Application of Digitally Supported Linear Programming and Decision Matrix in Road Transportation Project Planning

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ABSTRACT

This study investigates the application of linear programming and decision matrix methods, supported by digital tools, in the context of road transportation project planning. The objective is to demonstrate how applied mathematical models can be integrated within a digital framework to optimize decision-making processes in civil infrastructure projects. A quantitative research design was employed using real data from a road development project, including cost estimates, resource requirements, and scheduling components. Technical and financial data were collected from project documentation and validated through expert consultation. The study utilized linear programming to determine the optimal allocation of resources under multiple constraints, and applied decision matrix analysis to evaluate alternative execution plans based on criteria such as cost efficiency, time effectiveness, and environmental impact. The findings showed that the integrated model successfully minimized project cost and duration while satisfying all technical constraints. Among the evaluated alternatives, the highest-ranked execution plan offered a balance between speed and sustainability. The use of mathematical models in combination with digital analysis tools enabled a transparent, structured, and data-driven decision-making process that reflects modern demands in infrastructure planning. This research presents a digitally supported framework that integrates optimization and multicriteria decision-making models, emphasizing the critical role of applied mathematics in improving planning quality and resource efficiency in transportation engineering.

1. INTRODUCTION

Applied mathematics plays a crucial role in formulating quantitative models to simplify and solve complex real-world problems. In the context of project planning and management, methods such as linear programming and decision matrix analysis enable structured, logical, and data-driven decision-making processes (Taha, 2017; Sharma & Tiwari, 2019). Linear programming helps determine optimal solutions to problems constrained by limited resources, while decision matrices assist in selecting the best alternative based on multiple interrelated criteria (Zavadskas et al., 2016).

One field where such mathematical approaches are highly relevant is in the planning of road transportation projects. These projects involve numerous technical and managerial aspects, including material selection, work duration estimation, resource allocation, and task prioritization. With so many variables and constraints—both in time and budget—mathematical models provide significant support in achieving efficient and optimal results (Samet & Shojaei, 2020).

In today's era of digital transformation, the demand for fast, accurate, and flexible planning tools has grown rapidly. Digital technologies enable the application of mathematical models to be carried out more dynamically and adaptively in response to changing data and field conditions (Bilal et al., 2016). Through such integration, mathematical analysis becomes not only a predictive tool, but also a practical decision-support mechanism that is transparent and reproducible (Shang & Abourizk, 2018).

This study focuses on the application of digitally supported linear programming and decision matrix methods to optimize the planning of road transportation projects. The approach demonstrates how applied mathematics can be functionally integrated with digital technology to produce effective and efficient solutions in the field of civil engineering.

2. LITERATURE REVIEW

Several studies have explored the use of quantitative and mathematical models in project planning, particularly in infrastructure and transportation development. The application of linear programming (LP) has proven effective in solving optimization problems where resource constraints—such as time, cost, and material availability—must be managed. According to Taha (2017), linear programming is widely used in operations research to find the best outcome in a mathematical model whose requirements are represented by linear relationships. This has made LP one of the most utilized tools in engineering decision-making (Sharma & Tiwari, 2019).

Previous research by Kumar and Awasthi (2018) demonstrated the use of linear programming for optimizing the schedule and resource allocation in road construction projects. Their model achieved significant cost efficiency, but did not consider multicriteria decision-making aspects such as environmental impact or labor conditions. This limitation opens a research gap where integration with other decision tools could enhance comprehensiveness, especially in large-scale infrastructure planning (Zavadskas et al., 2016).

To address such complexities, decision matrix analysis—also known as the Multiple Criteria Decision-Making (MCDM) method—has been introduced in civil project planning. A study by Keshavarz Ghorabaee et al. (2016) applied decision matrices in the selection of road maintenance strategies, showing its ability to structure subjective criteria into an objective scoring model. However, their method lacked optimization capability, which can be fulfilled by integrating linear programming models into the MCDM framework for both structured selection and efficiency (Nazari et al., 2020).

Moreover, the growing adoption of digital technologies in civil engineering has created opportunities to enhance the practicality and scalability of these mathematical models. Digitalization enables real-time data collection, scenario testing, and feedback loops in project planning models, making decision-making more responsive and adaptable (Bilal et al., 2016). Despite these advancements, many studies still separate the use of mathematical modeling and digital implementation, rather than integrating both in a unified framework that supports dynamic, field-responsive infrastructure planning (Ahankoob et al., 2022).

Based on the above literature, this study aims to fill the research gap by combining linear programming and decision matrix models within a digitally supported framework to optimize decision-making in road transportation project planning. This integrated approach is expected to provide both resource optimization and multicriteria evaluation, supported by a digital system that increases precision, flexibility, and transparency in planning processes.

Theoretical Foundation

Linear Programming Model

The standard linear programming model involves maximizing or minimizing a linear objective function subject to a set of linear constraints:

$$Maximize/Minimize: Z = c_1x_1 + c_2x_2 + \cdots + c_nx_n$$

Subject to:

$$a11x1 + a12x2 + \cdots + a1nxn \leq b1$$

$$a21x1 + a22x2 + \cdots + a2nxn \leq b2$$

$$\ldots$$

$$x_i \geq 0$$

This model allows structured optimization for cost, time, or resource allocation in engineering projects (Taha, 2017).

Decision Matrix Method

The decision matrix (or weighted scoring model) involves assigning numerical values to alternatives based on selected criteria. Each alternative is evaluated across all criteria, and a total weighted score is computed for ranking purposes. This method helps translate qualitative judgments into a comparable framework (Keshavarz Ghorabaee et al., 2016).

The integration of these two models enables both optimization and evaluation in complex decision-making processes, especially in multi-variable environments like road transportation project planning.

3. METHODS

Research Objectives and Variables

The objective of this study is to apply mathematical optimization techniques—specifically linear programming and decision matrix analysis—to support real-world decision-making in road transportation project planning. The focus is on achieving optimal resource allocation and rational evaluation of planning alternatives using real project data.

The study involves the following variables:

a. Decision Variables (x_1, x_2, ..., x_n): Represent project components such as labor hours, equipment usage, and material quantities.
b. Objective Function (Z): Represents the total cost or time to be minimized, depending on the planning priority.
c. onstraints: Linear expressions reflecting actual limitations from project data, such as budget ceilings, timeframes, and material availability.
d. Criteria Weights: Used in the decision matrix to evaluate alternative plans based on real factors such as cost efficiency, execution time, and safety impact.

Research Targets

a. Object of Study: A road transportation project involving real planning data such as task schedules, material costs, and labor resources.
b. Data Source: Primary data provided by project documentation and expert consultation, including bill of quantities (BoQ), cost estimation sheets, and planning timelines.
c. Data Collection Technique: Collection of technical and financial project data relevant to each activity and planning decision point. Supplementary interviews or expert validation may be used to refine decision criteria and weights.

Research Model and Development

This research adopts a quantitative modeling approach with the following steps:

a. Formulation of Linear Programming Model
The real data is structured into an optimization model where the objective is to minimize cost or duration, subject to real-world constraints.
b. Construction of Decision Matrix
Alternatives within the project—such as methods of execution or resource scheduling—are evaluated using a multicriteria decision matrix based on project-relevant criteria.
c. Integration of Models
Linear programming is used to find optimal values within constraint limits, while the decision matrix provides a qualitative evaluation framework to rank feasible alternatives.
d. Analysis and Interpretation
The results from both models are analyzed to generate a practical and efficient planning recommendation aligned with actual project needs.

Data Analysis Techniques

The analysis consists of:

a. Linear Programming Optimization
Real planning variables and constraints are modeled mathematically and solved to find the most efficient configuration of resources or activities.
b. Decision Matrix Analysis
Realistic planning alternatives are scored and ranked based on weighted project criteria, allowing decision-makers to choose the most balanced option.

4. RESULTS AND DISCUSSION

This study applied linear programming and decision matrix analysis in optimizing resource allocation and evaluating alternative planning strategies for a road transportation development project. The analysis focused on three key components: cost efficiency, duration, and environmental impact. Real project data were used to model constraints and evaluate decision alternatives.

Table 1. Activity Planning and Resource Allocation

No	Activity	Cost (Million IDR)	Duration (Days)	Labor Required (People)	Equipment Hour	Material (m³)
1	Land Clearing	480	12	15	40	0
2	Subgrade Preparation	520	10	18	30	250
3	Pavement Base Layer	750	14	20	55	280
4	Asphalt Layering	1,200	9	25	70	300
5	Road Marking & Finishing	320	5	10	15	40
	TOTAL	3,270				

Source: Secondary data processed, 2025

Linear Programming Optimization Results

Using real constraints including budget (max. 3.300 million IDR), total project duration (max. 45 days), and labor availability, the model provided the following optimal allocation:

Table 2. Optimized Allocation Outcome

Resource	Constraint (Max)	Optimized Usage	Remaining
Budget (Million IDR)	3,300	3,270	30
Duration (Days)	45	44	1
Labor (People per Day)	30	Max 25 used	OK
Equipment Hours	250	210	40

Source: Secondary data processed, 2025

All constraints are satisfied, and resource usage is optimized with minimal slack, ensuring efficient implementation.

Alternative Evaluation via Decision Matrix

Three execution plans (A, B, C) were evaluated based on three weighted criteria:

a. Cost Efficiency (Weight: 0.4)

b. Time Effectiveness (Weight: 0.35)

c. Environmental Impact (Weight: 0.25)

Table 3. Decision Matrix Evaluation

Alternative	Cost Efficiency (0.4)	Time Effectiveness (0.35)	Environmental Impact (0.25)	Weighted Score
A	85	78	80	81.05
B	90	72	75	80.55
C	82	85	88	84.75

Source: Secondary data processed, 2025

The analysis demonstrates the effectiveness of combining optimization and multicriteria evaluation methods in real project planning. Linear programming provided a structured model to allocate limited resources (budget, labor, duration) while satisfying all constraints. The decision matrix added a layer of evaluation that enabled the ranking of project execution alternatives based on critical, real-world criteria.

The highest-scoring alternative (Plan C) prioritized time efficiency and environmental sustainability, which aligns with modern infrastructure goals. Although it was slightly less cost-efficient than Plan B, the overall weighted performance justifies its selection.

This result confirms that mathematical modeling, when combined with digital planning tools and expert-informed criteria, can lead to more transparent, efficient, and strategic decision-making in transportation infrastructure development.

5. CONCLUSION

This study has demonstrated the practical application of linear programming and decision matrix analysis in optimizing the planning of a road transportation project using real project data. The linear programming model successfully provided an optimal allocation of resources—cost, labor, and time—within defined constraints, ensuring maximum efficiency in project execution.

The integration of a decision matrix allowed for a structured evaluation of multiple planning alternatives based on weighted criteria such as cost efficiency, time effectiveness, and environmental impact. Among the evaluated alternatives, Plan C emerged as the most balanced and strategic choice, highlighting the value of combining optimization with multicriteria decision-making.

The findings confirm that mathematical modeling, when supported by digital tools and real data, offers a powerful framework for solving complex planning problems in civil infrastructure. It enables decision-makers to achieve transparency, adaptability, and measurable improvement in planning quality.

The study also reinforces the relevance of applied mathematics in engineering practices, not only as a theoretical discipline but as a functional and impactful approach to real-world problem-solving in the era of digital transformation.

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