Similarly, while [22] provide comprehensive analysis of ERP-BPMS evolution, their findings are based on commercial solutions that may be cost-prohibitive for Ukrainian utilities. The work of [23] on integrated ERP-BPMS for critical infrastructure offers valuable insights, but lacks detailed implementation guidance for resource-constrained environments. These studies collectively highlight the need for context-specific solutions that balance sophistication with practical feasibility.

Mastergaz, a leading HCS provider in Kyiv, Ukraine, epitomizes these concerns. Serving over 750,000 subscribers, Mastergaz long grappled with legacy infrastructure prone to breakdowns, fragmented data management practices, and budgetary constraints typical of many post-Soviet contexts. Until recently, operational decisions have been guided by spreadsheets, sporadic surveys, and offline risk logs. Although these ad hoc measures sometimes offer localized efficiencies, overall responsiveness and strategic planning remain reactive and siloed.

Seeking a more systematic and proactive approach, Mastergaz launched the BOS CIS platform in the early 2023. This platform fuses ERP capabilities (tracking financial data and scheduling resources) with BPMS modules (mapping and automating the workflow processes). Critically, it incorporates a dynamic MCDA mechanism akin to a constrained optimization algorithm that ranks and funds projects based on safety impact, seasonality, potential financial loss, and overall cost-effectiveness [13]. By processing real-time data on pipeline corrosion, unusual temperature fluctuations, or spikes in resident complaints, the BOS CIS can automatically elevate the priority of certain interventions. Mastergaz also conducts monthly review sessions in which municipal authorities, resident groups, and management analyze the updated rankings. This "human-in-the-loop" structure illustrates dynamic capabilities: as new risks emerge or stakeholder concerns intensify, resource allocations are recalibrated. The iterative feedback loop aligns with ISO 31000:2018 principles [24, 25], ensuring that risk identification and mitigation are not one-time events, but ongoing adaptive practices.

Over a six-month period, Mastergaz recorded tangible improvements. The critical heating service downtime dropped by 23 percent, while the mean repair times improved by 44.4 percent. Surveys indicated a 12 percent gain in customer satisfaction, reflecting a more responsive approach to local needs, and the monthly heating expenses decreased by 8 percent without additional budget infusions. These outcomes highlight the advantages of immediate issue detection, cross-functional collaboration, and systematic project rankings. By presenting performance dashboards to local stakeholders, Mastergaz also reduced information asymmetry, bolstering trust, an important aspect of stakeholder theory [26] and agency theory. Beyond operational efficacy, this transformation aligns with global sustainability agendas. By minimizing water and energy losses, Mastergaz contributed to SDG 6 (Clean Water and Sanitation) and SDG 7 (Affordable and Clean Energy). Meanwhile, continuous stakeholder dialogue resonates with Sustainable Cities and Communities (SDG 11), which emphasizes participatory and resilient urban infrastructure. For many post-Soviet utilities, the Mastergaz experience offers a workable template illustrating how real-time data, algorithmic decision support, and inclusive governance can be merged to overcome historically underfunded and technically outdated networks.

To investigate this integrated framework in a structured manner, this study pursues three lines of inquiry, each giving rise to a corresponding hypothesis. First, it examines whether combining risk management, stakeholder collaboration, and adaptive MCDA in one platform substantially improves the operational efficiency and decision-making for HCS services.

This line of inquiry underpins Hypothesis 1: Adopting an integrated approach significantly reduces service interruptions compared to fragmented methods. Second, it explores how real-time data and specialist input within the BOS CIS affect project prioritization under strict budget ceilings, leading to Hypothesis 2: Continuous data integration and feedback increase cost-effectiveness by improving benefits relative to project costs. Third, it addresses whether iterative communication and stakeholder involvement enhance cost savings, resource utilization, and user satisfaction, motivating Hypothesis 3: Structured, ongoing stakeholder engagement leads to clear gains in user satisfaction and fewer complaints.

Overall, this account extends beyond the basic narrative of digital transformation. This underscores how immediate field data – synchronized with rigorous stakeholder input and systematically updated MCDA – enables an HCS utility to detect issues earlier, allocate funds more judiciously, and strengthen accountability to citizens. By embedding these developments within the theories of risk management (ISO 31000:2018) [24], stakeholder engagement, and dynamic capabilities, Mastergaz illustrates practical pathways for reconciling technical limitations with political realities in delivering essential urban services. Although further investigation is warranted, especially multi-case studies and longer-term monitoring, the Mastergaz initiative is a promising template for bridging the theoretical ideals of integrated project management with the persistent constraints of aging infrastructure and limited public investment.

This research addresses these gaps by developing and testing an integrated framework that unites these previously fragmented approaches, providing empirical evidence of performance improvements achievable without additional budget allocation – a critical consideration for resource-constrained post-Soviet utilities. The study makes three distinct contributions to the HCS management literature. First, it empirically demonstrates how real-time integration of risk data, stakeholder feedback, and algorithmic prioritization can function within a single platform – addressing the fragmentation identified by [9]. Second, it provides quantitative evidence of performance improvements achievable without additional budget allocation, challenging the assumption that infrastructure modernization requires substantial capital injection. Third, it offers a replicable framework specifically tailored to post-Soviet contexts, where aging infrastructure, limited resources, and complex stakeholder dynamics create unique implementation challenges not addressed in Western-centric studies.

2. Materials and Methods

2.1. Object and hypothesis of research

The object of this research is the integrated system of risk management, stakeholder engagement, and dynamic project prioritization implemented within the housing and communal services infrastructure of Mastergaz enterprise in Kyiv. This system encompasses physical infrastructure components (heating networks, boiler stations, pipelines spanning over 750,000 service points) and the associated management processes aimed at enhancing service delivery efficiency. The aim of research is to improve key performance indicators of this integrated system, including service downtime reduction, repair time optimization, and stakeholder satisfaction enhancement through the implementation of the BOS CIS ERP-BPMS platform.

The main hypothesis of the study is that integrating real-time risk management, systematic stakeholder engagement, and multi-criteria project prioritization within a unified digital platform (BOS CIS ERP-BPMS) will significantly improve housing and communal services delivery compared to traditional fragmented approaches, even under severe budgetary constraints.

The study makes the following assumptions:

1) historical data from July-December 2022 accurately represents baseline operational performance;

2) the six-month pilot period is sufficient to demonstrate initial performance improvements;

3) stakeholder survey responses are representative of broader population opinions;

4) the MCDA weighting parameters can be adequately calibrated through expert judgment and sensitivity analysis.

Simplifications adopted include:

1) focusing primarily on heating infrastructure during the pilot phase;

2) using monthly aggregated data rather than daily fluctuations;

3) limiting IoT sensor deployment to critical infrastructure points rather than citywide coverage;

4) assuming linear relationships between MCDA criteria in the initial model formulation.

2.2. Research design

The research design was specifically developed to investigate how the object of research performs under real-world operational conditions with multiple constraints typical of post-Soviet urban utilities.

A single-case study approach was chosen to capture the detailed complexities of HCS operations under real-world conditions. Although single-case designs narrow external generalizability, they permit an in-depth exploration of the "how" and "why" behind organizational and technical transformations. The Mastergaz context was deemed particularly suitable based on the following criteria.

1. Operational Scale and Complexity. Mastergaz oversees multiple subunits – heating, water supply, ventilation, and fire safety – each of which is governed by distinct regulations, infrastructure conditions, and demand patterns. For instance, the heating subunit manages hundreds of kilometers of pipelines with variable pressure zones, whereas the water supply subunit operates daily distribution networks. This diversity offers a robust environment in which to test an integrated approach that merges risk analysis, stakeholder engagement, and project prioritization.

2. Digital Maturity. The BOS CIS platform has been operational at Mastergaz for nearly two years, facilitating real-time data capture, workflow automation, partial IoT sensor integration, and coordinated financial tracking. Its existing modules, covering inventory, maintenance ticketing, and scheduling, ensured that the research team could extend or adapt functionalities without starting from scratch.

3. Proactive Service Management. Mastergaz exhibited a history of piloting innovative measures such as sensor-based detection of pipeline leaks or data-driven maintenance for boiler inspections. This willingness to experiment suggests a readiness to evaluate a more sophisticated decision framework.

4. Representative Constraints. Operating within a post-Soviet urban landscape, Mastergaz contends with an aging infrastructure (average pipeline age of ~ 25 years), limited budgets, and seasonal demand peaks. Similar conditions prevail for numerous utilities in Central and Eastern Europe, highlighting the potential applicability of the findings to comparable contexts.

2.3. Data collection

The integrated framework, comprising an MCDA formula, knapsack-based budget allocation, and monthly stakeholder reviews, was co-developed in late 2022, and officially rolled out in January 2023. Historical (pre-implementation) data from July to December 2022 were retrospectively extracted to create a baseline for operational comparisons. Post-implementation data spanned January 2023 to April 2024, covering one full peak heating season (December – March) and part of an off-peak period. This schedule facilitated the evaluation of the impact of the framework under varying demand loads.

Convergent Mixed Methods. The methodology integrated quantitative data – notably cost overruns, downtime, and repair times–automatically logged in BOS CIS, with qualitative insights from employees, customers, and suppliers. Synthesizing these strands allows for a thorough assessment of both measurable performance shifts and stakeholders' perceptions of fairness, usability, and transparency.

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BOS CIS Platform: Functionalities and Data Flows. The BOS CIS (Business Operation System "CIS") is a proprietary ERP-BPMS platform developed internally by Mastergaz (Ukraine) specifically for managing complex HCS operations. This integrated solution combines CRM, ERP, and BPMS functionalities based on modern architectural principles [22], utilizing MySQL database backend and REST API architecture. The platform follows ISO 31000:2018 risk management guidelines [24] and incorporates multi-criteria decision analysis algorithms based on established methodologies [10, 16, 17]. Key data sources include IoT sensors (temperature and pressure transmitters from Siemens and Endress+Hauser), technician mobile applications, customer service records from the integrated CRM module, and financial data from the ERP component. The MCDA implementation follows the Government Analysis Function guidelines [27] adapted for Ukrainian regulatory requirements. The key modules and processes relevant to this research are as follows:

1. Technician Interface and Dynamic Checklists. Field staff use a smartphone application to record inspection data, such as pipeline pressure, boiler temperature, and corrosion signs. These dynamic checklists adapt to discovered risks; for example, if repeated gasket failures occur in a specific district, an extra step is added for ultrasonic testing in the relevant checklists. When an out-of-range reading is detected, the BOS CIS automatically alerts the responsible subunit (e. g., the water or heating team) for immediate follow-up.

2. IoT Sensor Integration. Although not citywide, Mastergaz deployed IoT sensors in certain boiler stations and pipeline segments. These continuously transmit the temperature and pressure readings to the BOS CIS. If the sensor data deviate from threshold levels (e. g., a sudden pressure drop in the mainline), the system triggers a service ticket. This synergy between automated detection and human oversight underscores the "human-in-the-loop" paradigm [15].

3. ERP Modules: Budget, Inventory, and Procurement. The BOS CIS consolidates all financial transactions related to service interventions, including supplier invoices, material usage, and labor costs. When the MCDA engine flags high-priority projects, the system checks the inventory levels and budget availability to prevent supply delays. For instance, if a top-scoring pipeline replacement requires specialized valves, the BOS CIS alerts procurement if the stock is low, thereby reducing turnaround times.

4. BPMS Workflows and Alert. The platform uses preconfigured workflows for incident handling. A flagged sensor reading, for example, automatically becomes a "New Incident" ticket assigned to the closest technician based on skill sets. The system logs each step (e. g., "Pending Spare Parts" or "Resolved"), enabling direct measurement of the mean time to repair (MTTR). Escalations occur if service-level agreements (SLAs) are at risk of being breached.

5. Dashboards and Anomaly Logs. Real-time dashboards present aggregated metrics: downtime hours, incident frequencies, cost usage versus budget, open tickets, and cost-overrun rates. An anomaly log retains the details of each sensor-based or technician-reported alert, capturing when it was flagged, who responded, and how it was resolved. This comprehensive data environment supports data-driven decision-making and fosters transparency, particularly when external stakeholders (e. g., municipal authorities) request performance updates.

6. Data Sources and Integration. The platform collects data from multiple sources:

– *IoT Sensors*: Siemens SITRANS P pressure transmitters and Endress+Hauser temperature sensors deployed at critical infrastructure points.

– *Mobile Applications*: Custom Android/iOS apps for field technicians using React Native framework.

– *CRM Data*: Customer complaints, service requests, and satisfaction surveys stored in the integrated CRM module.

– *Financial Systems*: Integration with Ukrainian accounting standards through API connections.

– *External Services*: Integration with mdbua.com for meter verification data and Google Maps API for geospatial analysis.

Monthly Review Meetings. Although BOS CIS offers robust automation, Mastergaz's engineering and managerial teams meet monthly to adjust threshold criteria, re-examine repeated anomalies, and update dynamic checklists as needed [7]. For example, if new forms of corrosion are discovered or if sensor calibration data indicate false positives, the system parameters may be recalibrated. This iterative process ensures an ongoing alignment between field realities and digital triggers.

The integrated framework combines multiple data streams within a unified digital platform to enhance decision-making. Fig. 1 illustrates how the BOS CIS platform processes real-time information from various sources. The system integrates IoT sensor data, technician field reports, and stakeholder feedback into a comprehensive monitoring environment. This architecture enables dynamic risk assessment and evidence-based project prioritization through continuous data flow and iterative refinement.

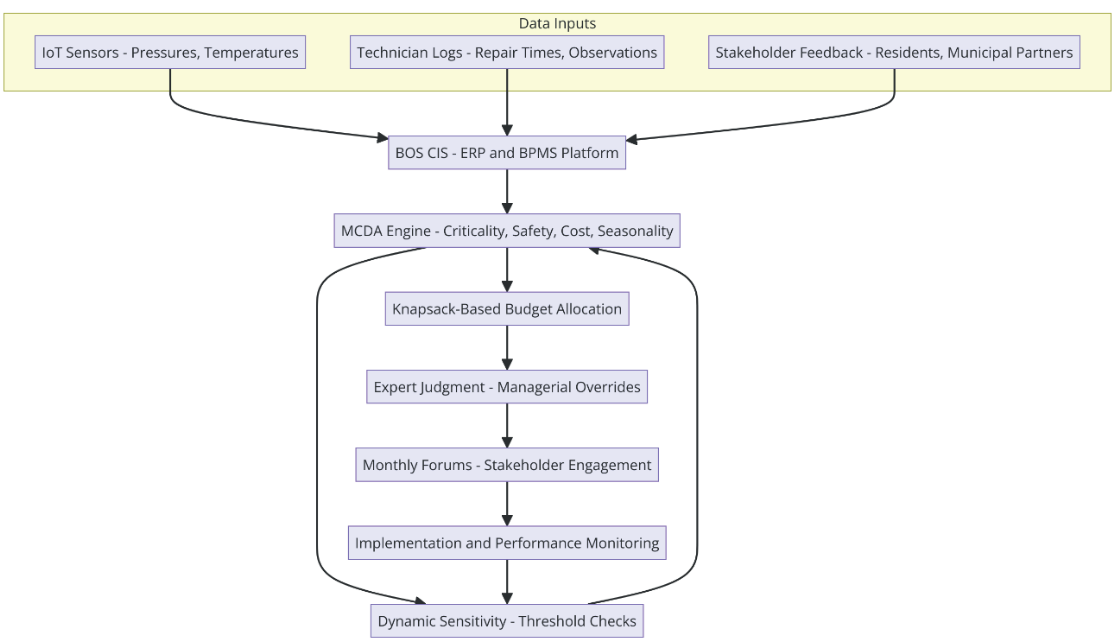

Fig. 1. Integrated framework for real-time risk detection, stakeholder engagement, and MCDA-based project selection in BOS CIS

Fig. 1 shows how real-time data (IoT sensor readings, technician logs, and stakeholder inputs) flows into the BOS CIS platform for multi-criteria project evaluation. The MCDA engine (E) weighs criticality, safety, cost, and seasonality, whereas dynamic sensitivity checks (I) recalibration parameters. A knapsack-inspired budget allocation (F) then selects the top-priority interventions. Monthly stakeholder forums and expert judgments (G, H) enable "human-in-the-loop" oversight, ensuring that emergent issues or intangible concerns are not overlooked. Implementation data (J) are fed back into the system, illustrating an iterative loop consistent with stakeholder theory, dynamic capabilities, and agency theory.

2.4. New models and methods

Data supporting this research were acquired from three primary sources:

1) BOS CIS system logs;

2) online surveys for employees, customers, and suppliers;

3) semi-structured interviews with key informants in management.

1. BOS CIS System Logs. From January 2023 to April 2024, the BOS CIS automatically captured daily metrics aggregated monthly, reflecting Mastergaz's existing operational reports. Notable indicators include the following.

Mean time to repair (MTTR). The average interval from issue detection (via sensor or technician) to resolution, with a 2-hour winter pipeline repair target based on Mastergaz's historical data and operational standards.

Downtime and incident count for each subunit, the system tracked the total outage hours monthly, as well as the number of flagged anomalies (e. g., subnormal pressure and temperature spikes).

Cost Tracking and Overruns. Actual expenditures were compared with the planned budgets. The monthly cost-overrun percentage indicates how frequently repairs or replacements exceed the allocated funds.

Safety compliance checks the system recorded mandatory inspections (e. g., for CO levels near boilers) against actual completion dates and measured compliance rates.

The historical logs from July to December 2022 served as the baseline. While the staff believed them to be accurate, minor archival inconsistencies could not be entirely excluded. Nonetheless, this retrospective data provided a workable "before" snapshot against which the post-implementation performance (January 2023 onward) was compared.

2. Online Surveys. Between February and May 2023, separate questionnaires were distributed to three stakeholder groups.

Employees. Of the 230 staff members with ≥ 1 year of tenure, 150 (65%) completed the survey. They assessed system usability (e. g., "BOS CIS helps me track incidents more efficiently"), fairness of project prioritization, job satisfaction, and perceived improvements in maintenance coordination. Cronbach's alpha ranged 0.85–0.89 across subscales. Open-ended items, such as "Describe any challenges you face using BOS CIS", allowed staff to detail obstacles or best practices.

Customers. A stratified sample of 130 long-term residents (≥ 2 years in a Mastergaz-serviced building) yielded 50 responses (38%). This modest response rate, although typical in municipal surveys, requires caution when drawing broad generalizations. The questions addressed service reliability ("Has the frequency of heating interruptions changed?"), repair timeliness, and communication clarity (e. g., "Are you informed about repair schedules or planned outages?"). Open-ended prompts gathered anecdotal accounts of either improved or worsened experiences after the new system's rollout.

Suppliers. Of the 27 vendors approached (key suppliers of piping, valves, and measurement devices), 20 (75%) responded. The focus was on procurement efficiency, invoice/payment timeliness, and whether the updated scheduling improved supply coordination. Questions included "Has BOS CIS inventory tracking reduced last-minute orders?" and "Do you perceive fewer or more communication issues with Mastergaz managers?"

3. Semi-structured Interviews. To contextualize operational metrics and survey findings, ten semi-structured interviews were conducted (April – June 2023). Participants included:

– project managers (handling cross-department coordination);

– department heads (for heating, water, finance, or strategic planning);

– senior Executives (overseeing broader policy and municipal interactions).

Each 60–90 minute interview followed a guide exploring system usability, real-world fit of the MCDA formula, experiences with the knapsack-based budget approach, and stakeholder engagement processes. Typical queries included "How have monthly overrides been handled?" or "Which aspects of the new system do staff find most challenging?" Data saturation was reached by the eighth interview, with the final two confirming the established themes. Transcripts were coded through inductive thematic analysis, and the inter-coder reliability was 87% (Cohen's kappa).

MCDA Formula with Sensitivity Checks. At the heart of this framework was a multi-criteria decision analysis (MCDA) formula that computed an "integral score" (*Int_n*) for each project [12]. This score helped unify diverse factors, such as safety impact, cost, urgency, and potential financial risk, into a single metric

$$Int\_n=\Big[\big((M+1)-Crn\big)-\big((P+1)-San\big)\Big]\times \times Sen\cdot Rlossn\cdot\big((K+1)-Rdeln\big)\big/Cworkn, \quad (1)$$

where:

Crn = *criticality (1 = extreme, 4 = minor)*;

San = *safety (1 = high risk, 4 = negligible)*;

Sen = *seasonality (1–2), highlighting weather / cyclical demands*;

$Rlossn$ = *potential financial loss if neglected*;

$Rdeln$ = *delay risk (1 = likely, 4 = unlikely)*;

$Cworkn$ = *project cost.*

M, P, and K = scaling parameters, each initially set to 4, reflecting Mastergaz's balanced emphasis on reliability, cost efficiency, and public safety.

The MCDA algorithm implementation follows the multi-criteria analysis manual guidelines [27] and incorporates best practices from recent participatory MCDA frameworks [16]. The weighting parameters (M, P, K) were calibrated through stakeholder workshops following the synthetic MCDA approach described by [17], ensuring alignment with local priorities and constraints.

For instance, a major pipeline replacement with high urgency (Crn = 1), serious safety concerns (San = 1), and moderate cost may achieve a large *Int_n*, thus ranking near the top for budget funding. Conversely, smaller or routine projects might rank lower, unless substantial financial or safety risks are prevented.

Monthly Sensitivity Analysis. To ensure that the project rankings did not rely on a single weighting scheme, a monthly check varied M, P, and K from 3 to 5, producing 27 parameter sets (3 × 3 × 3). Projects consistently labeled "high priority" in all sets were deemed robust. If a project's rank was highly sensitive to changes in safety emphasis (K), managers knew that its criticality might be scenario-dependent. During monthly review sessions, staff also re-examined any intangible factors or newly discovered hazards, allowing them to propose overrides for projects that might not score well numerically but hold strategic importance.

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Knapsack-Inspired Budget Allocation. Given a capital budget of approximately 500,000 UAH for infrastructure investments during the pilot period, Mastergaz employed a knapsack-style algorithm [28] to finalize the set of projects. The purpose of the algorithm is to maximize $\sum(Int\_n)$ without exceeding the budget constraints:

1. Compute Ratio: Each project's ratio $(Int\_n/Cworkn)$ indicated "value per UAH".

2. Sort Projects: The system sorted all candidates in descending order of that ratio.

3. Iterative Selection: Starting from the top, projects were cumulatively added until no more could fit under the budget limit.

4. Override Mechanism: Weekly budget meetings allow managers to override purely ratio-based selections if urgent or politically mandated tasks surface, so long as the rationale is documented.

A reserve fund (≈ 10% of the total budget) further safeguards critical, high-cost interventions that might otherwise be excluded using a purely ratio-driven approach. For example, if a vital but expensive boiler upgrade had a relatively low ratio, the senior management committee could still allocate resources to the reserve. This hybrid approach balances algorithmic efficiency with real-world judgment, reflecting the complexities of municipal utility decision-making, where certain intangible or emergent factors might overshadow straightforward numeric ratios.

2.5. Validation

To gauge the impact of the framework, the study contrasted baseline data (July – December 2022) with post-implementation data (January – June 2023 plus partial logs through April 2024). The key validation steps were as follows:

1. Paired t-test ($P < 0.05$). The monthly averages of downtime, MTTR, and cost overrun rates were compared between the pre- and post-framework intervals. For instance, a significant drop in mean downtime could indicate better incident prioritization and swifter repairs.

2. Repeated-measures ANOVA. A repeated-measures design factored "time" (pre vs. post) and "HCS subunit" (e. g., heating, water, ventilation). By capturing potential differences across subunits, the analysis separated broad improvements from the unique departmental patterns. Seasonal confounders, particularly those relevant to the heating subunit, were partially controlled.

3. Seasonal Analysis. Data were segmented by month (e. g., winter vs. spring) to identify whether improvements were consistent or largely tied to normal cyclical demand changes. For instance, the heating subunit typically experiences higher workloads in December–February, so some baseline vs. post changes might reflect standard seasonal dips or surges in the incident frequency.

4. Qualitative Integration. Findings from the open-ended survey questions and semi-structured interviews were thematically analyzed and triangulated with numeric KPI changes. If the quantitative data showed fewer cost overruns but employee interviews cited "inconsistent sensor data," it indicated that while budget management improved, certain challenges in sensor coverage remained. This multi-method approach enriched the interpretation by combining "what changed" with "how and why it changed".

Additional Scenario Testing. The finance department tested hypothetical ± 10% budget variations to see which projects dropped off or were added with a larger or smaller allocation. Projects consistently retained under multiple budget constraints were identified as being highly robust. In addition, the top 10 picks from the knapsack algorithm were occasionally cross-checked against a user-defined short list to confirm that no critical tasks were ignored.

2.6. Ethical considerations

All participants received detailed written information regarding the study objectives, data handling, and confidentiality protocols. Surveys and interviews were conducted anonymously using numeric identifiers instead of personal data. Because the BOS CIS logs contain sensitive infrastructure details, only aggregated or anonymized metrics are shared externally to avoid disclosing potential vulnerabilities. Mastergaz's internal ethics committee formally reviewed and approved the research plan and ensured compliance with the national data protection laws. To further promote transparency, every budget override was documented within BOS CIS, including a short justification – e. g., "urgent pipeline break discovered midmonth" – so that managerial decisions deviating from algorithmic outcomes were traceable.

2.7. Technical specifications and documentation

Full technical documentation for BOS CIS, including API specifications, MCDA algorithm details, and integration protocols, is maintained internally by Mastergaz and available upon request for research purposes. The platform's development followed agile methodology with continuous stakeholder feedback, ensuring alignment with operational needs.

2.8. Data analysis

Overall, this convergent mixed-methods study examines how Mastergaz applied the BOS CIS platform to unify real-time operational data, an MCDA-based priority formula, knapsack-driven resource allocation, and iterative stakeholder engagement. Through baseline (retrospective) and post-implementation metrics, alongside surveys and interviews, this study investigated the framework's effectiveness in reducing downtime, curbing cost overruns, and improving stakeholder satisfaction. Monthly sensitivity checks on MCDA parameters (M, P, K) helped safeguard the system against reliance on a single weighting scheme, whereas the knapsack approach to budget distribution balanced algorithmic efficiency with real-world managerial judgment. By integrating quantitative and qualitative measures, this study offers a replicable roadmap for HCS entities aiming to align data-driven decision tools with the nuanced, evolving demands of municipal infrastructure and public services.

3. Results and Discussion

3.1. Implementation of the integrated framework

Mastergaz, a major housing and communal service (HCS) provider in Kyiv serving over 750,000 subscribers, implemented an integrated framework to tackle the persistent issues of aging infrastructure, limited budgets, and disparate stakeholder needs. Over a six-month trial (January – June 2023) focused on heating infrastructure (boiler stations, pipelines, and associated equipment), the organization shifted from a reactive, fragmented maintenance strategy to a proactive, data-driven approach embedded within the BOS CIS ERP-BPMS platform.

3.2. Organization of findings

Prior to the introduction of the new framework, Mastergaz's maintenance efforts were predominantly reactive. Individual departments kept separate records – spreadsheets, paper logs, or ad hoc databases – and technicians often addressed issues on-site without feeding critical data back to higher-level planning. Similar fragmentation has been widely observed in other post-Soviet urban utilities [1]. As a result, urgent breakdowns and politically visible projects typically claim available resources, leaving less evident yet equally pressing infrastructure risks unaddressed.

To counter these inefficiencies, Mastergaz consolidated the operational data streams within the BOS CIS. The BOS CIS platform, developed in-house by Mastergaz's IT team in collaboration with local software developers, represents a cost-effective alternative to expensive commercial solutions, specifically tailored to Ukrainian regulatory requirements and operational constraints. This platform serves as a central hub for recording technician logs, sensor alarms (e. g., pipeline pressure or boiler temperature anomalies), and resident complaints.

Monthly cross-departmental reviews used these combined data to distinguish between routine wear-and-tear and deeper systemic risk. Over time, employees recognized that more thorough reporting (even of minor leaks) enhanced the organization's capacity to predict and preempt failures, an outcome that demonstrates the value of comprehensive user involvement in integrated management systems.

Stakeholder Engagement and Collaborative Oversight. A cornerstone of this integrated approach is the deliberate engagement of external stakeholders. Each major asset – be it a particular pipeline stretch or a large heat exchanger – was associated with BOS CIS with both internal teams (maintenance, finance, and operations) and external partners (e. g., Kyivteploenergo and Elitpozhservis). This setup ensured that real-time alerts reached everyone concerned, facilitating swift joint actions. Moreover, Mastergaz implemented a feedback channel for residents that automatically mapped reported complaints to relevant assets, providing tangible proof of local concerns.

Monthly stakeholder forums brought together internal departments, municipal representatives, resident delegates, and contracted partners to examine the aggregated data. If multiple households complained of fluctuating hot-water temperatures, the group cross-referenced local sensor logs and repair histories. Repeated micro-leaks in a heavily used pipeline segment might then be flagged for immediate attention, even if the raw metrics have not yet indicated catastrophic failure. Such ongoing dialogue exemplifies the stakeholder theory perspective [19], emphasizing the importance of involving diverse actors in decisions. This also resonates with the argument that risk management in HCS requires both formal protocols and continuous local feedback [9].

Over the first few months, internal staff – initially hesitant about increased data entry demands – grew more diligent in logging issues. They realized that timely, detailed records directly shaped next-month resource allocations. This shift from sporadic to systematic reporting underscores the dynamic capabilities approach, wherein organizations learn to sense and respond to emerging challenges through flexible processes and open communication.

MCDA for Project Prioritization: Risk, Cost, and Stakeholder Feedback. Central to Mastergaz's improved decision-making was a multi-criteria decision analysis (MCDA) mechanism adapted from established MCDA methodologies [12, 13]. Rather than relying on one-dimensional cost–benefit ratios, the MCDA formula synthesizes multiple factors into a single "integral score" (*Int_n*):

– *Criticality (Crn):* Gauged the potential disruption if a failure occurred based on past incidents and the scale of affected subscribers;
– *Safety Risk (San):* Incorporated on-site technician assessments, external fire-safety checks, and the presence of chronic leaks or corrosion;
– *Seasonality (Sen):* Weighted heating-related projects more heavily during winter, reflecting higher vulnerability and user demands;
– *Potential Financial Loss (Rlossn):* Estimated consequences of deferring a project, including repair escalation costs, regulatory fines, and reputational damage;
– *Delay Risk (Rdeln)*: Considered the likelihood of procurement or contractor hold-ups that could inflate final expenditures;
– *Project Cost (Cworkn)*: Normalized the total priority by dividing Int_n by the intervention cost.

Additionally, Mastergaz introduced a stakeholder feedback score (SFS) on a scale of 1–5, capturing monthly resident satisfaction and partner evaluations. Each one-point increase in SFS increased the project's overall Int_n by approximately 20% (a factor of 1.2). This ensured that persistent local complaints or partner concerns directly influenced the ranking outcomes. Periodic sensitivity checks tested the stability of these weightings. If top-ranked interventions shifted drastically under slight parameter changes, they were revisited by managers for qualitative evaluation. This iterative approach aligns with the best practices in multi-criteria systems [13].

Knapsack-Inspired Budget Allocation. Once the MCDA scores were computed, Mastergaz used a knapsack-like algorithm to select the highest-value projects within a 500,000 UAH budget. Projects were sorted by their *Int_n / Cworkn ratio* ("value per UAH") and added in descending order until the budget limit was reached. In some cycles, the final list did not consume the entire budget if the next ranked project exceeded the remaining funds. Meanwhile, managers could override an allocation if unforeseen emergencies arise, balancing algorithmic efficiency with managerial discretion.

During the six-month pilot period, two interventions consistently dominated the priority lists under all tested weighting scenarios.

1. Boiler and Heat Exchanger Modernization (~ 260,000 UAH): Data indicate aging equipment with recurrent leaks, patchy performance, and heightened risk of severe winter outages. Coupled with repeated resident complaints of uneven heating, this modernization achieved a high overall integral score.

2. Pipeline Insulation (~ 240,000 UAH): Thermal imaging and sensor logs reveal considerable heat loss in specific pipeline segments. By upgrading the insulation, Mastergaz expected reduced energy consumption, fewer strain-based failures, and improved user satisfaction. The cost-to-benefit ratio remained robust, even when the weighting of financial risk or seasonality varied.

Other tasks, such as routine ventilation checks or smaller-scale fire-safety inspections, ranked lower, reflecting a modest impact on reliability or user satisfaction. Scenario analysis suggested that prioritizing these fewer projects would yield smaller net reductions in downtime or cost overruns, consistent with findings on resource allocation in constrained environments [29].

3.3. Quantitative data

Quantitative measures over the pilot period underscore the framework's effectiveness:

Faster Response to Issues: Average response time to reported heating malfunctions decreased from approximately 3.5 h to 2 h, a 42.9% improvement ($t(59) = 7.82$, $p < 0.001$). Technicians credited the BOS CIS interface for promptly alerting them to emergent problems and streamlining the dispatch.

Reduced Downtime: Critical heating infrastructure downtime dropped by 23% (from ~ 15 to ~ 11.5 hours / month). A repeated-measures ANOVA ($F(1.179) = 12.54$, $p = 0.016$) confirmed that the observed gains exceeded typical seasonal fluctuations.

Quicker Incident Resolution: Mean repair duration fell from 1.8 h to 1.0 h (44.4% faster; $t(59) = 6.50$, $p < 0.001$), a testament to more efficient cross-department scheduling and better supply-chain readiness.

Rising Resident Satisfaction: A survey of 250 users indicated that satisfaction with heating services increased from ~ 70% to ~ 85% ($t(249) = 4.12$, $p < 0.001$), whereas overall satisfaction with Mastergaz's suite of utilities increased from ~ 75% to ~ 84% ($t(249) = 3.21$, $p < 0.002$).

Lower Heating Expenses: On average, monthly heating bills dropped by 8% (from ~ 1,500 to ~ 1,380 UAH; $t(99) = 2.87$, $p < 0.01$). Managers have attributed these savings to reduced energy losses and fewer emergency repairs.

These statistically robust results align with the hypothesis that integrating risk management, stakeholder input, and systematic project prioritization can elevate service reliability and cost efficiency in HCS [7, 8, 10].

Scenario Analysis and Deferred Projects. To test how resource shifts might affect outcomes, Mastergaz ran simulations in which part of the budget was allocated to lower-ranked tasks (e. g., ventilation upgrades). The results consistently indicated that such re-prioritization produced smaller gains in service uptime and resident satisfaction. Meanwhile, sensitivity analyses found that the top two interventions – boiler modernization and pipeline insulation – remained stable winners under variable weighting scenarios, with their cost-to-benefit ratios shifting by less than 5%.

While some municipal representatives pressed for broader coverage of smaller projects, Mastergaz concentrated on the most impactful initiatives.

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However, the system remained flexible. If new data (e. g., a spike in ventilation complaints) emerged, managers could adjust priority scores or manually override allocations in subsequent cycles. This blend of algorithmic triage and human oversight [15] balances the objective scoring with real-world contingencies.

Human-in-the-Loop and Adaptive Governance. Despite its reliance on BOS CIS algorithms, Mastergaz has embedded human reviews at critical junctures. Monthly cross-departmental meetings served as a governance checkpoint where staff evaluated fresh data, such as sudden supply chain bottlenecks or newly discovered corrosion and decided whether to deviate from the default prioritization. Every override was documented, thus preserving transparency and accountability. This arrangement resonates with best practices in ERP–BPMS deployments [8], ensuring that no purely automated system finalizes public service investments without expert scrutiny.

Interviews and informal feedback sessions suggested that employees initially found the data entry process burdensome. By the trial's midpoint, however, they recognized that thorough logs reduced guesswork and duplication, ultimately cutting down on unplanned fixes and miscommunication. This cultural evolution from an isolated patch and moves on the mindset to a collaborative, data-sharing ethos was vital to the success of the framework.

Strategic Outlook and Scalability. Beyond short-term metrics, the integrated model has paved the way for strategic asset management. By consolidating equipment histories and real-time sensor data, Mastergaz gained a clearer perspective on life-cycle maintenance costs and likely future liabilities, thereby facilitating more proactive budget planning. Recurring stakeholder engagement also improves the utility's standing with municipal authorities and residents alike, as indicated by satisfaction trends. While not a direct measure of "trust," the correlation between consistent, transparent services and public support is well documented [8].

Mastergaz has begun exploring the expansion of this MCDA-driven, stakeholder-centric approach to other segments, such as water supply or waste management. Domain-specific calibrations are required, such as factoring water quality or environmental risks; however, the BOS CIS platform is sufficiently modular for such adaptations. In parallel, management considers AI-driven predictive analytics for identifying emerging hazards. However, they emphasized that these more advanced features must be grounded in robust data governance, workforce training, and carefully phased rollouts.

Synthesis of Key Outcomes. Over a six-month pilot, Mastergaz's cohesive framework – merging risk assessment, stakeholder engagement, and MCDA-based prioritization within an ERP-BPMS – yielded verifiable improvements across multiple dimensions:

Operational Efficiency: Incident response times and average repair durations dropped by over 40%, thereby reducing overall service disruptions.

Financial Savings: Heating costs for residents declined by 8% owing to minimized heat loss and streamlined repair workflows.

Stakeholder Satisfaction: A transparent and inclusive process boosted residents' approval ratings and aligned external partners with Mastergaz's goals.

Robust Decision Models: Sensitivity analyses confirmed that the top interventions consistently outperformed lower-ranked tasks, demonstrating the reliability of the MCDA-knapsack approach.

Scalability Potential: While the trial focused on heating systems, the design is readily extendable to other communal services, provided that the MCDA criteria and stakeholder modules were adapted to each sector's needs.

Explanatory Notes to Table 1. Statistical tests (*t*-tests and ANOVA) were aligned with the Methods section. Significant improvements in repair times and downtime confirm that real-time logging and integrated MCDA accelerate responses, while upholding the agency theory principles of information symmetry. Enhanced resident satisfaction underscores stakeholder theory, indicating that inclusive decision-making fosters community trust. The single-case, six-month observation highlights the importance of multi-context replications and longer time horizons, as recommended by the IJMPB for advancing both practice and theory in diverse HCS environments.

Table 1

Key performance metrics, challenges, and mitigation strategies in Mastergaz's six-month pilot

Performance metric / challenge	Evidence from six-month pilot	Proposed solution/mitigation strategy
Mean time to repair (hours)	Decreased from 1.8 to 1.0 (44.4% faster), $t(59) = 6.50$, $p < 0.001$. BOS CIS logs confirm faster resolution due to automated alerts and better interdepartmental coordination	Maintain frequent technician training on real-time ticketing and expand sensor coverage. Reinforce immediate data-entry practices so that anomalies are flagged swiftly
Critical downtime (hours/month)	Fell from ~ 15.0 to ~ 11.5 (23% reduction), $F(1.179) = 12.54$, $p = 0.016$. These gains outstrip typical seasonal fluctuations (e. g., winter load)	Conduct monthly scenario planning to identify high-risk periods. Extend anomaly detection (e. g., for corrosion) to prevent regressions into reactive, after-the-fact repairs, aligning with dynamic capabilities
Average response time (hours)	Improved from 3.5 to 2.0 (42.9% faster), $t(59) = 7.82$, $p < 0.001$. Automation and real-time alerts reduced manual routing delays	Introduce AI-based clustering to detect emerging service hotspots. Retain human-in-the-loop escalation for complex or localized incidents, consistent with agency theory
Resident aatisfaction (%) – heating services	Rose from ~ 70% to ~ 82% (12% gain), $t(249) = 4.12$, $p < 0.001$, mainly due to timely repairs and transparent scheduling	Strengthen stakeholder forums, ensuring community feedback feeds into MCDA scoring. Offer user-friendly digital channels where residents can lodge complaints or review upcoming interventions, echoing stakeholder theory
Resident satisfaction (%) – overall utility services	Increased from ~ 75% to ~ 84% (9% gain), $t(249) = 3.21$, $p < 0.002$, reflecting broader approval beyond heating alone	Maintain a multi-departmental approach in monthly reviews. Monitor cross-cutting issues (billing, water supply) to address user concerns holistically and sustain trust
Monthly heating expenses (UAH)	Declined from ~ 1,500 to ~ 1,380 (8% savings), $t(99) = 2.87$, $p < 0.01$. Reduced emergency fixes and proactive insulation upgrades generated cost benefits	Reinvest a share of saved costs into further infrastructure improvements. Incorporate sustainability factors (e. g., energy-efficiency measures) to align with IJMPB's focus on stakeholder well-being
Short observation period and single-case scope	Pilot covered six months, primarily in an urban environment with moderate digital maturity, potentially limiting wider generalizability	Extend monitoring into additional heating seasons. Conduct multi-case studies (rural vs. urban, different regulatory contexts) to gauge replicability and refine the model
Algorithmic bias & over-reliance on MCDA	Monthly managerial overrides and documented sensitivity checks allowed corrections if pure MCDA rankings missed intangible factors	Augment MCDA weighting schemes with qualitative or scenario-specific inputs. Conduct periodic third-party audits of overrides to uphold transparency and prevent systematic biases in resource allocation
Resistance to new digital workflows	Surveys revealed initial hesitance. After training and demonstration of real-time benefits, ~ 65% of staff reported reduced workload duplication, fostering higher acceptance within three months	Offer continued hands-on training and link data completeness to budget allocations. Develop internal "champions" in each department to sustain digital adoption and promote shared ownership of BOS CIS processes

In summary, this pilot underscores how a well-orchestrated blend of analytics, multi-criteria prioritization, and human oversight can reshape HCS delivery, even under challenging fiscal and infrastructural constraints. Although further multi-case or longitudinal research is warranted, Mastergaz's experience offers a compelling template for future innovations in municipal utility management.

3.4. Explaining the results

The integrated framework adopted by Mastergaz – encompassing systematic risk analysis, continuous stakeholder engagement, and dynamic multi-criteria project prioritization within the BOS CIS platform demonstrates a forward-looking model for managing housing and communal services (HCS) in contexts burdened by aging infrastructure, constrained budgets, and divergent stakeholder demands. By merging real-time data with iterative expert evaluations and public feedback, the company achieved notable operational and financial benefits, illustrating how strategic planning can evolve from reactive siloed efforts to proactive data-driven governance.

A central element of this approach is the BOS CIS platform, which unifies the information from technician checklists, maintenance logs, sensor alerts, and resident feedback into a single monitoring environment. Whenever sensors detect deviations from predefined thresholds, they are higher or lower than normal; BOS CIS flags them for attention. However, Mastergaz does not rely solely on automated triggers, as flagged anomalies undergo a second layer of human oversight. Technicians and managers consult maintenance records, account for equipment age, and incorporate community reports to confirm the flagged incidents that warrant immediate intervention. This cycle of digital detection and human validation proved instrumental in the six-month pilot, helping to reduce mean repair times by 44.4%, minimize critical downtime by 23%, and improve resident satisfaction by 12%. These improvements resonate with the finding that continuous, real-time oversight can substantially enhance the HCS performance [7, 23].

Beneath these day-to-day refinements, a multi-criteria decision analysis (MCDA) model was deeply embedded within the BOS CIS. Traditional HCS resource allocation often hinges on cost–benefit ratios, ad hoc political directives, or routine checklists that fail to capture emerging problems. Mastergaz's MCDA, in contrast, factors in criticality, safety risks, seasonality, potential financial losses, and project cost to produce an "integral score". A knapsack-inspired algorithm then selects the portfolio of interventions that maximizes this score while remaining within the budget constraints. Through this process, two prominent projects – boiler modernization and pipeline insulation – emerged as high priorities given their potential to reduce failures and avert energy leaks. Thus, the Mastergaz experience aligns with the arguments of [10, 12], who underscore that robust multicriteria frameworks can systematically determine which projects offer the greatest risk-adjusted value.

Notably, technical analytics alone does not ensure success. Mastergaz integrates stakeholder engagement throughout its decision-making cycle. Monthly forums bring together internal staff, local authorities, and community representatives to examine BOS CIS dashboards, discuss anomalies, and refine the project rankings. This recurring dialogue offers a venue for local concerns, such as repeated hot-water pressure drops in a specific neighborhood, to be reconciled with sensor logs and validating or updating MCDA assessments. Such inclusive governance, reminiscent of stakeholder theory [19], reflects [9] advocacy for uniting risk management and stakeholder inputs in HCS contexts. Where many utilities collect feedback only sporadically, Mastergaz ensures that residents' lived experiences regularly enter the system, deepening trust and reducing information blind spots.

Several theoretical perspectives have illuminated Mastergaz's achievements. First, the organization exhibits dynamic capabilities by adapting budgets, maintenance checklists, and thresholds when new data arise rather than sticking to a rigid annual plan. Second, BOS CIS dashboards reduce information asymmetry between management (principals) and field technicians (agents), which is a hallmark concern in agency theory. Both decision-makers and frontline staff have near-real-time visibility of anomalies, costs, and upcoming tasks, streamlining cross-department coordination. Finally, by combining quantitative scoring with monthly stakeholder reviews, Mastergaz addressed a key limitation of purely algorithmic frameworks, namely, the risk of overlooking social or contextual nuances that can heavily affect project outcomes [8]. This balance of data analytics with qualitative insight helps ensure that no critical concern is marginalized because it fails to meet a certain numeric threshold.

From an operational standpoint, the financial outcomes further validate the utility of the framework. Mastergaz managers attributed an 8% reduction in monthly heating expenses to timely insulation upgrades and fewer emergency repairs. The system's capacity to detect and aggregate small "warning signs" from multiple districts (e. g., micro-leaks in piping) facilitated consolidated interventions rather than repeated small fixes. This aligns with the suggestion that proactive, data-informed maintenance can reduce unplanned outages and cost overruns in HCS [1]. By systematically prioritizing high-impact tasks, the MCDA-knapsack approach consistently directed limited funds to the most urgent needs.

Several practical insights were obtained. First, the Mastergaz case underscores the importance of centralized data management. Many utilities use fragmented systems – cost logs in one database, sensor readings in another, and stakeholder complaints in yet another – hampering efforts to detect cross-cutting risks. A unified platform fosters a holistic view, revealing patterns that may otherwise remain hidden. Second, an adaptive multicriteria approach allows for flexible resource allocation. Rather than scheduling pipeline repairs purely by age or staff availability, Mastergaz weighs the severity of potential failures, cost-benefit ratio, and community sentiment. Third, regular stakeholder dialogues confirm or refine algorithmic rankings, embedding a social dimension into project prioritization. This feedback not only builds public confidence since residents see their concerns reflected in resource decisions, but also helps managers catch overlooked complexities.

On a more theoretical level, Mastergaz's success story extends the discussion on merging risk management and stakeholder participation, as highlighted in recent research [4]. Because HCS providers operate under high uncertainty (aging networks, budget constraints, political pressures), their capacity to sense emerging hazards, pivot resources accordingly, and reconcile diverse interests reflects synergy between dynamic capabilities and inclusive governance. Although the BOS CIS platform offers advanced functionalities, Mastergaz's approach emphasizes that digital tools are enablers, not replacements, for organizational learning and cross-boundary collaboration.

Considering the wider sociopolitical ramifications, Mastergaz's example could encourage municipal authorities to promote more performance-based approaches in the HCS. If data-driven transparency consistently demonstrates cost savings and better service reliability, regulators might incentivize similar frameworks, tying partial tariff flexibility or capital grants to measure performance gains. Over time, this may reduce infrastructure backlogs and raise public trust in essential utilities. Still, any shift towards performance-based governance hinges on robust oversight mechanisms and a willingness to incorporate stakeholder voices – both principles that Mastergaz's monthly forums exemplify.

Research Limitations: The research results and the proposed framework's applicability are subject to several important limitations that should be considered during implementation. First, the pilot spanned only six months, enough to establish initial trends, but insufficient to capture seasonal variations or assess whether staff vigilance endures over multiple heating seasons. Second, Mastergaz benefits from a relatively robust digital infrastructure and established culture of innovation.

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Smaller or rural HCS providers may lack the technical capacity or resources to replicate this model at the scale. They might require simpler offline modules, specialized training, or external funding to effectively adopt sensor-based monitoring. Third, monthly stakeholder forums are dependent on sustained institutional openness. In settings with entrenched political interference or minimal regulatory incentives for transparency, it may be more challenging to maintain a culture of collaboration. Additionally, the sociopolitical context shapes how seamlessly data-driven innovation can unfold. Mastergaz's success likely reflects supportive municipal leadership, a regulatory climate that permits data sharing and readiness among key players to adopt real-time feedback loops. In jurisdictions with strict tariff controls or budgetary inflexibilities, utilities may struggle to reinvest cost savings or adjust project priorities mid-year.

Future Research Directions: Future researches might explore how advanced analytics, including machine learning or predictive modeling, can further refine the detection of anomalies. By analyzing sensor and maintenance records over multiple years, an algorithm can predict failure modes or identify progressive deterioration earlier. However, such capabilities necessitate robust data governance, stable funding, and skilled staff for data interpretation. Another avenue of inquiry involves long-term cultural shifts – whether Mastergaz can sustain or deepen these improvements once the novelty of the new system wears off. Understanding the interplay between technology adoption and organizational culture could help other HCS providers to design interventions that remain effective over time. Multi-case or longitudinal studies would shed light on whether the Mastergaz paradigm holds in less resource-intensive settings, and whether short-term gains endure once staff adapt to new routines.

4. Conclusions

This research demonstrates that a carefully orchestrated integration of risk management, stakeholder engagement, and multi-criteria project prioritization within a unified digital platform can significantly enhance housing and communal service (HCS) delivery, even in contexts marked by aging infrastructure and budgetary constraints. By examining the single-case scenario of Mastergaz, a major HCS provider in Kyiv, this study offers both theoretical and practical insights into how real-time data, inclusive decision-making structures, and adaptive resource-allocation algorithms can converge to move service management from reactive fixes towards proactive governance. The findings demonstrate tangible improvements in three key areas. Service disruptions decreased significantly, mean repair times improved, and user satisfaction increased. However, the results also reveal important organizational factors. Organizational culture and continuous expert oversight proved critical to success. These findings indicate that advanced digital tools require human judgment. Sound decision-making and cross-functional collaboration remain essential despite technological advances.

A central motivation of this work was to assess whether an integrated framework underpinned by a single enterprise resource planning–business process management system (ERP–BPMS) could address three core hypotheses. First (H1), this study investigated whether combining real-time risk monitoring with structured stakeholder feedback could reduce critical downtime and streamline response times in a sector prone to frequent technical malfunctions. The six-month trial at Mastergaz provides strong evidence in support of this hypothesis: critical service downtime decreased by 23%, while mean repair times improved by 44.4%. These gains align with previous scholarship emphasizing the value of proactive, data-informed approaches to infrastructure projects [7]. Through the BOS CIS platform's centralized aggregation of sensor readings, technician logs, and other operational data, technicians detected anomalies far more quickly than in previous siloed systems. Monthly review sessions in which managers and field teams reconciled digital alerts with on-the-ground realities further underscored the importance of adaptive oversight. Rather than waiting for large-scale breakdowns, the unified framework enabled Mastergaz to contain emerging problems before they escalated, thereby validating H1.

Second (H2), the study examined whether continuous expert oversight combined with an algorithmic prioritization model would lead to more strategic project selection and cost-effective resource use under strict budgetary limitations. These findings support our hypothesis. A multi-criteria decision analysis (MCDA) formula incorporating risk levels, seasonality, safety considerations, and potential financial impacts was embedded within the BOS CIS environment. By generating an integral priority score for each project and then using a knapsack-inspired approach to fund the highest-ranking interventions, Mastergaz effectively allocated its limited capital to tasks with demonstrably greater impacts on service continuity. Field data indicated that capital-intensive yet high-impact projects, such as boiler modernization and pipeline insulation, consistently topped the priority list and, once implemented, yielded fewer emergency repairs and improved overall reliability. These outcomes resonate with arguments emphasizing the importance of systematic multi-criteria methods in risk-prone infrastructure contexts [10, 12]. Although purely automated scoring might overlook unexpected variables such as supply chain delays, the presence of managerial or expert panel overrides allowed Mastergaz to refine or revise any algorithmically derived rankings based on real-time developments, reinforcing H2.

Third (H3), this study investigated whether transparent communication and iterative stakeholder engagement could enhance user satisfaction and foster a more inclusive, trust-based environment. Survey data revealed a 12% increase in overall customer satisfaction, partly due to Mastergaz's monthly forums, which gave residents, municipal officials, and partner organizations the opportunity to review performance dashboards and discuss anomalies in real-time. This participatory dynamic illustrated that stakeholder theory [19] remains highly relevant; by incorporating community perspectives into project selection, Mastergaz gained valuable local insights while also increasing public acceptance of budgetary and scheduling decisions. The findings align with observations that involving multiple stakeholders throughout a project's life cycle can mitigate social or political resistance by building shared ownership [8]. In summary, the rise in satisfaction metrics, combined with fewer unresolved complaints, provides clear empirical support for H3.

Although these results highlight the considerable promise of integrated approaches, the single-case focus and six-month observation window inevitably limit the external generalizability. Mastergaz operates under relatively favorable conditions for digital transformation, including robust in-house IT capabilities and established pilot programs for remote sensing. Smaller or more resource-constrained utilities may lack technical expertise to implement an advanced MCDA or maintain near-real-time sensor reporting. Regulatory environments also differ substantially across regions, potentially shaping the efficacy of data-sharing and stakeholder forums. Even so, the pilot suggests that once an organization can consolidate operational data, streamline communication, and periodically recalibrate project priorities, notable efficiency can emerge. Future research should adopt multi-case or comparative designs across diverse HCS operators – rural vs. urban and public vs. private – to determine the contextual factors that most strongly predict success.

One of the key lessons of this study is the importance of combining the top-down and bottom-up perspectives. While the BOS CIS platform excels at uniting operational metrics (e. g., pipeline corrosion levels and technician response times) with strategic planning objectives, the capacity for managerial or expert panel overrides ensures that intangible factors, such as community frustration or unexpected political mandates, are not overlooked. This hybrid digital-and-human model resonates with the dynamic capabilities' framework, highlighting the need for organizations to sense risks, seize opportunities, and periodically transform internal processes to remain adaptive.

Another lesson centers on the iterative nature of data-driven improvements. Although Mastergaz realized substantial gains early on, sustaining or extending those gains may require ongoing recalibrations of the MCDA parameters, refining sensor thresholds, and continued investment in staff training. Without these iterative refinements, any integrated system risks become routine, thereby undermining the proactive ethos that initially spurred significant change.

Future investigations could delve deeper into artificial intelligence (AI) enhancements, particularly machine learning models trained on historical sensor data, past intervention outcomes, and user feedback. Such approaches might further refine predictive risk management by identifying subtle warning signs of asset degradation or service disruptions, and enabling dynamic budget allocation in real time. There is scope for exploring how cultural and political factors influence stakeholder engagement. In some contexts, municipalities may restrict transparency or limit the frequency of public forums, dampening the collaborative momentum observed in Mastergaz. A multi-year examination might reveal whether stakeholder enthusiasm persists once early successes become normalized or if additional incentives and policy frameworks are needed to sustain effective participation over time.

Acknowledging these complexities, the Mastergaz experience demonstrates tangible operational and strategic benefits. The reduction in downtime and accelerated repair cycles illustrate that data-driven methods can lower the economic costs and public dissatisfaction often associated with recurring HCS disruptions. Regular stakeholder dialogues not only elevated community satisfaction, but also supplied feedback loops that minimized potential mismatches between algorithmic rankings and local expectations. From a theoretical perspective, the findings show how risk management, stakeholder collaboration, and priority-based budgeting, long treated as separate concerns, can reinforce each other when unified within a single digital platform. Moreover, the study aligns with the International Journal of Managing Projects in Business's aims of advancing both theory and practice in project management by promoting multidisciplinary stakeholder-centered approaches that encompass sustainability and public well-being.

The Mastergaz case underscores the viability of merging real-time risk monitoring, stakeholder engagement, and MCDA-driven resource allocation for overhaul HCS operations. Support for the three hypotheses – decreasing downtime and response time, enhancing project selection under budgetary constraints, and boosting user satisfaction – emphasizes the effectiveness of integrative strategies that rely on both sophisticated digital tools and ongoing human judgment. Although further multicase and longitudinal studies are required to confirm the robustness of the framework in different institutional and geographic contexts, the pilot findings indicate that such an approach can help bridge the gap between reactive and proactive governance. As urban populations expand and infrastructure ages, a balanced model that synthesizes data analytics, collaborative oversight, and flexible decision-making could provide a vital blueprint for sustaining and modernizing essential public services in line with the best practices in project management.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

Data will be made available on reasonable request.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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