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A Systematic Literature Review On The Development Of A Systems Engineering Management Model Based On Value Engineering And Multi-Criteria Decision-Making For Material Selection In Roads Fund Infrastructure Projects In Timor-Leste

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Abstract

Material selection is a critical decision-making process in road infrastructure projects because it directly affects construction costs, technical performance, sustainability, and long-term maintenance requirements. Existing decision-making practices in many developing countries, including Timor-Leste, primarily focus on initial costs and often neglect functional value, lifecycle performance, and sustainability considerations. This study aims to develop a Systems Engineering Management (SEM) model based on Value Engineering (VE) and Multi-Criteria Decision-Making (MCDM) for material selection in Roads Fund Infrastructure Projects in Timor-Leste. A Systematic Literature Review (SLR) following the PRISMA 2020 guidelines was conducted using publications indexed in Scopus and Web of Science from 2015 to 2025. The review identified key criteria, decision-making methods, and integration frameworks related to VE, MCDM, and SEM. The

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findings indicate that integrating VE and MCDM within a systems engineering framework enhances decision transparency, value optimization, and sustainability. The proposed model provides a comprehensive decision-support framework for effective and value-based material selection in road infrastructure projects.

Keywords: Systems Engineering Management, Value Engineering, Multi-Criteria Decision-Making, Material Selection, Road Infrastructure, Timor-Leste, Systematic Literature Review.

INTRODUCTION

Infrastructure development is widely recognized as a fundamental driver of economic growth, social development, and regional connectivity. Among various types of infrastructure, road networks play a critical role in facilitating the movement of goods, services, and people while supporting national productivity and competitiveness. The quality and sustainability of road infrastructure significantly influence transportation efficiency, accessibility, and long-term socioeconomic development. Consequently, governments worldwide continue to invest heavily in road construction and rehabilitation projects to improve mobility and stimulate economic activities. World Bank reports that transport infrastructure remains one of the most important enablers of sustainable development, particularly in developing countries where infrastructure gaps continue to constrain economic performance and social inclusion.

In recent years, increasing pressure to improve infrastructure performance while controlling construction costs has intensified the need for more effective decision-making processes in construction project management. Infrastructure stakeholders are expected to achieve multiple objectives simultaneously, including cost efficiency, technical quality, environmental sustainability, resilience, and lifecycle performance. Traditional decision-making approaches that rely primarily on initial construction costs often fail to capture the complexity of these interrelated objectives, resulting in suboptimal project outcomes and increased maintenance expenditures over time. Therefore, the adoption of systematic and value-oriented decision-support frameworks has become increasingly important in infrastructure management.

One of the most widely recognized approaches for enhancing project value is Value Engineering (VE). Value Engineering is a structured methodology that seeks to maximize project value by improving functionality while minimizing unnecessary costs. Rather than focusing solely on cost reduction, VE emphasizes achieving the required functions at the lowest total cost without

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compromising quality, reliability, safety, or performance. Numerous studies have demonstrated that the application of VE can significantly improve project outcomes by identifying innovative alternatives, optimizing resource utilization, and enhancing lifecycle value in construction projects (Gouda et al., 2024).

Alongside the development of Value Engineering, the growing complexity of infrastructure projects has increased the adoption of Multi-Criteria Decision-Making (MCDM) techniques. Material selection decisions frequently involve conflicting criteria such as strength, durability, environmental impact, lifecycle cost, constructability, availability, and maintenance requirements. MCDM methods provide analytical tools that enable decision-makers to evaluate alternatives systematically based on multiple criteria simultaneously. Recent studies indicate that methods such as the Analytic Hierarchy Process (AHP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Analytic Network Process (ANP), and VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) have become increasingly popular for supporting construction material selection and infrastructure planning because of their ability to improve transparency, consistency, and objectivity in decision-making (Bajwa et al., 2025; Van Dua, 2024).

The integration of Value Engineering and Multi-Criteria Decision-Making has emerged as a promising approach for addressing the challenges associated with complex infrastructure decisions. While VE provides a systematic framework for identifying functional requirements and generating value-oriented alternatives, MCDM offers quantitative techniques for evaluating and ranking those alternatives based on multiple performance criteria. The combination of these approaches enables decision-makers to balance technical, economic, environmental, and social considerations within a single decision-support framework. Recent studies have demonstrated that integrated VE–MCDM models can substantially improve project performance, optimize resource allocation, and support sustainable infrastructure development (Elsayed, 2024; Gouda et al., 2024).

Despite these advancements, the majority of existing studies focus primarily on building construction projects, industrial applications, and manufacturing systems. Comparatively limited attention has been devoted to road infrastructure projects, particularly in developing countries where financial constraints, environmental challenges, and material availability issues create unique decision-making complexities. Furthermore, many studies apply VE and MCDM independently without integrating them within a broader Systems Engineering Management (SEM) framework. As a result, existing approaches often fail to capture the systemic interactions among project objectives, stakeholder requirements, engineering constraints, and long-term

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infrastructure performance.

Systems Engineering Management has gained increasing recognition as an effective framework for managing complex engineering systems through a holistic and lifecycle-oriented perspective. SEM integrates technical, managerial, operational, and organizational dimensions to ensure that project decisions are aligned with stakeholder needs and system objectives. By incorporating decision-support methodologies into a systems engineering framework, infrastructure organizations can improve coordination, reduce uncertainty, and enhance decision quality across the entire project lifecycle. Consequently, integrating VE and MCDM within a Systems Engineering Management framework offers a promising opportunity to establish a more comprehensive and robust model for infrastructure decision-making.

The need for such an integrated model is particularly evident in Timor-Leste, where infrastructure development remains a national priority. Since gaining independence, the Government of Timor-Leste has invested substantial financial resources in transportation infrastructure through various funding mechanisms, including the Roads Fund and Infrastructure Fund programs. Road infrastructure is considered essential for improving regional connectivity, facilitating trade, supporting rural development, and strengthening national economic integration. Nevertheless, many road projects continue to face challenges related to material performance, maintenance costs, project sustainability, and resource utilization (Government of Timor-Leste, 2020).

One of the critical challenges encountered in road infrastructure projects in Timor-Leste concerns the selection of construction materials. Material selection decisions are often influenced by short-term budget considerations rather than comprehensive evaluations of lifecycle performance, environmental sustainability, local resource availability, and long-term maintenance implications. The use of imported materials that may not be fully compatible with local climatic and geological conditions has frequently contributed to premature pavement deterioration and increased maintenance requirements. Consequently, there is a growing need for a more systematic and evidence-based decision-making framework that can support the selection of optimal materials for road infrastructure projects.

Existing planning and feasibility assessment frameworks in Timor-Leste provide limited guidance regarding the application of value-based and multi-criteria decision-making approaches in material selection processes. Current decision practices largely emphasize technical compliance and initial project costs, while broader considerations related to functionality, sustainability, risk, and lifecycle value receive less attention. This situation highlights a significant gap between

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contemporary decision-support methodologies and current infrastructure management practices in Timor-Leste.

From an academic perspective, a review of the literature reveals several important research gaps. First, there is a lack of studies that integrate Value Engineering and Multi-Criteria Decision-Making within a Systems Engineering Management framework specifically for road infrastructure projects. Second, empirical studies examining the application of integrated VE–MCDM approaches in developing countries remain limited. Third, little research has focused on the contextual adaptation of these methodologies to support infrastructure decision-making in Timor-Leste. These gaps indicate the need for a comprehensive framework capable of combining value-oriented analysis, multi-criteria evaluation, and systems thinking into a unified decision-support model.

Therefore, this study proposes the development of a Systems Engineering Management Model Based on Value Engineering and Multi-Criteria Decision-Making for Material Selection in Roads Fund Infrastructure Projects in Timor-Leste. The proposed model seeks to integrate the functional analysis capabilities of Value Engineering, the analytical rigor of Multi-Criteria Decision-Making, and the holistic perspective of Systems Engineering Management to support transparent, objective, sustainable, and value-driven material selection decisions. By addressing the identified theoretical and practical gaps, this research is expected to contribute to the advancement of infrastructure decision-making knowledge while providing practical guidance for policymakers, engineers, and project managers involved in road infrastructure development in Timor-Leste.

LITERATURE REVIEW

Systems Engineering Management in Infrastructure Projects

Systems Engineering Management (SEM) is a multidisciplinary management approach that integrates technical, organizational, economic, and operational aspects throughout the lifecycle of a project. SEM emphasizes the systematic coordination of stakeholder requirements, functional analysis, decision-making processes, risk management, and performance optimization to achieve project objectives efficiently. In infrastructure projects, SEM provides a structured framework for managing complex interactions among technical specifications, resource constraints, environmental considerations, and project stakeholders. The increasing complexity of infrastructure systems has led researchers to advocate for systems-oriented approaches that support informed decision-making and enhance project performance through integrated management processes.

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Within the context of road infrastructure development, SEM plays a critical role in facilitating trade-off analysis among competing project objectives such as cost efficiency, technical performance, sustainability, durability, and maintainability. Traditional decision-making approaches often focus on isolated technical parameters, whereas SEM promotes holistic evaluation by considering interdependencies among system components. This systems perspective is particularly relevant for Roads Fund Infrastructure projects in developing countries, where financial constraints, environmental challenges, and limited availability of construction materials require more comprehensive decision-support mechanisms.

Recent developments in systems engineering emphasize the integration of advanced decision-support tools into management frameworks. The combination of structured engineering methodologies with multi-criteria decision-making techniques has been identified as an effective strategy for improving decision transparency, reducing uncertainty, and enhancing infrastructure sustainability. As a result, SEM has increasingly become a foundational framework for integrating Value Engineering and Multi-Criteria Decision-Making in construction and infrastructure management.

Value Engineering Theory and Applications

Value Engineering (VE) is a systematic methodology aimed at maximizing project value by improving functional performance while minimizing lifecycle costs. The concept of value is generally defined as the ratio between function and cost, where improvements can be achieved either by increasing functionality without increasing costs or by reducing costs without compromising performance. Since its introduction by Miles, VE has evolved into one of the most widely adopted approaches for cost optimization and performance enhancement in construction projects.

The VE process typically consists of information gathering, function analysis, creative idea generation, evaluation of alternatives, development of recommendations, and implementation planning. Through these stages, project teams systematically evaluate existing designs and identify alternative solutions capable of delivering superior value. Contemporary studies demonstrate that VE contributes significantly to reducing construction costs while maintaining or improving technical performance and quality standards.

Recent research has expanded the scope of VE beyond cost reduction toward sustainability and innovation. Gouda et al. (2024) proposed an integrated framework combining Building Information Modeling (BIM) and Value Engineering, demonstrating that digital technologies can

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significantly improve the efficiency of value analysis and alternative evaluation. Their findings indicate that integrating BIM with VE enhances project value optimization by enabling more accurate assessment of design alternatives and lifecycle costs.

The growing emphasis on sustainable construction has also increased the relevance of VE in material selection. Researchers have shown that VE can support the identification of environmentally responsible materials while simultaneously improving economic performance. By incorporating sustainability criteria into function analysis, VE enables project stakeholders to evaluate alternatives based on long-term value rather than initial costs alone. This capability is particularly important for road infrastructure projects, where material choices significantly influence lifecycle performance and maintenance costs.

Multi-Criteria Decision-Making for Material Selection

Material selection is recognized as one of the most complex decision-making processes in construction engineering because multiple technical, economic, environmental, and social criteria must be evaluated simultaneously. The increasing demand for sustainable and resilient infrastructure has further intensified the complexity of material selection decisions. Consequently, Multi-Criteria Decision-Making (MCDM) methods have emerged as essential tools for supporting objective and transparent decision-making in construction projects.

MCDM refers to a group of analytical methods designed to evaluate and rank alternatives based on multiple criteria that may be conflicting in nature. Among the most frequently applied techniques are the Analytic Hierarchy Process (AHP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR), Analytic Network Process (ANP), PROMETHEE, and COPRAS. These methods provide systematic procedures for assigning weights to criteria and evaluating alternative solutions according to stakeholder preferences and project objectives.

Recent systematic reviews indicate a substantial increase in the application of MCDM methods for sustainable material selection within the construction industry. Bajwa et al. (2025) found that hybrid MCDM approaches are becoming increasingly dominant because they combine the strengths of multiple techniques and improve decision robustness. Their review revealed that AHP, TOPSIS, and VIKOR remain the most frequently used methods for evaluating construction materials under sustainability criteria.

The popularity of AHP stems from its ability to decompose complex decisions into hierarchical structures and quantify expert judgments through pairwise comparisons. By

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calculating priority weights and consistency ratios, AHP provides a rigorous mechanism for determining the relative importance of evaluation criteria. Consequently, AHP has become one of the most widely used methods in construction material selection and infrastructure planning.

TOPSIS has also gained widespread acceptance because it evaluates alternatives based on their relative proximity to an ideal solution and distance from a negative ideal solution. The method is computationally efficient and capable of handling large decision matrices involving multiple criteria and alternatives. Studies consistently report that TOPSIS performs effectively when integrated with weighting methods such as AHP, resulting in more reliable and practical decision-support systems.

Integration of Value Engineering and Multi-Criteria Decision-Making

Although VE and MCDM have traditionally been applied independently, recent studies emphasize the benefits of integrating these approaches within a unified decision-support framework. VE provides the functional and value-oriented perspective necessary for identifying alternative solutions, while MCDM supplies the analytical tools required to evaluate and rank those alternatives systematically. The integration of both approaches enables decision-makers to consider functional performance, economic feasibility, sustainability, and stakeholder preferences simultaneously.

Research demonstrates that combining VE and MCDM improves the quality of material selection decisions by introducing quantitative rigor into the value analysis process. Alternative materials identified during VE workshops can be evaluated using MCDM techniques such as AHP and TOPSIS, allowing project teams to prioritize options according to multiple performance criteria. This integrated approach enhances transparency, consistency, and accountability in infrastructure decision-making.

Aldrees et al. (2025) developed an integrated Value Engineering and Multi-Criteria Decision-Making framework for selecting alternative pipe materials in construction projects. Their findings indicate that automation of the VE process combined with MCDM evaluation significantly improves the efficiency and reliability of material selection. The study highlights the potential of integrating value-oriented analysis with analytical decision models for infrastructure applications.

The increasing adoption of hybrid decision models reflects a broader trend toward data-driven infrastructure management. Several studies suggest that the integration of VE, MCDM, BIM, lifecycle assessment, and sustainability indicators can substantially improve project outcomes by balancing cost, functionality, environmental performance, and long-term resilience.

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Such developments provide a strong foundation for the creation of advanced Systems Engineering Management models tailored to infrastructure decision-making.

Material Selection in Road Infrastructure Projects

Material selection significantly influences the performance, durability, sustainability, and lifecycle costs of road infrastructure projects. Inadequate material selection may result in premature pavement deterioration, increased maintenance costs, reduced service life, and poor environmental performance. Consequently, selecting appropriate construction materials is considered a strategic decision that directly affects project success.

Traditional material selection approaches have often prioritized initial construction costs, overlooking broader considerations such as lifecycle performance, environmental impact, resource availability, and maintenance requirements. However, contemporary infrastructure management increasingly recognizes the importance of adopting holistic evaluation frameworks that incorporate economic, technical, environmental, and social criteria. This shift has accelerated the adoption of MCDM-based decision-support systems in road engineering and infrastructure planning.

The application of hybrid decision models is particularly relevant in developing countries, where infrastructure agencies must balance budget limitations with the need for durable and sustainable road networks. Factors such as local material availability, transportation costs, climatic conditions, environmental regulations, and technical performance requirements often create complex trade-offs that cannot be adequately addressed through single-criterion decision approaches. As a result, integrated VE–MCDM frameworks have emerged as promising solutions for supporting evidence-based material selection in road infrastructure projects.

Research Gap and Conceptual Foundation

Despite substantial progress in the fields of Value Engineering and Multi-Criteria Decision-Making, the literature reveals several important gaps. Most existing studies focus on building construction projects rather than road infrastructure systems. Furthermore, many investigations apply VE and MCDM independently, without integrating them within a broader Systems Engineering Management framework. This limitation restricts the ability of existing models to address the complexity of infrastructure decision-making, particularly in resource-constrained environments.

Another notable gap concerns the limited number of studies conducted in developing

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countries, especially within the context of Timor-Leste. Existing Roads Fund and infrastructure planning frameworks in Timor-Leste provide limited guidance regarding systematic, value-based, and multi-criteria material selection processes. Consequently, there remains a need for a comprehensive Systems Engineering Management model capable of integrating Value Engineering and Multi-Criteria Decision-Making into a unified decision-support framework specifically designed for road infrastructure projects.

Based on the identified gaps, this study proposes the development of a Systems Engineering Management model that integrates Value Engineering and Multi-Criteria Decision-Making for material selection in Roads Fund Infrastructure Projects in Timor-Leste. The proposed framework seeks to combine the functional orientation of VE, the analytical rigor of MCDM, and the systemic perspective of SEM to support transparent, sustainable, and evidence-based infrastructure decision-making. Top of Form

METHODOLOGY

Research Approach

This study adopts a Systematic Literature Review (SLR) approach based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines developed by Page et al. (2021). The SLR method was selected because it enables the identification, selection, evaluation, and synthesis of scientific evidence through a rigorous, transparent, and replicable process. In this study, the SLR is employed to examine the development of research concerning the integration of Systems Engineering Management (SEM), Value Engineering (VE), and Multi-Criteria Decision-Making (MCDM) in material selection for road infrastructure projects. The synthesized findings serve as the theoretical and conceptual foundation for developing a Systems Engineering Management model based on Value Engineering and Multi-Criteria Decision-Making that is suitable for Roads Fund Infrastructure Projects in Timor-Leste.

The PRISMA 2020 framework was chosen because it is currently recognized as the international standard for conducting and reporting systematic reviews. It provides a structured procedure for literature searching, duplicate removal, screening, eligibility assessment, and final study inclusion. By applying PRISMA 2020, this study aims to achieve a high level of methodological rigor while minimizing selection bias and ensuring transparency throughout the review process.

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Research Questions

This systematic review is designed to address several research questions related to the development and integration of Value Engineering, Multi-Criteria Decision-Making, and Systems Engineering Management in the context of material selection for road infrastructure projects.

The review seeks to investigate how Value Engineering has been applied in construction and road infrastructure projects, identify the most widely used MCDM techniques for material selection, examine the integration of VE and MCDM within Systems Engineering Management frameworks, explore the critical factors influencing decision-making effectiveness in material selection, and establish a conceptual foundation for developing a Systems Engineering Management model tailored to Roads Fund Infrastructure Projects in Timor-Leste.

Literature Search Strategy

A systematic literature search was conducted using several internationally recognized databases indexed in Scopus and Web of Science. The selection of databases was based on their extensive coverage of engineering, construction management, decision sciences, and systems engineering research.

Table 3.1 Databases Used for Literature Search

No.	Database
1	Scopus
2	Web of Science Core Collection
3	ScienceDirect
4	SpringerLink
5	Wiley Online Library
6	Taylor & Francis Online
7	IEEE Xplore

The literature search covered publications from January 2015 to December 2025. This time frame was selected to capture the most recent developments in Value Engineering, Multi-Criteria Decision-Making, Systems Engineering Management, sustainable construction, and material selection research.

The search strategy employed combinations of keywords and Boolean operators (AND, OR). The principal search terms included Value Engineering, Multi-Criteria Decision-Making,

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Material Selection, Road Infrastructure, Road Construction, Pavement Engineering, Systems Engineering, and Systems Engineering Management. Searches were conducted within article titles, abstracts, and keywords to maximize relevance while maintaining a manageable scope of literature.

Inclusion and Exclusion Criteria

To ensure the quality and relevance of the reviewed literature, strict inclusion and exclusion criteria were applied. The inclusion criteria were designed to identify studies directly related to the research objectives, while the exclusion criteria were intended to eliminate studies lacking methodological rigor or substantive relevance.

Table 3.2 Inclusion and Exclusion Criteria

Criteria	Inclusion	Exclusion
Publication Year	2015–2025	Before 2015
Document Type	Peer-reviewed journal articles	Books, conference proceedings, theses, editorials
Language	English	Non-English
Indexing	Scopus or Web of Science	Non-indexed publications
Research Topic	VE, MCDM, SEM, Material Selection	Irrelevant topics
Full Text Availability	Available	Unavailable

The application of these criteria ensured that only high-quality studies with direct relevance to the development of SEM, VE, and MCDM frameworks for material selection were included in the review.

Systematic Literature Review Procedures Based on PRISMA 2020

The systematic review followed the four main stages recommended by the PRISMA 2020 guidelines, namely Identification, Screening, Eligibility, and Included Studies. Each stage was conducted sequentially to ensure that only studies meeting all predefined criteria were retained for the final synthesis.

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Identification Stage

The identification stage involved systematic searches across all selected databases using the predefined search strings. The retrieved records were exported into reference management software and spreadsheet databases to facilitate data management and duplicate detection.

Table 3.3 Results of Literature Identification

Database Source	Number of Records
Scopus	682
Web of Science	274
ScienceDirect	241
SpringerLink	127
Wiley Online Library	74
Taylor & Francis Online	51
IEEE Xplore	37
Total	1,486

The search process resulted in a total of 1,486 records, with the majority originating from Scopus and Web of Science, reflecting their extensive coverage of engineering, management, and construction-related research.

Screening Stage

During the screening stage, duplicate records were removed, followed by a preliminary assessment of titles and abstracts. Studies that were not directly related to Value Engineering, Multi-Criteria Decision-Making, Systems Engineering Management, road infrastructure, or material selection were excluded.

Table 3.4 Screening Results

Description	Number of Records
Records identified	1,486
Duplicate records removed	286
Remaining records	1,200
Excluded based on title screening	648
Excluded based on abstract screening	344
Records retained for full-text assessment	208

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Most of the excluded studies focused on applications of MCDM in manufacturing, healthcare, energy systems, and supply chain management, which were outside the scope of this review.

Eligibility Stage

The eligibility stage involved a comprehensive full-text review of all remaining articles. Each study was assessed in terms of research objectives, methodological approach, variables investigated, empirical validation, and relevance to the development of SEM, VE, and MCDM frameworks.

Table 3.5 Reasons for Full-Text Exclusion

Reason for Exclusion	Number of Articles
Did not address material selection	38
Did not employ VE or MCDM approaches	42
Lacked empirical validation	26
Full text unavailable or incomplete	11
Not related to road infrastructure or construction	34
Total excluded	151

The full-text assessment revealed that several studies addressed decision-making methodologies in general but did not specifically focus on construction material selection or systems engineering applications in road infrastructure projects.

Included Studies Stage

Studies that satisfied all inclusion criteria and passed the quality assessment process were included in the final synthesis. These studies were analyzed to identify research trends, methodological approaches, key variables, conceptual frameworks, and research gaps relevant to the development of an integrated SEM–VE–MCDM model.

Table 3.6 Distribution of Included Studies

Research Theme	Number of Studies
Value Engineering	13
MCDM-Based Material Selection	18

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AHP and TOPSIS Applications	12
Systems Engineering Management	7
Integration of VE and MCDM	7
Total	57

A total of 57 studies were ultimately included in the qualitative synthesis. This number is considered sufficiently comprehensive to capture the current state of knowledge while maintaining a focused review of the specific research domain.

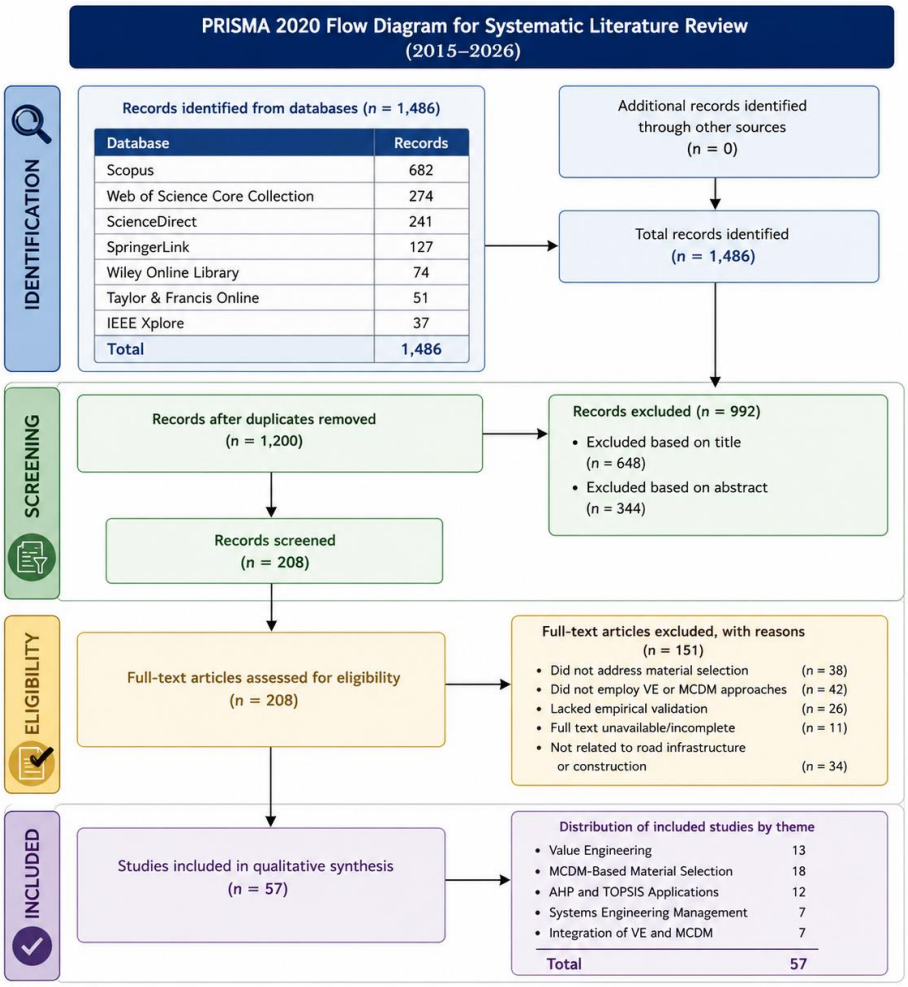


Figure 1.
PRISMA 2020 Flow Diagram for the A Systematic Literature Review on the Development of a Systems Engineering Management Model Based on Value Engineering and Multi-Criteria Decision-Making for Material Selection in Roads Fund Infrastructure Projects in Timor-Leste, 2015 to 2026

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Figure 3.1. PRISMA 2020 Flow Diagram for the Systematic Literature Review on the Development of a Systems Engineering Management Model Based on Value Engineering and Multi-Criteria Decision-Making for Material Selection in Roads Fund Infrastructure Projects in Timor-Leste

RESULTS AND DISCUSSION

Overview of the Literature Review Results

This study employed a Systematic Literature Review (SLR) following the PRISMA 2020 guidelines to identify, evaluate, and synthesize scientific evidence related to Systems Engineering Management (SEM), Value Engineering (VE), Multi-Criteria Decision-Making (MCDM), and material selection in road infrastructure projects. The literature search covered publications indexed in Scopus and Web of Science between January 2015 and December 2025. Following the identification, screening, eligibility assessment, and inclusion stages, a total of 57 studies met all inclusion criteria and were retained for qualitative synthesis.

The selected studies demonstrate a significant increase in scholarly interest in decision-support frameworks for infrastructure management over the past decade. The findings reveal that Value Engineering and Multi-Criteria Decision-Making have become increasingly important tools for addressing the complexity of material selection decisions in construction projects. However, the literature also indicates that these approaches are often applied separately rather than within an integrated Systems Engineering Management framework. This observation highlights an important research opportunity for developing a comprehensive decision-support model specifically tailored to road infrastructure projects in Timor-Leste.

Publication Trends and Research Distribution

The distribution of publications reveals a growing research interest in sustainable infrastructure decision-making, particularly after 2020. This trend corresponds with the increasing global emphasis on lifecycle performance, sustainability assessment, resilience, and digital transformation within the construction industry. The majority of the reviewed studies were published between 2021 and 2025, indicating that integrated approaches combining engineering management, sustainability, and decision science represent an emerging research domain.

Table 4.1 Distribution of Included Studies by Research Theme

Research Theme	Number of Studies	Percentage (%)

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Material Selection Using MCDM	18	31.58
Value Engineering Applications	13	22.81
AHP and TOPSIS Applications	12	21.05
Systems Engineering Management	7	12.28
Integration of VE and MCDM	7	12.28
Total	57	100.00

The results indicate that MCDM-based material selection represents the dominant research theme, accounting for approximately 31.58% of the included studies. This finding suggests that researchers increasingly recognize the complexity of infrastructure material decisions and the need for structured analytical approaches. In contrast, studies focusing explicitly on Systems Engineering Management account for only 12.28% of the reviewed literature, indicating that SEM remains underexplored within the context of infrastructure material selection.

Value Engineering in Material Selection

The literature demonstrates that Value Engineering has evolved from a traditional cost-reduction methodology into a comprehensive value optimization framework. Earlier studies primarily emphasized minimizing project costs without compromising functionality. However, more recent studies increasingly incorporate sustainability, lifecycle performance, environmental impact, and stakeholder value into the VE process.

The reviewed literature consistently shows that VE contributes significantly to identifying alternative materials capable of delivering equivalent or improved functionality at lower lifecycle costs. Several studies report that VE implementation can reduce project costs by 10% to 25% while maintaining or enhancing technical performance. Furthermore, the integration of digital technologies such as Building Information Modeling (BIM) has improved the effectiveness of VE workshops by facilitating the visualization and evaluation of design alternatives.

From a road infrastructure perspective, VE enables decision-makers to evaluate materials not only based on initial acquisition costs but also on durability, maintenance requirements, environmental performance, and long-term serviceability. This broader perspective is particularly relevant for Timor-Leste, where road infrastructure projects frequently operate under budget constraints while requiring durable solutions capable of withstanding tropical climatic conditions.

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Multi-Criteria Decision-Making Methods for Material Selection

The findings indicate that MCDM methods have become the dominant analytical tools for material selection in construction and infrastructure projects. Among the various techniques identified, the Analytic Hierarchy Process (AHP) emerged as the most frequently applied method due to its ability to structure complex decisions and quantify expert judgments through pairwise comparisons.

TOPSIS was identified as the second most frequently used method because of its ability to rank alternatives according to their proximity to an ideal solution. Many studies employ a hybrid AHP-TOPSIS approach, whereby AHP determines criterion weights and TOPSIS ranks alternative materials. This combination is widely regarded as one of the most effective approaches for material selection because it combines expert knowledge with mathematical rigor.

Table 4.2 Most Frequently Applied MCDM Methods

Method	Frequency	Percentage (%)
AHP	21	36.84
TOPSIS	17	29.82
VIKOR	8	14.04
ANP	5	8.77
PROMETHEE	3	5.26
Others	3	5.26
Total	57	100.00

The dominance of AHP and TOPSIS reflects their flexibility, ease of implementation, and suitability for infrastructure decision-making. These methods allow decision-makers to evaluate multiple criteria simultaneously while maintaining transparency and consistency throughout the decision process.

Integration of Value Engineering and Multi-Criteria Decision-Making

One of the most important findings of this review concerns the increasing trend toward integrating VE and MCDM within a unified decision-support framework. The literature demonstrates that VE and MCDM complement each other effectively because each addresses different aspects of decision-making.

Value Engineering primarily focuses on identifying project functions, evaluating value, and

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generating alternative solutions. In contrast, MCDM methods provide mathematical mechanisms for evaluating and prioritizing these alternatives according to multiple criteria. Consequently, integrating VE and MCDM creates a more comprehensive framework capable of supporting complex infrastructure decisions.

Several studies report that integrated VE-MCDM frameworks improve decision quality by reducing subjectivity, increasing transparency, and ensuring that both qualitative and quantitative factors are considered. These integrated approaches are particularly effective for evaluating construction materials, where technical, economic, environmental, and social criteria must be balanced simultaneously.

Table 4.3 Comparative Roles of VE and MCDM

Aspect	Value Engineering	MCDM
Primary Objective	Value Optimization	Alternative Ranking
Focus	Function and Cost	Multiple Criteria Evaluation
Nature	Qualitative and Functional	Quantitative and Analytical
Output	Alternative Solutions	Priority Ranking
Contribution	Value Improvement	Decision Support

The complementary nature of these approaches supports their integration within a Systems Engineering Management framework, thereby enhancing overall decision effectiveness.

Systems Engineering Management as an Integrative Framework

The review findings indicate that Systems Engineering Management provides the most suitable framework for integrating VE and MCDM into a unified infrastructure decision-support model. SEM emphasizes holistic thinking, stakeholder integration, lifecycle management, and systems optimization, making it particularly relevant for complex infrastructure projects.

Unlike conventional decision-making approaches, SEM considers infrastructure projects as interconnected systems rather than isolated technical components. This perspective enables decision-makers to evaluate interactions among project objectives, technical requirements, environmental conditions, stakeholder expectations, and resource constraints.

The literature suggests that integrating VE and MCDM within SEM can improve project outcomes by supporting systematic decision-making across the entire project lifecycle. Such integration facilitates better coordination among stakeholders, enhances transparency, and

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reduces uncertainty associated with material selection decisions.

Development of the Proposed SEM–VE–MCDM Model

Based on the synthesis of the reviewed literature, this study proposes a conceptual framework consisting of three integrated components: Systems Engineering Management, Value Engineering, and Multi-Criteria Decision-Making.

The first component involves Systems Engineering Management, which establishes the overall governance structure, stakeholder requirements, system objectives, and decision-making environment. The second component consists of Value Engineering activities, including function analysis, value assessment, and alternative generation. The third component comprises Multi-Criteria Decision-Making methods, specifically AHP and TOPSIS, which are used to determine criterion weights and rank alternative materials.

Table 4.4 Proposed SEM–VE–MCDM Framework

Framework Component	Main Function
Systems Engineering Management	System integration and decision governance
Value Engineering	Function analysis and value optimization
AHP	Criteria weighting
TOPSIS	Alternative ranking
Decision Support Output	Optimal material selection

The proposed framework provides a structured process for selecting road construction materials based on technical performance, economic feasibility, environmental sustainability, and stakeholder requirements.

Implications for Roads Fund Infrastructure Projects in Timor-Leste

The findings have significant implications for infrastructure management in Timor-Leste. Current material selection practices often prioritize initial costs without adequately considering lifecycle performance, sustainability, and maintenance requirements. Such practices can lead to increased maintenance expenditures and reduced infrastructure durability.

The proposed SEM–VE–MCDM model offers a more systematic and evidence-based approach to material selection by integrating value analysis, multi-criteria evaluation, and systems thinking. The model enables Roads Fund decision-makers to evaluate alternative materials

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comprehensively and transparently while considering the unique environmental, economic, and institutional conditions of Timor-Leste.

Furthermore, the framework can support policy development by providing a standardized methodology for material evaluation within feasibility studies, project planning, and infrastructure investment decisions. The adoption of such a model has the potential to improve resource allocation, enhance infrastructure sustainability, and increase the long-term value of public investments in road infrastructure.

DISCUSSION

The review identifies several critical gaps in the existing literature. First, there remains a limited number of studies that integrate Systems Engineering Management, Value Engineering, and Multi-Criteria Decision-Making within a single decision-support framework. Second, most existing studies focus on building construction rather than road infrastructure projects. Third, empirical research conducted in developing countries remains scarce, particularly in Southeast Asia and Timor-Leste.

These findings confirm the originality and significance of the present study. By proposing a Systems Engineering Management model based on Value Engineering and Multi-Criteria Decision-Making for material selection in Roads Fund Infrastructure Projects in Timor-Leste, this research contributes both theoretically and practically to the advancement of infrastructure decision-support systems.

CONCLUSION

This systematic literature review demonstrates that the integration of Systems Engineering Management (SEM), Value Engineering (VE), and Multi-Criteria Decision-Making (MCDM) provides a comprehensive and robust framework for material selection in road infrastructure projects. The findings indicate that Value Engineering contributes to identifying and optimizing functional value, while MCDM methods, particularly AHP and TOPSIS, offer systematic and transparent mechanisms for evaluating and ranking material alternatives based on multiple technical, economic, environmental, and sustainability criteria. The review further reveals that although substantial research has been conducted on VE and MCDM independently, studies integrating these approaches within a Systems Engineering Management framework remain limited, particularly in the context of road infrastructure projects in developing countries. Based on the synthesis of 57 selected studies, this research proposes an integrated SEM–VE–MCDM

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conceptual framework that supports value-based, evidence-driven, and sustainable material selection decisions. The proposed model has significant potential to enhance decision quality, optimize resource utilization, improve infrastructure performance, and strengthen long-term sustainability in Roads Fund Infrastructure Projects in Timor-Leste.

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