Development of an Electronic System for Multi-Objective Optimization of Administrative Activities in Construction Projects Using NSGA-II

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ABSTRACT

This study presents a comprehensive multi-objective decision-support model designed to optimize the time, cost, and quality of administrative and support processes in construction projects through a virtual management platform. A non-dominated sorting genetic algorithm II (NSGA-II) is employed to solve the mathematical model, and its performance is validated against the exact epsilon-constraint method. The practical efficacy of the proposed model was evaluated using a real-world high-rise commercial-residential building case study in Tehran. Computational results reveal that the cumulative time spent on administrative workflows under traditional management totaled 3,934,517 hours. Implementation of the proposed virtual management framework compressed this bureaucratic time to 480,710.3 hours, representing a 87.78% reduction without altering the physical execution timeline on-site. Furthermore, financial analysis demonstrates that traditional administrative overhead costs of 1,934,222,652 IRR were reduced to 273,510,000 IRR under the virtual system, achieving an 85.86% cost saving. The findings confirm that localized virtual project management, combined with Pareto-optimal trade-offs, significantly enhances administrative workflow efficiency in large-scale construction enterprises.

KEYWORDS

Electronic Management, Construction Project Management, Mathematical Modeling, Genetic Algorithm, Administrative Workflows.

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Introduction

Rapid urbanization and the increasing complexity of modern metropolitan infrastructure have introduced severe operational and financial pressures on public and private construction entities. While substantial research in construction engineering and management has focused on physical field operations such as structural scheduling, heavy machinery logistics, and material supply chain management the administrative layer of project delivery has remained largely unexamined. In traditional site administration, bureaucratic processes including engineering submittals, progress payment certifications, site instructions, and change orders rely heavily on paper-based, sequential approvals. This structural inefficiency creates hidden scheduling delays, inflated overhead expenditures, and frequent administrative friction among key stakeholders, including clients, consultants, and general contractors. To address these systemic bottlenecks, digital transformation and virtual project management platforms offer a promising paradigm [1]. Virtual management leverages modern telecommunication infrastructures to facilitate real-time data exchange, automated document tracking, and transparent inter-organizational communication [2, 3]. Nevertheless, existing enterprise resource planning and document management systems typically act as static digital repositories. They lack dynamic, mathematical decision-making mechanisms capable of resolving inherent conflicts between project duration, overhead expenditures, and management quality [4, 5]. This paper fills this crucial methodological gap by formulating a multi-objective 0-1 integer programming model specifically tailored to the administrative and support processes of building projects. By integrating a Fuzzy Network Analysis Process (Fuzzy ANP) to capture inter-process dependencies with the Non-Dominated Sorting Genetic Algorithm II (NSGA-II) [6, 7], this study provides project managers with a robust Decision Support System (DSS). The primary contribution lies in quantifiably demonstrating how virtualizing bureaucratic workflows can compress project support timelines and reduce overhead costs while preserving stringent quality control standards.

Methodology

The empirical foundation of this research is grounded in a real-world case study of the Hamila commercial-administrative complex in western Tehran, comprising a 27-story structure with an 8,100 square meter footprint. Data collection involved structured interviews and field observations with an expert panel comprising project managers, technical office leads, supervising engineers, and client representatives. To ensure mathematical rigors, a systematic multi-step methodology was established: (1) Identification and Screening of Workflows: From an initial pool of 38 administrative and support processes, 17 critical representative activities (spanning scheduling, daily/weekly/monthly reporting, delay analysis, work statements, adjustment claims, site approvals, as-built drawings, procurement, and inventory control) were selected based on time-criticality, repetition, and financial impact. (2) Network Dependency Analysis: The interdependencies and feedback loops among these 17 administrative workflows were quantified using Fuzzy ANP. Pairwise comparison matrices were constructed, and consistency ratios were strictly maintained below the 0.1 threshold to guarantee data reliability. The generated Network Process Matrix served as a foundational input for the mathematical model. (3) Mathematical Formulation: A 0-1 multi-objective optimization model was formulated with three conflicting objective functions: minimizing total administrative lead time, minimizing total indirect support costs, and maximizing workflow process quality (incorporating accuracy, error reduction, and stakeholder satisfaction). (4) Algorithmic Solution and Parameter Calibration: Due to the NP-hard nature of the combinatorial formulation, NSGA-II was implemented in MATLAB. Key parameters were systematically calibrated through empirical test runs on the project dataset: initial population size (N_{pop} = 100), maximum iterations ($MaxIt$ = 200), crossover probability (P_c = 0.80), and mutation probability (P_m = 0.15). (5) Robustness and Validation: To ensure statistical reproducibility, the algorithm was subjected to 30 independent runs using distinct random seeds. Furthermore, small- and medium-scale instances of the model were validated against the exact epsilon-constraint solution method implemented in LINGO software.

Results and Discussion

The computational performance of the proposed NSGA-II algorithm demonstrated high efficiency and convergence stability across all tested problem sizes. Comparative analysis with the exact epsilon-constraint method revealed that while the exact approach experienced exponential computational time growth on larger datasets rendering it impractical for real-time site management NSGA-II consistently obtained high-quality Pareto fronts in reasonable execution times. Descriptive statistical evaluation across performance metrics confirmed that NSGA-II achieved superior Mean Ideal Distance (MID = 194,445) and a higher number of non-dominated solutions (NOP = 76.4) compared to the exact approach. To illustrate the decision-making capability of the proposed algorithm, a three-dimensional

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Pareto-optimal frontier generated for a representative problem instance involving 12 activities, 5 response strategies, and 4 primary processes is presented in Figure 1.

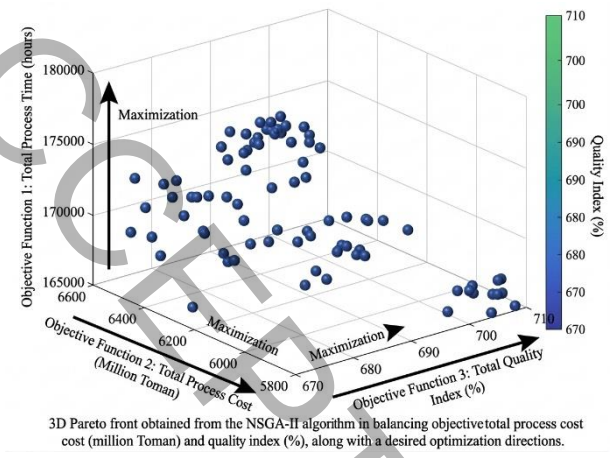


Figure 1. Three-dimensional Pareto frontier illustrating trade-offs among administrative time, cost, and quality

As shown in Figure 1, the non-dominated solution surface maps the precise non-linear trade-offs among the three objective functions. The time objective ranges between 670 and 710 hours, total cost varies from 5,800 to 6,600 million IRR, and the quality performance index calibrates between 165,000 and 175,000 units. The structural topology of this frontier indicates that compressing administrative lead times beyond a certain threshold requires parallel processing and intensified resource allocation, which escalates financial costs non-linearly. However, the multi-objective model prevents extreme degradation in workflow quality, allowing project executives to select an optimal operational strategy based on real-time liquidity and schedule constraints. In terms of macro-level project impacts over the 24-month contract duration, a comparative analysis between traditional paper-based management and the proposed virtual electronic system demonstrated dramatic efficiency gains. Under traditional management, the cumulative time consumed across all 17 administrative workflows amounted to 3,934,517 hours. Under the optimized virtual management system, this duration was compressed to 480,710.3 hours achieving a 78.87% reduction in bureaucratic lead times. Financially, traditional administrative processes incurred a total overhead cost of 1,934,222,652 IRR. The localized virtual platform reduced these expenses to 273,510,000 IRR, which corresponds to 14.14% of the traditional cost baseline and represents an overall cost saving of 85.86%. These reductions stem directly from eliminating paper documentation, minimizing physical transit for authorizations, reducing clerical manual labor, and automating inventory and payment verification workflows.

Conclusions

This study demonstrates that transitioning from traditional paper-based project administration to a virtual management platform integrated with NSGA-II optimization significantly increases operational efficiency in construction projects, yielding a ۸۷.۷۸% reduction in bureaucratic lead times and an 85.86% savings in overhead expenditures. The NSGA-II algorithm exhibits robust computational performance and convergence stability over exact mathematical methods, offering project decision-makers a reliable tool to dynamically balance time, cost, and quality trade-offs. Future research may extend this multi-objective optimization framework by integrating Building Information Modeling (BIM) and blockchain-based smart contracts to achieve fully automated and legally secure administrative execution across complex infrastructure projects.

References

[1] Nouri, F., Khorasani, M. and Barzegar, M.J., 2017. "Electronic Human Resource Management: Applications and Role in Modern Organizations." In Proceedings of the 4th National Conference on Applied Economics and Management, Tehran, Iran.

[2] Matsuda, M., Nishi, T., Hasegawa, M. and Matsumoto, S., 2019. "Virtualization of a supply chain from the manufacturing enterprise view using e-catalogues." Procedia CIRP, 81, pp. 932–937.

[3] Ferreira, L., Lopes, N., Ávila, P.S., Castro, H., Varela, M.L.R., Putnik, G.D., Martinho, R., Rijo, R., Miranda, I.M. and Cruz-Cunha, M.M., 2017. "Virtual Enterprise integration management based on a Meta-enterprise – a PMBoK approach." Procedia Computer Science, 121, pp. 1112–1118.

[4] El-Rayes, K. and Kandil, A., 2005. "Time-cost-quality trade-off analysis for highway construction." Journal of Construction Engineering and Management, 131(4), pp. 477–486.

[5] Zheng, D.X., Ng, S.T. and Kumaraswamy, M.M., 2004. "Applying a genetic algorithm-based multiobjective approach for time-cost optimization." Journal of Construction Engineering and Management, 130(2), pp. 168–176.

[6] Sharma, K. and Trivedi, M.K., 2021. "AHP and NSGA-II-based time–cost–quality trade-off optimization model for construction projects." In Artificial Intelligence and Sustainable Computing, Springer, Singapore, pp. 45–63.

[7] Deb, K., Pratap, A., Agarwal, S. and Meyarivan, T.A.M.T., 2002. "A fast and elitist multiobjective genetic algorithm: NSGA-II." IEEE Transactions on Evolutionary Computation, 6(2), pp. 182–197.

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