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DYNAMIC INFRASTRUCTURE RISK MANAGEMENT: REAL-WORLD IMPLEMENTATION AND VALIDATION OF THE IRMM AT MASTERGAZ

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Introduction. Infrastructure risk management is increasingly critical for maintaining the reliability and sustainability of essential services, particularly as infrastructure systems grow in complexity and interdependence [1]. The present study introduces the Infrastructure Risk Management Method (IRMM), with its core component – the Infrastructure Risk Index (IRI) – designed to integrate criticality, vulnerability, and external influences into a single quantitative metric. This approach responds to the limitations of traditional, static models by accounting for the continuous evolution of technological, regulatory, and environmental factors [2]. The IRI strengthens project managers' abilities to anticipate and mitigate risks in dynamic environments [3; 4]. Conventional frameworks often lack the flexibility to capture rapidly changing conditions, resulting in gaps between predicted risks and real-time system vulnerabilities [5]. The IRMM addresses these gaps through its focus on dynamic assessments.

Review of recent research and publications. Modern research on infrastructure risk management covers issues of predictive modeling, which is highlighted in the works of the following scientists: Abdullah E., Yakob R., Abdullah M.H.S.B. [1]; Kabir S., Papadopoulos Y. [3], also aspects of increasing the resilience of critical infrastructure are studied in detail, which is highlighted in the works of the following scientists: Cavalieri F., Franchin P. [2]; De Felice F., Petrillo A., Baffo I. [6], the basic principles and practical service strategies are explored in the works of the following scholars: Gunawan I., Hallo L., Nguyen T. [7]; Mottahedi A., Barabadi A. and others. [8].

At the same time, studies by Rasheed N., Shahzad W., Khalfan M., Rotimi J. [9], as well as Urbina O., Sousa H., Teixeira E., Matos J. [10] focus on investigating the importance of risk identification and prioritization, and technological innovations in the field of dynamic risk assessment and the application of machine learning are analyzed in the works of Cheimonidis P., Rantos K. [4] and Secundo G., Mele G., Passiante G., Ligorio A. [11].

Despite this strong research, real-world validation of dynamic models is underdeveloped, and the integration of operational data into risk assessment remains limited. Further research could be directed towards creating adaptive and scalable risk management systems that integrate technical and human factors.

This study examines the IRMM's implementation at Mastergaz, analyzing 50 infrastructure projects over two years. The research combines qualitative insights from interviews with quantitative data from surveys and performance metrics, providing comprehensive evidence of the method's applicability [12; 8]. The investigation addresses two core hypotheses: first, that IRMM implementation significantly reduces infrastructure failure rates, and second, that the IRI reliably predicts risks, facilitating more informed decisions by project managers [10]. Through examination of project outcomes, the study validates these hypotheses while advancing the broader discourse on infrastructure risk management [13]. By positioning the IRMM within both scholarly and practical contexts, this research demonstrates its potential for scalability across various infrastructure sectors [3]. The aim is to evaluate the real-world implementation and predictive reliability of the IRMM, with particular emphasis on the IRI, in infrastructure projects at Mastergaz.

Objectives. This research aims to: 1) assess the IRI's effectiveness in predicting infrastructure risks; 2) evaluate whether IRMM implementation reduces failure rates; 3) examine the model's stability through sensitivity analysis; and 4) validate the methodology using empirical data from representative infrastructure projects.

Main material and results. This study employed a case study approach at Mastergaz, chosen for its leadership in the infrastructure sector and diverse operational portfolio spanning gas, water, and heating systems – providing an ideal environment for evaluating the IRMM [10]. Fifty infrastructure projects were analyzed over two years, selected based on infrastructure type variety, availability of complete historical data, and representation of different complexity levels [8]. This sample size ensured comprehensive coverage across maintenance and installation scenarios while maintaining data consistency for quantitative analysis.

Data were gathered through a mixed-methods strategy combining qualitative insights from structured interviews with project managers and field technicians alongside quantitative records from documentation [14]. This approach strengthened methodological rigor through diverse data sources [7]. Surveys collected information on three main dimensions – criticality, vulnerability, and external influences – serving as the foundation for calculating the Infrastructure Risk Index (IRI) using the formula:

$$ir = \sum_{i=1}^{n} c_i v_i e_i .$$

Where ir represents overall infrastructure risk, c_i indicates criticality, v_i denotes vulnerability, and e_i captures external influences for each infrastructure element [15]. The resulting values were evaluated using statistical techniques including correlation and regression analysis to compare predicted risks with observed outcomes [16].

Project oversight utilized the ERP-BPMS BOS CIS platform, which captured near-real-time metrics while maintaining human verification through designated technical personnel who checked data inputs using standard protocols and cross-validated automated alerts. The validation process included retrospective review of infrastructure failures, enabling direct comparison between IRI values and actual breakdowns to demonstrate predictive accuracy [10]. Sensitivity analysis assessed how variations in the three key parameters influenced aggregate risk levels, offering insights into model stability across diverse operational conditions [17; 18]

Project oversight utilized the ERP-BPMS BOS CIS platform for capturing near-real-time metrics, while maintaining human verification through experienced engineers who validated system outputs. This hybrid approach ensured reliability by combining automated data collection with on-ground checks, maximizing precision in statistical analyses. The platform enabled continuous monitoring of risk metrics, allowing project managers to implement proactive measures as conditions evolved [9].

Dynamic risk assessment represents the IRMM's key innovation. Unlike conventional static models that fail to address rapid infrastructure changes, the IRMM's routine reassessment of c_i, v_i, and e_i parameters through BOS CIS responds efficiently to emerging threats while strengthening organizational resilience [4]. This approach aligns with hybrid decision-making processes that capture diverse vulnerabilities [19].

Preventive strategies based on historical failure data identified potential failure points and recommended targeted maintenance, contingency planning, and specialized training, reducing service disruptions [20]. Tracking adjustments in IRI scores following these initiatives confirmed the approach's scalability in real-world settings.

Future research will examine IRMM's applicability to transportation and energy sectors, with automated IRI estimations potentially enabling real-time risk evaluations across multiple contexts [18]. A culture of improvement was maintained through feedback workshops where project managers contributed to methodology refinement, ensuring manual protocols and BOS CIS automation complemented each other effectively. The IRMM's integration with Mastergaz's existing workflows delivered systematic risk evaluations applicable to organizations facing complex risk landscapes.

By combining multi-criteria analyses with sensitivity assessments and continuous risk updates, the IRMM advances infrastructure risk management through a structured yet adaptable approach that balances automated inputs with expert reviews for robust decision-making [2].

The findings from applying the IRMM at Mastergaz demonstrate its effectiveness in residential infrastructure settings (2022–2024). Fifty projects (budgets under $100,000) were categorized into three groups: multi-apartment building maintenance, involving critical systems with elevated risk levels [8]; communal system servicing, with complex interdependencies requiring careful evaluation [6]; and minor infrastructure upgrades with unique but less complex risks [21].

The IRMM showed clear advantages over static approaches like Monte Carlo simulations, which depend heavily on accurate input assumptions [22]. Its dynamic assessment framework proved more flexible for rapidly changing conditions compared to the Analytic Network Process (ANP), which demands significant computational resources [23]. Results showed a 20% reduction in infrastructure failures for multi-apartment buildings and 15% improved efficiency for communal systems – highlighting benefits over methods like the Critical Risks Method (CRM) that lack real-time adaptability [24].

Data acquisition combined surveys, interviews, and documentation, with the BOS CIS platform enhancing monitoring reliability [25] and enabling rapid updates consistent with modern monitoring technologies [18]. Unlike multi-hazard models and Bayesian networks that require extensive computational resources [26; 11], the IRMM balanced analytical depth with practical accessibility – bridging gaps between advanced solutions like machine learning models and smaller-scale projects [27].

Table 1 presents average IRI values and failure rates by project category. Multi-apartment buildings showed the highest IRI scores and failure rates, reflecting their complexity, while maintenance projects in less critical environments registered the lowest risk levels. Retrospective validation confirmed the IRMM's predictive power, with higher IRI values correlating to higher failure rates. Sensitivity analyses demonstrated stability, showing that parameter variations did not compromise the model's ability to identify high-risk scenarios.

Table 1

Average IRI Values and Failure Rates by Project Category

Project Category	Average IRI Value	Failure Rate (%)
Multi-Apartment Buildings	0.75	12
Communal Systems	0.60	8
Maintenance Projects	0.50	5

Source: developed by the authors

Table 1 guided targeted preventive initiatives through prioritized maintenance schedules, contingency measures, and personnel training. In multi-apartment buildings, systematic inspections and timely interventions achieved a 20% reduction in failures, while aging communal systems received immediate retrofits that prevented breakdowns during peak usage. Project feedback refined risk assessment approaches, demonstrating the IRMM's iterative enhancement capabilities. BOS CIS integration enabled real-time reassessment, as evidenced during a multi-apartment maintenance campaign where rapid response to increased plumbing vulnerability prevented further issues.

Table 2 quantitatively validates the IRMM's effectiveness, showing significant reductions in emergency service requests across all project categories. Multi-apartment buildings saw a 30% decrease, while communal systems and maintenance projects experienced approximately 33% reductions. These consistent improvements across categories confirm that dynamic risk management approaches effectively limit operational disruptions and enhance infrastructure dependability through real-time analytics.

Table 2

Emergency Service Requests Before and After IRMM Implementation

Project Category	Emergency Requests (Before)	Emergency Requests (After)	Reduction (%)
Multi-Apartment Buildings	20	14	30
Communal Systems	30	20	33.3
Maintenance Projects	15	10	33.3

Source: developed by the authors

Table 2 results also demonstrate the IRMM's adaptability across sectors, with preliminary trials in transportation and energy confirming the framework's adjustability to diverse project specifications. Integration with Mastergaz's existing management processes and BOS CIS required minimal coordination while enabling seamless implementation. Stakeholder adoption improved through targeted education highlighting operational relevance. Despite effectiveness, the method revealed limitations – particularly its dependence on historical data, suggesting potential enhancement through machine learning and real-time analytics [21; 27].

While the IRMM addresses multiple risk dimensions, further research into regulatory shifts and economic volatility remains necessary to enrich risk profiles. Nevertheless, results from Mastergaz provide a foundation for broader exploration and confirm the method's capacity to enhance project resilience across complex operational contexts.

Table 3 illustrates practical IRMM application through three representative projects, demonstrating how engineers computed the Infrastructure Risk Index and implemented preventive measures. Each case utilized near-real-time BOS CIS data combined with on-site technical evaluations. The parameters c_i, v_i, and e_i were assigned using checklists and field personnel interviews, accounting for equipment age, potential service disruptions, and seasonal factors.

Table 3

Illustrative IRMM Project Cases at Mastergaz

Project Description	c_i (Criticality)	v_i (Vulnerability)	e_i (External Influences)	Calculated $ir = c_i \times v_i \times e_i$	Main Intervention	% Drop in Emergency Calls	Other Notable Results
Repair of an aging heating pipeline in a 12-floor building	3	3	2	18	Replaced corroded pipes, added extra insulation	25	Reduced downtime from 8 hours/mo to 3 hours/mo
Installation of new water meters in a multi-apartment complex	2	1	1	2	Implemented thorough leak tests, staff training	15	Lower complaint rate by 10%, sped up meter readings
Electrical panel upgrade in communal corridors	3	2	2	12	Rewired panel, introduced surge protectors	20	Fewer short circuits, improved safety compliance

Source: developed by the authors

As demonstrated in Table 3, even modest parameter changes yielded different ir values signaling varying urgency levels. Interventions ranged from immediate component replacement to enhanced quality checks. Over three months, these projects showed improvements in emergency response times and client satisfaction, aligning with Mastergaz's broader pattern of handling 200–300 daily service requests where rapid risk identification is crucial.

The illustrative cases highlight practical application: high c_i and v_i values in the heating pipeline repair reflected widespread impact and wear, while moderate c_i in water meter installation indicated limited disruption potential. The electrical panel upgrade showed elevated c_i due to its critical nature and moderately high v_i from outdated wiring. In each case, parameter values guided intervention prioritization according to the ir formula, with on-site verification ensuring accuracy. This human-software approach enabled responsive workflows and reinforced the quantitative results in Tables 1–2.

These cases confirm that targeted mitigation rapidly reduces disruption likelihood even with varying initial ir scores. The ability to adjust parameters for shifting conditions demonstrates IRMM's broad applicability. As Mastergaz serves 750,000+ residents, BOS CIS data enables ongoing parameter refinement, creating a dynamic feedback cycle that minimizes failures and enhances cost-effectiveness.

The findings validate IRI as a reliable predictor of infrastructure failures, confirming that data-driven assessment enhances risk identification. Projects with higher IRI values experienced proportionally higher failure rates, supporting the need for robust management of complex systems [5]. By incorporating dynamic inputs, IRMM addresses limitations of static approaches like Quantitative Risk Assessments whose utility diminishes in rapidly evolving conditions [4].

IRMM's key strength lies in continuous risk evaluation updates – more streamlined than computationally demanding Bayesian networks while maintaining accuracy [3]. This dynamic aspect fosters ongoing improvement and strengthens operational resilience compared to multi-hazard methods lacking responsive recalibration [18].

The method's preventive planning focus identifies potential weaknesses through historical data analysis, enhancing system resilience through targeted interventions [28]. Unlike static maintenance protocols [29], IRMM provides responsive capabilities without requiring substantial technological investments needed for advanced machine learning platforms [30].

Compared to resource-intensive simulation models better suited for large projects [19; 8], IRMM's adaptable design accommodates varying complexity levels, as demonstrated in transportation and energy implementations [31]. Its compatibility with existing ERP systems bridges compliance-focused traditional solutions [32] and costly AI-driven alternatives while offering potential for future integration with IoT sensors and AI algorithms for granular insights [33; 34], provided user training prevents adoption barriers [35].

The results confirm our second hypothesis that IRMM meaningfully predicts infrastructure failures, allowing managers to anticipate and mitigate high-risk conditions. This supports the method's value in both academic and operational contexts, especially given increasing infrastructural complexity.

Despite positive outcomes, the IRMM has limitations. Its reliance on historical data may restrict responsiveness to abrupt external changes – a limitation potentially addressed through predictive analytics and machine learning integration [27], though this would require additional expertise and resources. Implementation barriers included resistance to methodological changes and training requirements [35]. Future research should focus on refining the approach for rapidly changing environments through simulation-based models and hybrid approaches [8], exploring additional external factors, and testing applications in larger-scale projects.

Conclusions. The IRMM demonstrates significant value as a comprehensive risk management framework through its IRI methodology. By integrating criticality, vulnerability, and external influences, it enables effective quantitative risk assessments across diverse operational conditions. The fifty Mastergaz case studies revealed that continuous monitoring facilitates swift responses to evolving challenges, minimizing failures and enhancing efficiency. Retrospective validation confirmed the correlation between IRI values and actual failures.

The method's scalability across infrastructure contexts warrants further exploration in transportation and energy sectors, with potential enhancement through automated IRI calculations. Established feedback mechanisms strengthened organizational collaboration while maintaining the framework's adaptability.

From a managerial perspective, IRMM provides timely risk information guiding preventive maintenance and targeted interventions without requiring prohibitive implementation costs. Theoretically, it bridges the gap between complex, resource-intensive models and simpler static approaches by demonstrating how multiple risk factors can integrate into a single indicator. This contributes an empirically-grounded perspective on infrastructure risk management's evolution to address modern challenges.

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Dynamic infrastructure risk management: real-world implementation and validation of the IRMM at Mastergaz.

This study introduces and evaluates the Infrastructure Risk Management Method (IRMM), with particular emphasis on the Infrastructure Risk Index (IRI) as a quantitative measure to identify and mitigate risks in infrastructure projects. A two-year case study was conducted at Mastergaz, a leading infrastructure firm, involving fifty projects. Data were collected through structured interviews and surveys administered to project managers and field technicians. The IRI was calculated by integrating criticality, vulnerability, and external influences, and then analyzed in conjunction with historical performance metrics. The findings demonstrate a strong correlation between IRI values and observed failure rates, highlighting the IRMM’s predictive capability. Dynamic assessments allowed continuous monitoring and informed preventive strategies, such as maintenance schedules and contingency plans, thereby reducing infrastructure failures. Scalability was also evident, suggesting broader applicability in sectors like transportation and energy. By integrating real-time data and aligning with existing project management frameworks, the IRMM advances infrastructure risk management practices. This dynamic, proactive approach fosters improved decision-making and resilience in evolving operational environments, offering a valuable foundation for further research and practical implementation.

Key words: infrastructure risk management, infrastructure risk index, dynamic assessment, preventive planning, real-time data, project management, Mastergaz.

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Динамічне управління інфраструктурними ризиками: практичне впровадження та валідація IRMM на прикладі Mastergaz.

В статті представлено та оцінено Метод управління інфраструктурними ризиками (IRMM) з особливою увагою до Індексу інфраструктурного ризику (IRI) як кількісного показника для ідентифікації та пом’якшення ризиків у рамках інфраструктурних проєктів. Дослідження базується на дворічному кейсі компанії Mastergaz – провідної інфраструктурної фірми, в межах якого проаналізовано 50 проєктів із різними рівнями складності та бюджетом до 100 000 доларів США. Проєкти було розподілено на три основні категорії: обслуговування багатоквартирних будинків, сервісне обслуговування комунальних систем та модернізація інфраструктури. Збір даних здійснювався за допомогою структурованих інтерв'ю та анкетування керівників проєктів і технічного персоналу, а також через аналіз історичної документації та показників продуктивності. Розрахунок IRI здійснювався шляхом інтеграції показників критичності (c_i), вразливості (v_i) та зовнішніх впливів (e_i) за формулою ir = sum(i=1 to n)(c_i * v_i * e_i), що дозволило отримати комплексну оцінку ризиків для кожного елемента інфраструктури. Результати показали сильну кореляцію між значеннями IRI та фактичними випадками відмов, що підтверджує прогностичну здатність IRMM. Впровадження методу призвело до зниження кількості аварійних викликів на 30–33% у всіх категоріях проєктів та зменшення частоти відмов на 20% у багатоквартирних будинках і на 15% у комунальних системах. Інтеграція з платформою ERP-BPMS BOS CIS забезпечила динамічний моніторинг у реальному часі та оперативне коригування параметрів ризику. На відміну від статичних методів, таких як моделювання Монте-Карло чи Аналітичний мережевий процес (ANP), IRMM забезпечує баланс між глибиною аналізу та практичною доступністю, не вимагаючи значних обчислювальних ресурсів. Виявлено потенціал масштабування методу в інших галузях, зокрема в транспорті та енергетиці. Метод пропонує структурований, але гнучкий підхід до управління ризиками, який поєднує автоматизований аналіз з експертною оцінкою, що особливо важливо для організацій зі складними ризиковими профілями. Такий динамічний, проактивний підхід підсилює якість прийняття рішень і стійкість в умовах змінного операційного середовища, створюючи підґрунтя для подальших досліджень і практичного застосування.

Ключові слова: управління інфраструктурними ризиками, індекс інфраструктурного ризику, динамічна оцінка, превентивне планування, дані в реальному часі, управління проєктами, Mastergaz.