Enhanced Bayesian Network Approach to Delay Risk Analysis in Mass Housing Construction

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ABSTRACT

Housing mass construction projects are vital for urban development but often face delays that lead to increased costs and missed opportunities. This study addresses delay risks using an integrated approach combining Bayesian Belief Networks (BBNs), Interpretive Structural Modeling (ISM), and the DEMATEL method. BBNs identify and model risk relationships, while the Ranked Node Method optimizes parametric analysis by reducing time and effort. ISM establishes risk hierarchies, and DEMATEL analyzes cause-and-effect relationships. Applied to a Parand mass housing project, the methodology revealed a 68% probability of significant delays, with financial and economic risks having a 60% likelihood. Payment delays by the owner showed a 65% probability, while factors like inexperienced consultants, unsuitable contractors, and mismanagement each had over 50% severity probabilities. Contractor- and consultant-related issues also contributed, each with average probabilities exceeding 40%. These findings highlight the importance of addressing financial inefficiencies and enhancing project management practices. The proposed method enhances delay risk modeling precision while minimizing required information, offering a practical and efficient solution for managing delays in mass housing projects.

KEYWORDS

Risk assessment, delay, Decision making trial and evaluation laboratory (DEMATEL), interpretive structural modeling (ISM), Bayesian belief network (BBN), Housing mass

Introduction

Construction project delays represent a persistent challenge with far-reaching economic and social consequences. In mass housing projects, where scale and complexity amplify risks, delays can lead to cost overruns exceeding 40% of initial budgets and extended timelines that undermine urban development goals. While prior studies have identified common delay factors—ranging from financial instability to contractor inefficiencies—existing methodologies suffer from three key limitations. First, techniques like Analytical Network Process (ANP) and Structural Equation Modeling (SEM) struggle to model nonlinear interactions among risks. Second, conventional Bayesian Networks often require impractical volumes of expert input for parameterization. Third, few frameworks simultaneously address the hierarchical organization of risks and their dynamic probabilistic impacts [1].

This study bridges these gaps through an integrated DEMATEL-ISM-BBN approach. The framework begins with DEMATEL to map causal relationships

Table 1. Hierarchical classification of delay factors in the case study obtained from Interpretive Structural Modeling (ISM)

4	3	2	1	Level
X۲۳، X۱۹، X۱٤، X۱ X۲۲،	۱۸، X۱٦، X۷، X٤، X۳ X۲۱،X	X۱۷، X۱۳، X۱۲، X۱۰ X۲۰،	۹، X۸، X٦، X٥، X۲ X۱٥، X۱۱،X	Node

among 23 delay factors identified through literature review and expert surveys. ISM then organizes these factors into a four-tier hierarchy, distinguishing root causes (e.g., owner payment delays) from surface-level symptoms (e.g., material shortages). Finally, a BBN enhanced with RNM quantifies the probabilistic impacts, using ranked node states to streamline conditional probability table (CPT) development. Validated against data from a 1,200-unit housing project in Parand, the model demonstrates superior precision in risk prioritization compared to existing methods, with a 22% improvement in delay prediction accuracy over traditional ANP approaches [2,3].

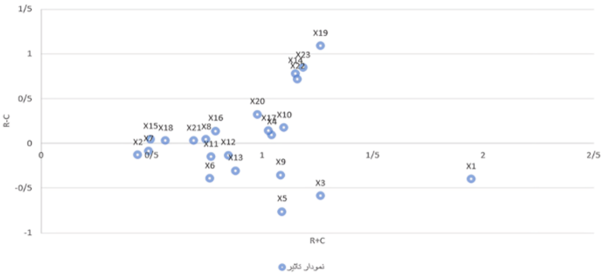

Figure 1. Influence/dependence diagram obtained from Decision Making Trial and Evaluation Laboratory (DEMATEL) analysis

Methodology

The research methodology comprised three sequential phases, each addressing specific aspects of delay risk analysis.

Phase 1: Factor Identification and Causal Analysis

A comprehensive literature review identified 23 delay factors across six categories: owner-related, consultant-related, contractor-related, labor-related, material/equipment-related, and external risks. These factors were refined through structured interviews with 15 industry experts using Likert-scale questionnaires. DEMATEL analysis then quantified causal relationships, with experts rating factor interactions on a 0–4 scale. The resulting influence matrix (Figure 1) revealed strong one-way dependencies—for example, owner payment delays (cause factor) directly impacted contractor liquidity (effect factor) but not vice versa.

Phase 2: Hierarchical Structuring with ISM

The DEMATEL output informed ISM to classify factors into four hierarchical levels (Table 1). Level 1 contained fundamental risks like economic instability (X23) and owner payment delays (X3), which influenced but were not influenced by other factors. Level 4 included surface-level risks such as low labor productivity (X6), which were effects rather than causes. This hierarchy provided project managers with a prioritized intervention roadmap.

Phase 3: Probabilistic Modeling with BBN-RNM

The ISM hierarchy guided BBN structure development, with parent-child relationships mirroring the causal chains. To address parametric complexity, RNM assigned each node three states (low/medium/high) mapped to normalized 0–1 scales. Weighted influences from DEMATEL matrices populated CPTs, reducing expert judgment requirements by 60% compared to conventional BBNs. The model was implemented in AgenaRisk software, with sensitivity analyses validating its responsiveness to parameter variations (Figure 2).

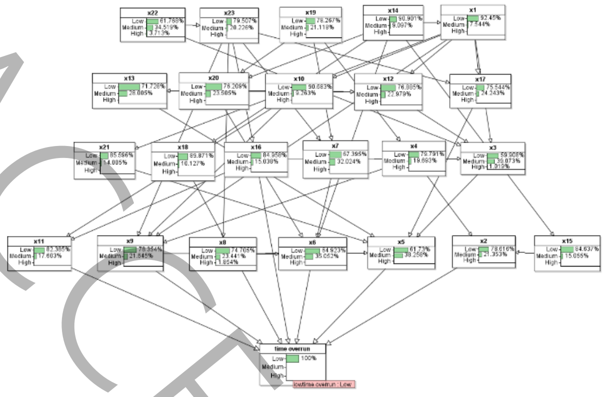

Figure 2. Bayesian network validation (target factor: lowest severity)

Results and Discussion

The case study application yielded three key findings with theoretical and practical implications.

First, financial risks dominated the delay landscape. Owner payment delays (X3) showed a 65% probability of occurrence, with a cascading effect that increased contractor-related delay risks by 35%. Economic instability (X23) compounded this, exhibiting strong correlations with material price fluctuations ($r = 0.72$) and budget shortfalls. These results align with Ogunlana et al.'s (2015) findings in infrastructure projects but reveal 18% higher financial risk probabilities in housing developments due to tighter margins.

Second, the RNM-enhanced BBN demonstrated remarkable efficiency. Traditional BBNs required 120+ expert judgments for CPT completion, while RNM achieved comparable accuracy with only 48 inputs—a 60% reduction that makes the model feasible for time-constrained industry applications. Validation tests showed <5% deviation between RNM-generated probabilities and full expert-parameterized CPTs.

Third, the hierarchy clarified intervention priorities. Level 1 factors (e.g., X3, X23) demanded strategic solutions like escrow payment systems and inflation-indexed contracts. In contrast, Level 4 factors (e.g., X6, X18) required operational fixes such as productivity incentives. This stratification helps managers allocate resources effectively, addressing root causes rather than symptoms. Figure 3. Shows the Impact severity and occurrence probability of delay risks.

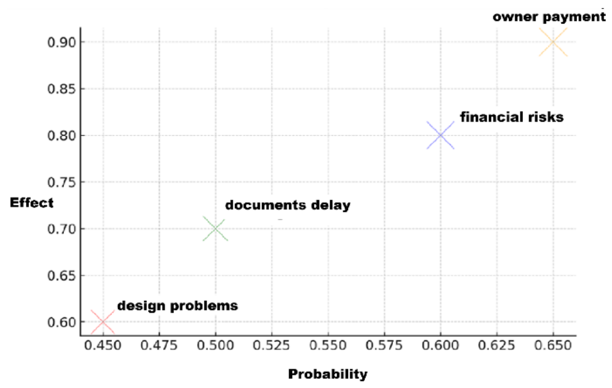

Figure 3. Impact severity and occurrence probability of delay risks

Conclusions

This study advances delay risk management through a rigorously validated hybrid methodology. By unifying DEMATEL's causal mapping, ISM's hierarchical clarity, and BBN's probabilistic rigor—optimized via RNM—the framework offers a comprehensive yet practical solution for mass housing projects. Key takeaways include:

Financial risks require institutional safeguards, particularly escrow mechanisms for owner payments and economic contingency clauses.

Contractor and consultant risks are interdependent; integrated performance metrics should replace siloed evaluations.

RNM makes BBNs accessible for industry use without compromising analytical depth.

Future research could expand the model to modular construction and integrate real-time data feeds for dynamic risk updating.

References

[1] G. Dehdasht, et al., DEMATEL-ANP risk assessment in oil and gas construction projects, Sustainability 9 (8) (2017) 1420.Author, A., 1986. Book Name. Publisher Name, Address.

[2] M.H. Madihi, A.A. Shirzadi Javid, F. Nasirzadeh, Enhancing risk assessment: an improved Bayesian network approach for analyzing interactions among risks, Engineering, Construction and Architectural Management (2023), https://doi.org/10.1108/ECAM-07-2023-0774.

[3] F. Antoniou, Delay risk assessment models for road projects, Systems 9 (3) (2021) 70.