

BIM-Integrated InfraWorks and MCDM Approaches for Road Alignment Selection: Comparative Evaluation Using VIKOR and TOPSIS

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Abstract Traditionally, the planning and design of road infrastructure projects relied on conventional methods. However, with technological advancements, the InfraWorks tool, integrated into BIM, has become essential for planning these projects in a realistic environment. This process begins with the evaluation of multiple route alternatives, comparing them based on technical, environmental, and economic criteria, to select the optimal option. The primary objective of this research is to replace the most flood-prone road section among those connecting the city of Sidi Belattar to RN 90, located on the left bank of the Chellif River in Algeria. To achieve this, the multi-criteria decision-making (MCDM) methods VIKOR and TOPSIS are used to evaluate and rank the different options. The analysis is based on MCDM methods, combining two complementary approaches: VIKOR (VIsekriterijumsko KOMpromisno Rangiranje) and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), to rank the alternatives. The results revealed a general consistency between the two methods, designating the first alternative as the optimal solution to replace the vulnerable section of the existing route. In conclusion, this approach represents a significant advancement thanks to the integration of InfraWorks and MCDM methods, offering an innovative approach to optimize the planning and design of road infrastructure

from the early stages of development.

Keywords Road, InfraWorks, BIM, VIKOR, TOPSIS, MCDM

1. Introduction

The planning and design of road infrastructure projects have traditionally relied on conventional techniques. However, with the advent of digital technologies in infrastructure planning, Building Information Modeling (BIM) has emerged as a powerful tool that streamlines planning, design, project management, and the analysis of areas typically inaccessible to operators [1], [2]. This enables a more scalable and integrated approach. By ensuring more efficient sharing of information and better coordination of activities, BIM can greatly promote collaboration between the various stakeholders in a road project [3], [4].

In the road sector, the launch of an infrastructure project generally begins with the preliminary design phase (PDP). This stage's objective is to produce, evaluate, and categorize various design alternatives. The process of choosing between these variants is a particularly complex

and poorly structured problem, especially in the field of civil engineering, and more specifically in road infrastructure projects [5]. The PDP phase provides an in-depth evaluation of the different variants according to various topographical, geological, environmental and economic criteria, with the aim of identifying the most suitable alternative. These methods make it possible to consider heterogeneous and often contradictory criteria, integrating the preferences of the various stakeholders. For example, Toan [6] demonstrates how the progressive removal of variations allows for the adjustment of the final ranking's sensitivity while taking the relative significance of the criteria into account. At this point, making decisions is essential to the project's success. Once all the alternatives have been analyzed, the variant with the best performance is selected for further development during the detailed design phase (DDP).

In this context, multi-criteria decision-making (MCDM) methods play a fundamental role in improving the quality of the decision-making process and ensuring more informed choices, helping decision-makers to choose between alternatives involving multiple conflicting criteria [7].

Among the MCDM approaches, the VIKOR and TOPSIS methods offer complementary advantages, making them particularly suitable for evaluating road route alternatives. VIKOR aims to identify an optimal compromise solution by considering the proximity of alternatives to the ideal and the balance between conflicting criteria [8], while TOPSIS ranks options based on their relative distance from the ideal and anti-ideal solutions [9]. Their joint integration, combined with the use of three-dimensional modelling tools such as Autodesk InfraWorks, enables a more detailed, visual, and interactive analysis of design alternatives [10]. This methodological approach improves the quality of the decision-making process by providing stakeholders with a rigorous and multidimensional assessment of the available alternatives, considering technical, economic and environmental constraints from the earliest stages of planning.

The integration of the BIM approach through InfraWorks with MCDM is a major advance in road infrastructure planning [11]. Autodesk InfraWorks software allows high-fidelity modeling of the existing environment using a wide range of geospatial data. The result is a realistic, accurate and contextualized representation of the territory from the earliest stages of the project, providing a solid basis for technical analysis and decision-making. This 3D representation is not limited to simple visualization. It also allows for a detailed examination of the interactions between the different components of the project, facilitating the identification of technical, topographical or environmental constraints. The preliminary analysis tools integrated into InfraWorks offer advanced features based on quantitative criteria such as fill

and excavation volumes, route lengths and gradients. In traditional approaches, these criteria were often evaluated in a simplistic manner, using binary indicators such as 'plus' or 'minus,' which significantly limited the depth of the analysis. In contrast, InfraWorks provides accurate and actionable technical data, which is essential for rigorously evaluating the relevance of each design variant. Thanks to its interactive and immersive environment, InfraWorks improves overall understanding of the project and enhances communication between stakeholders by providing intuitive and educational visual aids. This advanced visualization capability facilitates the simplification, structuring, and objectification of the collective decision-making process. This paradigm shift reflects a transition toward a more integrated and multidimensional evaluation approach, more closely aligned with the complexity of technical, economic, and environmental challenges. It thus enables the identification of the optimal solution that meets the project's objectives in a more rigorous and transparent manner.

At the same time, several studies have examined the integration of BIM into the decision-making process related to infrastructure management. For example, Ariffin et al. [12] analyzed the factors influencing the adoption of the BIM-FM approach in facility management in Malaysia, highlighting the need to introduce it from the initial stages of projects. Similarly, Pathan et al. [13] showed that combining BIM with multi-criteria decision analysis methods could increase the resilience of infrastructure to natural hazards, particularly flooding. However, an in-depth review of the literature highlights a significant gap: the lack of effective integration between 3D modelling environments, such as Autodesk InfraWorks, and MCDM methods, particularly during the preliminary design phase. More specifically, none of the reviewed studies employed a 3D modeling tool to automatically extract the technical indicators required for evaluating and ranking route alternatives. This discontinuity limits the exploitation of the analytical and visual potential offered by current digital tools. In this context, we regard the incorporation of such an approach as a significant step forward in methodological development. It would make it possible to improve the accuracy of the analysis, objectify the decision-making process, and promote a more rigorous and transparent evaluation of route alternatives. Such an approach would also contribute to scientific innovation in the field of road infrastructure by bringing digital modeling and decision-making techniques closer together.

Finally, this study aims to propose an integrated decision-making methodology combining advanced digital visualization tools (InfraWorks) with powerful multi-criteria algorithms (TOPSIS & VIKOR). The approach is applied to a case study involving the reconfiguration of a road section vulnerable to localized flooding in the Sidi Belattar region of Algeria.

This study is organized into six sections. The first

section presents the general context, the research objectives, and a review of the literature on BIM, multi-criteria analysis, and their application to road infrastructure projects. The second section describes the study area. The third section outlines the methodology adopted, including the modelling of route variants using InfraWorks software and the application of the VIKOR and TOPSIS multi-criteria methods. The fourth section presents the results obtained, illustrated by comparative tables and visualizations. The fifth section offers a critical discussion of the results and methods used. The study is concluded in the sixth section, which also provides suggestions for further research and a summary of the major contributions.

2. Geography of the Study Region

As part of our study, we selected a strategic area of the wilaya of Mostaganem, located in western Algeria, encompassing part of the Dahra Mountains. The study area stretches between the locality of Sidi Belattar and National

Road 90 (RN90), near the Chellif River, as illustrated in Figure 1. It covers an area of approximately 88 km² lying between latitude 36°01'36" North and longitude 0°16'10" East.

This territory is of particular interest due to its geographical position at the crossroads of agricultural, environmental, and road accessibility challenges. It is bordered by the Kerrada forest and dam to the north, the Chellif River to the south, RN90 to the east, and the town of Sidi Belattar to the west. The terrain morphology mainly consists of undulating peneplains interspersed with moderate slopes, especially near RN90. The vegetation is relatively sparse, dominated by scattered forest covers. The semi-arid climate is characterized by high temperatures and low rainfall, averaging no more than 360 mm per year. The hydrographic network is well developed, with the Chellif River as the main watercourse running along the southern edge of the area. This river, subject to seasonal flooding, is the source of recurring floods. A significant event occurred in January 2017, when rising waters caused the complete flooding of the road section connecting Sidi Belattar to RN90.

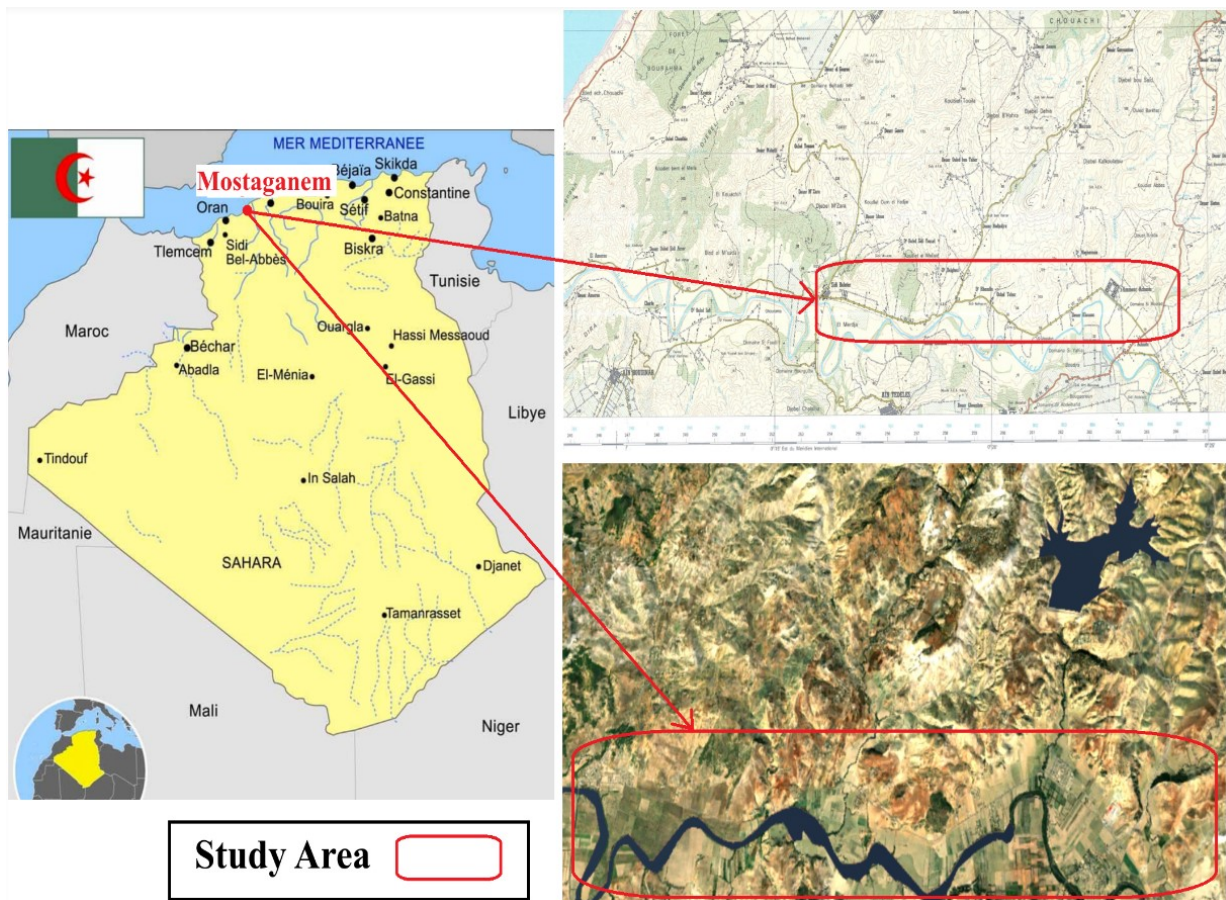


Figure 1. Location of the study region in Algeria

3. Materials and Estimation Methodology

This methodology aims to evaluate and identify the optimal solution for replacing a section of road that is highly susceptible to flooding and has frequently been inundated over the past ten years due to the annual floods of the Chellif River. To address this challenge, it integrates the building information modeling process from the initial design phase of road infrastructure, with a particular focus on the use of Autodesk InfraWorks. This approach makes it possible to simulate several alternative routes and enables early assessment of their relevance and feasibility at a stage when the project structure is still evolving and available resources, particularly standard BIM library objects, may be limited [14].

The evaluation of alternatives is based on the application of recognized multi-criteria analysis methods, in particular VIKOR and TOPSIS, which provide a rigorous methodological framework for decision-making in contexts of uncertainty or conflict between criteria [15].

These techniques enable effective classification and prioritization of variants based on multiple and heterogeneous criteria, such as technical feasibility, overall cost, environmental impact, and resilience to hydrological risks. Integrated into a BIM environment, they enhance the transparency and consistency of the decision-making process by offering dynamic visualization, a collaborative approach, and real-time interaction between stakeholders. This synergy between multi-criteria methods and BIM technologies thus contributes to more informed, systemic, and sustainable decision-making in the field of infrastructure.

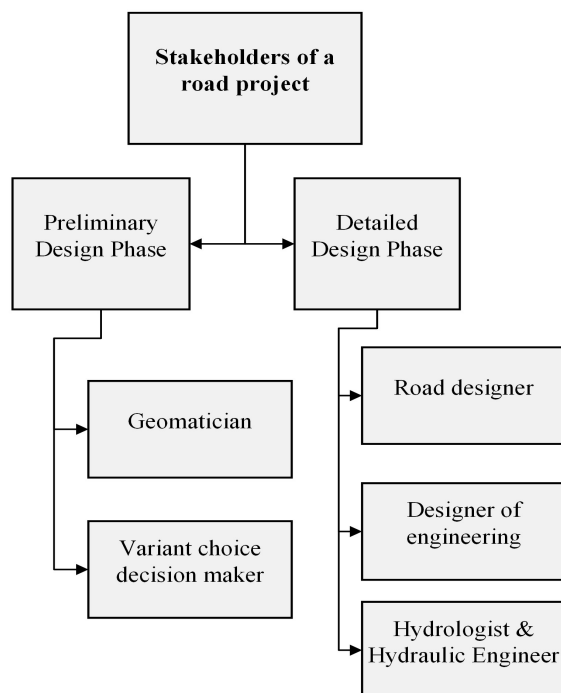


Figure 2. Stakeholders in a road project

This approach relies heavily on interdisciplinary collaboration. As illustrated in Figure 2, there is close interaction between the geomatics specialist, who provides accurate and up-to-date geospatial data, and the decision-maker, who is responsible for evaluating and selecting the most relevant options. This collaboration maximizes the value of InfraWorks simulations while ensuring that the choices made meet the growing demands for project performance, sustainability, and safety.

Therefore, the proposed methodology forms part of a structured approach that effectively supports strategic decisions in contexts particularly exposed to climatic and hydrological hazards by combining the rigor of multi-criteria decision-making techniques with the potential of BIM.

In the vast field of multi-criteria decision-making methods, several approaches such as MABAC, MAIRCA, ELECTRE III, MARCOS, and PROMETHEE are frequently used to evaluate complex projects.

Each method offers specific advantages, but also limitations depending on the type of data, the nature of the criteria, and the requirements for the readability of the results [16]. For example, ELECTRE III is recognized for its ability to handle imprecise or qualitative preferences, but it requires delicate parameterization and can be difficult for non-experts to interpret [17]. MARCOS and MABAC, although effective in certain studies, still suffer from a lack of large-scale empirical validation and are less integrated into commonly used software tools [18].

In this context, the choice of the VIKOR and TOPSIS methods is based on their complementarity, their theoretical soundness, and their widespread adoption in the field of infrastructure evaluation. TOPSIS offers an intuitive and rigorous approach for ranking alternatives according to their proximity to an ideal solution, which is particularly useful in projects where the criteria are mainly quantitative (cost, time, impact, etc.). Conversely, VIKOR stands out for its ability to provide an acceptable compromise between overall performance and worst performance, thus addressing situations where stakeholders have conflicting objectives. This approach is especially relevant in road projects, where the optimization of one criterion is often at the expense of another (e.g., minimizing costs without damaging the environment). Therefore, the combined use of VIKOR and TOPSIS ensures both clarity of rankings and robustness of trade-offs, making it a strategic choice for the multi-criteria evaluation of road route variants [8].

3.1. Using the BIM Tool to Plan the Road Layout

Among the most widely used BIM tools in the field of infrastructure engineering, Autodesk InfraWorks stands out for its advanced features for planning, visualizing, and evaluating road projects, particularly during the preliminary design phases. InfraWorks allows users to generate realistic and contextual 3D models that incorporate a wide variety of criteria, making it particularly

well suited to multi-criteria analysis. In this study, the performance of the different generated alternatives was evaluated using the TOPSIS and VIKOR methods. InfraWorks facilitates this process by supporting the creation of multiple route variants, while offering dynamic visualization and access to relevant technical data, as illustrated in Figure 3.



Figure 3. Dynamic visualization of a road variant in InfraWorks

As part of the evaluation, eight alternatives were mapped directly using the InfraWorks tool, as shown in Figure 4. This software provides detailed information on each variant, such as route length, gradients, longitudinal and cross-sectional profiles, number of engineering structures, and automatically calculated earthwork volumes. These features accelerate preliminary studies, improve the quality of estimates, and facilitate comparison between options. Thanks to its integration into a BIM approach for infrastructure, InfraWorks contributes to more rigorous and informed decision-making when selecting the optimal variant.



Figure 4. Representation of the variants by the InfraWorks tool

3.2. Using the Multi-Criteria Decision-Making VIKOR and TOPSIS

Multi-criteria decision-making approaches are frequently used in various sectors to address complex problems involving the selection or ranking of variants. These approaches enable the simultaneous evaluation of multiple, often conflicting, criteria in order to compare and rank alternatives in an objective and rational manner.

For this research, we selected two MCDM techniques renowned for their robustness and performance: TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) and VIKOR (VIšekriterijumsko KOMpromisno Rangiranje). The objective is to determine the optimal variant among several route alternatives, based on a rigorous multi-criteria analysis. In addition, a comparative

analysis of the advantages and constraints of these two techniques is suggested to clarify their respective areas of application.

The combined methodology of the TOPSIS and VIKOR approaches allows for a more nuanced evaluation, considering both the proximity to an ideal solution and the necessary compromises between criteria. The TOPSIS method assumes that an optimal solution is the one that is closest to the ideal option while being furthest from the anti-ideal option. It provides a clear and intuitive ranking by calculating the Euclidean distance between each alternative and these two references [19].

In contrast, a compromise approach is introduced by the VIKOR method. It stands out for its ability to manage the incomparability between alternatives or certain criteria and to integrate a weighting mechanism between overall satisfaction and individual satisfaction into the criteria. VIKOR performs a partial aggregation of performance according to the preferences of decision-makers, which makes it possible to propose a compromise solution that represents a balance between the most influential criteria [20].

These two methods are particularly well suited to road infrastructure assessment issues, where technical, economic, environmental and social criteria must be analyzed simultaneously. Figure 5 presents a detailed flowchart of the methodological approach adopted, illustrating the different stages of the two methods. This visual representation promotes a better understanding of the underlying processes and allows for a systematic and in-depth analysis of the results obtained.

3.2.1. Application of the VIKOR Method

The VIKOR (VIšekriterijumsko KOMpromisno Rangiranje) model is another robust MCDM technique developed by Opricovic and Tzeng in 2004 [21].

In addition to its reputation as a robust and proven multi-criteria method, the VIKOR method was chosen for several reasons. First, this method is distinguished by its focus on finding a compromise solution, making it a tool particularly suited to contexts where stakeholders have divergent preferences. Unlike other multi-criteria decision-making methods that prioritize only optimal solutions, VIKOR focuses on obtaining a solution acceptable to all parties, based on the concept of proximity to the ideal solution [22].

Furthermore, VIKOR allows for the relative importance of criteria to be considered, thanks to the allocation of weights that reflect the priorities of decision-makers. This flexibility guarantees easy adaptation to varied decision-making contexts, whether in the economic, environmental, or technical fields. Furthermore, the VIKOR method stands out for its ability to handle uncertainty and approximate assessments, making it particularly relevant in contexts where available data are incomplete or imprecise. Finally, it provides a ranking of alternatives while identifying the best compromise solution, thus facilitating decision-making [23].

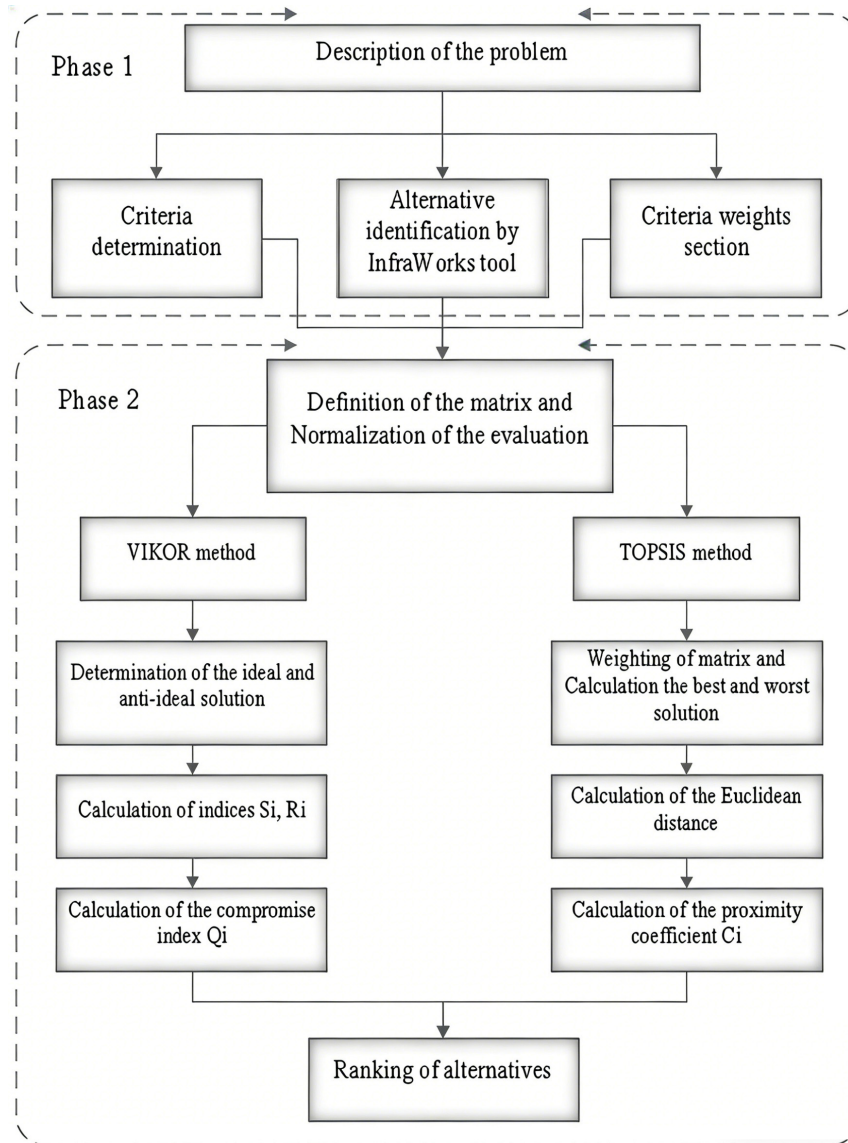


Figure 5. Flow diagram for the applied methods' sub-steps

The VIKOR method can be broken down into five steps [24]:

- **Step 1:** Definition and Normalization of the input matrix

This stage involves defining the alternatives to be evaluated and the decision criteria and assigning levels to each criterion for each alternative in the matrix. The data is then normalized so that the values of the criteria lie between 0 and 1, allowing a fair comparison between the alternatives. To do this, we apply Equation (1) to obtain new matrix entries.

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^n x_{ij}^2}} \quad (1)$$

- **Step 2:** Determination of the ideal and anti-ideal solution

In this step, determine the ideal solution X_i^+ (the best

value for each criterion) and the anti-ideal solution X_i^- (the worst value for each criterion) according to Equations (2) and (3).

$$X_j^+ = \max r_{ij} \quad (2)$$

$$X_j^- = \min r_{ij} \quad (3)$$

- **Step 3:** Calculation of distance measurements S_i and R_i

The distance measurements are computed at this stage. First, using Equation (4) as a guide, S_i stands for the weighted total of the deviations of each alternative from the ideal solution. Next, using Equation (5), R_i represents the largest deviation (worst-case scenario) for each choice.

$$S_i = \sum_{j=1}^m w_j \frac{x_i^+ - r_{ij}}{x_i^+ - x_i^-} \quad (4)$$

$$R_i = \max_j (w_j \frac{x_i^+ - r_{ij}}{x_i^+ - x_i^-}) \quad (5)$$

- **Step 4:** Calculation of the compromise index

This stage involves figuring out each alternative's compromise index, or Q_i . With the use of this index, we can order the options based on how close they are to Equation (6), the optimal compromise solution.

$$Q_i = U * \frac{S_i - S^*}{S^- - S^*} + (1 - U) \frac{R_i - R^*}{R^- - R^*} \quad (6)$$

where U is a weighting parameter (often set to 0.4), representing the degree of importance given to the compromise strategy.

S^* and S^- are the minimum and maximum values of S_i respectively.

R^* and R^- are the minimum and maximum values of R_i respectively.

- **Step 5:** Ranking of alternatives

The alternatives are ranked according to the three indices calculated previously: S_i , R_i , Q_i . These indices represent respectively the weighted sum of the deviations from the ideal solution, the maximum weighted deviation and the compromise index which combines the two. The alternatives are ranked in ascending order, that is, from the lowest to the highest value for each index. The Q_i index is particularly important because it allows the best compromise solution to be identified. The alternative with the smallest Q_i value is initially considered the best solution.

3.2.2. Application of the TOPSIS Method

The TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method is a multi-criteria decision-making approach widely used in decision support [25]. Its popularity is based on its conceptual simplicity and its ability to provide clear and interpretable results. The fundamental principle of TOPSIS is based on intuitive logic: an alternative is considered optimal if it is closest to the ideal solution (the one that maximizes beneficial criteria and minimizes undesirable criteria) and furthest from the non-ideal solution (the one that represents the worst possible outcome) [26], [27]. In other words, TOPSIS seeks to maximize similarity to the ideal solution while minimizing proximity to the least desirable solution.

TOPSIS's prominence in the multi-criteria decision support sector can be attributed to its many benefits. First, it is characterized by its simplicity of implementation, requiring no complex software, making it accessible even with basic tools like Excel. This simplicity is further supported by its structured analytical framework, which provides an orderly and transparent way to assess and contrast options, guaranteeing decision-making transparency. Furthermore, TOPSIS demonstrates great adaptability, as it can be applied to a variety of decision-making problems, whether economic, environmental, technical, or social in nature. Finally, the method is distinguished by its reliability, as it relies on

precise and complete information regarding the defined criteria, ensuring a rigorous and consistent evaluation of alternatives [28].

The TOPSIS method is divided into five main steps [29]:

- **Step 1:** Definition and Normalization of the input matrix

This stage involves defining the alternatives to be evaluated and the decision criteria and assigning levels to each criterion for each alternative in the matrix. The data is then normalized so that the values of the criteria lie between 0 and 1, allowing a fair comparison between the alternatives. To do this, we apply Equation (7) to obtain new matrix entries.

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^n x_{ij}^2}} \quad (7)$$

- **Step 2:** Matrix weighting

Using a weighting factor for criteria between 0 and 1 according to Equation (8), the score matrix is obtained by multiplying the matrix entries by the weights associated with the criteria.

$$V_{ij} = w_j \times r_{ij} \quad (8)$$

- **Step 3:** Calculation of the best and worst solution

For each criterion, calculate the most favorable associated value A^+ and the least A^- according to the nature of the criterion using the equations presented in Equations 9 and 10.

$$A^+ = \{\max_j V_{ij} (i \in J^+) \setminus \min_j V_{ij} (i \in J^-)\} \quad (9)$$

$$A^- = \{\min_j V_{ij} (i \in J^+) \setminus \max_j V_{ij} (i \in J^-)\} \quad (10)$$

- **Step 4:** Calculation of the Euclidean distance to the ideal alternative and the negative alternative

By calculating the vectors D^+ and D^- using Equations 11 and 12, we evaluate all the deviations of each alternative. These deviations are expressed as Euclidean distances, representing both the shortest distance to the ideal solution and the greatest distance to the non-ideal solution between the values of each criterion and the associated values already evaluated in the previous step.

$$D_i^+ = \sqrt{\sum_{j=1}^m (V_j^+ - V_{ij})^2} \quad (11)$$

$$D_i^- = \sqrt{\sum_{j=1}^m (V_j^- - V_{ij})^2} \quad (12)$$

- **Step 5:** Proximity calculation and ranking of alternatives

In the last step, the proximity coefficient of each alternative is determined according to Equation (13), which is obtained by the rate (between 0 and 1 or, equivalently, between 0% and 100%). It is a matter of choosing the one that is closest to the favorable ideal

solution A+ and as far as possible from the unfavorable ideal solution A-. The alternatives are then ranked in descending order of their C_i values. Accordingly classify the alternatives according to their proximity to the ideal alternative and the negative alternative.

$$C_i = \frac{D_i^-}{D_i^- + D_i^+} \quad (13)$$

Table 1 below highlights the explanation of the different symbols in the formulas above.

Table 1. Symbols used in the formulas of the methods employed

Symbol	Explanation
x_{ij}	The value of alternative i according to the criterion j
r_{ij}	The normalized value of alternative i according to the criterion j
w_j	The weight of each criterion
V_{ij}	The weighted value of alternative i with respect to criterion j
A^+	The positive ideal solution is the theoretical alternative that would have the best possible values for all criteria
A^-	The negative ideal solution is the theoretical alternative that would have the worst possible values for all criteria
D_i^+	The Euclidean distance between alternative i and the positive ideal solution
D_i^-	The Euclidean distance between alternative i and the negative ideal solution
C_i	The proximity coefficient of each alternative
S_i	The overall satisfaction score for alternative i
R_i	The maximum regret measure for alternative i
S^*	The best overall satisfaction value
S^-	The worst overall satisfaction value
R^*	The least regret
R^-	The greatest regret
U	The strategy coefficient (weighting parameter)
Q_i	The compromise score for alternative i

4. Results

The evaluation of road alignment alternatives in this study is based on a set of multi-criteria indicators defined in close collaboration with public works professionals. This collaboration, which involved engineers, technicians, and experts from the Directorate of Public Works in Algeria, enabled the incorporation of institutional technical expertise to ensure the relevance, operational validity, and sectoral compliance of the selected criteria.

The chosen criteria aim to comprehensively reflect the technical, economic, functional, and territorial dimensions

of a road infrastructure project. Their selection is grounded in standard practices in transportation engineering, while also considering the specificities of the local context. A total of ten criteria were identified and adopted:

- Section length (C1): Total distance of the proposed alignment. This is directly related to construction and maintenance costs.
- Lateral clearance (C2): Minimum distance between each alternative and the edge of the Chellif Valley. This is a safety indicator and measures exposure to natural hazards.
- Earthworks balance (C3): Difference between cut and fill volumes. It reflects the complexity and environmental and financial cost of earthmoving operations.
- Maximum slope (C4): Absolute value of the steepest slope, whether uphill or downhill. This criterion affects road safety, vehicle energy consumption, and driving comfort.
- Construction cost (C5): Overall estimated budget required to implement each alternative.
- Curvature rate (C6): Percentage ratio of the cumulative arc lengths of curves to the total alignment length. This indicates the sinuosity of the alignment, with implications for safety and comfort.
- Number of structures (C7): Particularly bridges, which represent structurally and financially significant elements.
- Estimated travel time (C8): Average duration required to traverse the section under standard traffic conditions.
- Proximity to built-up areas (C9): Minimum distance between the alignment and existing urban zones. This reflects accessibility and territorial integration.
- Land to be compensated (C10): Surface area of private land requiring expropriation and financial compensation.

Regarding the orientation of preferences, the criteria are categorized as shown in Table 2.

Altogether, these criteria constitute a robust methodological foundation for the application of multi-criteria decision-making methods such as TOPSIS and VIKOR, ensuring a coherent, comprehensive, and contextually grounded evaluation of road alignment alternatives.

4.1. Results of the VIKOR Method

To choose the compromise option that is closest to the ideal, the VIKOR technique considers both individual regret and group pleasure. It is a multi-criteria method that aims to minimize the largest disadvantage while optimizing the overall criteria. Each variant is evaluated using two key indices: S_i , which represents the overall deviation from the ideal solution, and R_i , which reflects the maximum individual deviation across all criteria. Based on

these indices, a composite score Q_i is calculated to rank the alternatives, with lower values indicating better performance, corresponding to sorting in ascending order.

The analysis of the results reveals that Variant 1 emerges as the most favorable compromise solution, with a Q_i score of 0.048, indicating full compliance with VIKOR's conditions. It is followed by Variant 3, which scores 0.24, while Variants 2 and 5 obtain scores of 0.54 and 0.56, respectively. Variants 8, 6, 4, and 7 have Q_i scores of 0.60, 0.71, 0.78 and 1.00, placing them at the lower end of the ranking. This classification is illustrated in Figure 6.

4.2. Results of the TOPSIS Method

The TOPSIS method aims to identify the optimal

alternative from a set of alternatives, based on multiple evaluation criteria. It operates on the principle of dual optimization: minimizing the distance to the ideal solution while maximizing the distance from the least desirable one. Each alternative is assessed according to its proximity to these two extremes and ranked based on its similarity to the ideal solution, with higher scores indicating better performance. This corresponds to a ranking in descending order.

The analysis of the results shows that Variant 1 clearly stands out as the best-performing variant, with a score of 0.90. It is followed by Variant 3 (0.71), then by Variants 2 and 8, which score 0.67 and 0.66, respectively. Variants 6, 4, 5, and 7 rank lower, with close scores of 0.65, 0.42, 0.30, and 0.11, as shown in the ranking presented in Figure 7.

Table 2. Input matrix for road performance criteria

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
Unit	m	m	m ³	%	DA	%	-	s	m	m ²
V 1	12698,87	293,50	77651,67	13,98	367004933,90	52,88	2,00	571,45	49,20	253977,36
V 2	12849,73	126,90	114972,84	14,74	359405121,20	59,71	2,00	578,24	17,30	256994,66
V 3	12452,61	203,10	250032,63	14,48	500069568,40	49,42	2,00	560,37	41,40	249052,12
V 4	12875,55	114,90	502374,31	14,14	976624275,60	45,56	2,00	579,40	28,90	257510,98
V 5	12643,46	162,80	635215,75	14,58	13699762040	51,42	2,00	568,96	13,90	252869,10
V 6	12448,15	103,90	38321,34	14,55	354931386,50	43,51	2,00	560,17	17,70	248963,08
V 7	12602,07	130,20	852682,72	13,90	1863490031,00	60,72	2,00	567,09	24,50	252041,42
V 8	11686,88	85,50	3820,43	10,13	261548203,30	55,85	2,00	525,91	12,30	233737,60

To be minimized: C1 (length), C3 (earthwork), C4 (slope), C5 (cost), C7 (number of bridges), C8 (travel time), C10 (land compensation).

To be maximized: C2 (clearance), C6 (curvature rate favorable to safety), C9 (proximity to urban areas).

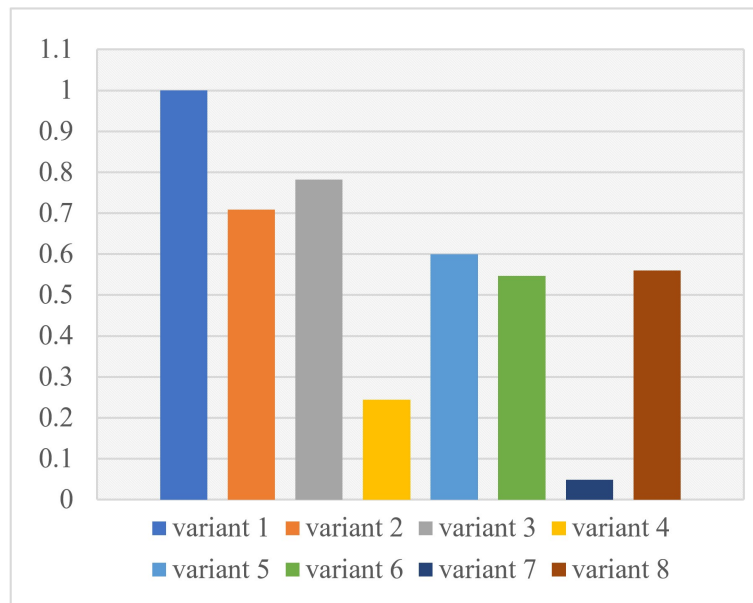


Figure 6. Ranking of the eight alternatives based on the compromise score

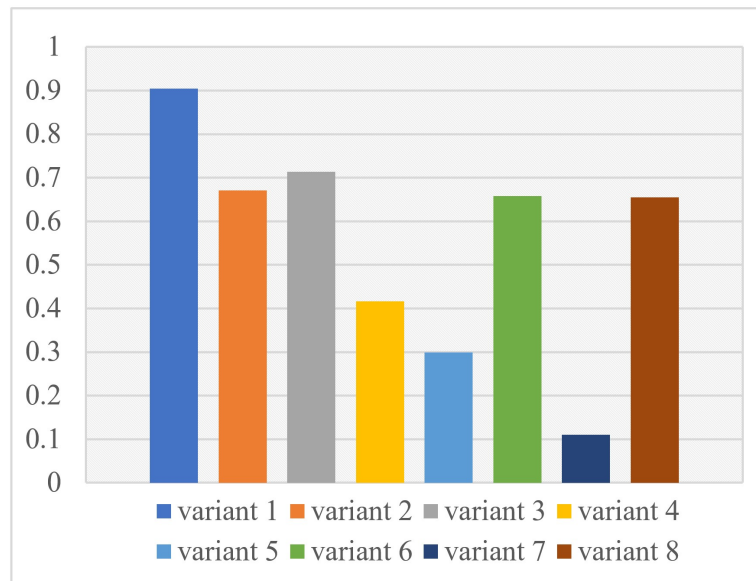


Figure 7. Ranking of the eight variants based on their closeness coefficient

5. Discussion and Analysis

In this paper, the multi-criteria evaluation of the eight road route variants using the VIKOR and TOPSIS methods allows for a comparison of two complementary approaches to decision-making. While VIKOR focuses on finding a compromise between overall satisfaction and individual regret, TOPSIS is based on the principle of proximity to an ideal solution, minimizing the distance to the optimal option and maximizing the distance to the least favorable one. The joint analysis of these methods sheds light on the robustness of the rankings and the sensitivity of the alternatives to the methodology used.

The VIKOR method uses the S_i (overall deviation from the ideal solution) and R_i (largest individual deviation) indices, from which the composite Q_i score is calculated. The results indicate that Variant 1 clearly stands out as the most favorable compromise solution, with a score of $Q_i = 0.048$, fully satisfying the VIKOR acceptability conditions. It is followed by Variant 3 ($Q_i = 0.24$), Variant 2 ($Q_i = 0.54$), and Variant 5 ($Q_i = 0.56$). The remaining Variants 8, 6, 4, and 7 have higher scores, 0.60, 0.71, 0.78, and 1.00, respectively, placing them at the bottom of the ranking (Figure 6).

The TOPSIS method evaluates alternatives based on their relative closeness to the ideal solution, using a similarity coefficient C_i , where higher values indicate better performance. In this case as well, Variant 1 ranks the highest with a score of $C_i = 0.90$, followed by Variant 3 ($C_i = 0.71$), Variant 2 ($C_i = 0.67$), and Variant 8 ($C_i = 0.66$). Variants 6, 4, 5, and 7 receive decreasing scores of 0.65, 0.42, 0.30, and 0.11, respectively, confirming partial consistency with the VIKOR ranking (Figure 7).

A sensitivity analysis of the results with respect to variations in the criteria weights was conducted based on five distinct scenarios, as presented in Table 3. Each scenario corresponds to an alternative configuration of the weights assigned to the criteria, reflecting different priorities or decision-making perspectives. The results reveal remarkable stability in the ranking of the route alternatives, both with the TOPSIS method and the VIKOR method. No significant changes were observed in the order of preference of alternatives, despite the variations in weightings. This consistency demonstrates the robustness of the two multi-criteria decision-making approaches used. It highlights their ability to produce reliable and coherent results, even in the presence of uncertainties or changes in input parameters. Consequently, this robustness strengthens the credibility of the conclusions drawn in the evaluation of the route alternatives and confirms the relevance of the TOPSIS and VIKOR methods as decision-support tools in complex contexts that are sensitive to stakeholder preferences.

A detailed analysis of the five scenarios evaluated according to each criterion, as well as the results from the VIKOR and TOPSIS methods, highlights a marked consistency: Variant 1 consistently stands out for its performance, occupying the top positions in all rankings (see Table 4). As a result, it emerges as the most relevant flood risk mitigation strategy in the examined area. Variant 3, often ranked second, constitutes a credible alternative. In contrast, Variants 2 and 8 rank intermediately, while Variants 4, 5, and 6 exhibit generally inferior performance. Variant 7, for its part, consistently ranks last, underscoring its poor alignment with the project objectives.

Table 3. Varying weights for each scenario

Weight	Length	Clearance	Earthworks	Slope	Cost	Curvature rate to safety	Number of bridges	Travel time	Proximity to urban areas	Land compensation
Scenario 1	0,08	0,17	0,15	0,11	0,17	0,08	0,12	0,02	0,04	0,06
Scenario 2	0,07	0,15	0,13	0,11	0,16	0,12	0,11	0,04	0,06	0,05
Scenario 3	0,08	0,17	0,14	0,11	0,20	0,11	0,06	0,03	0,04	0,06
Scenario 4	0,07	0,16	0,15	0,13	0,18	0,10	0,09	0,03	0,05	0,04
Scenario 5	0,11	0,17	0,14	0,12	0,15	0,09	0,11	0,02	0,04	0,05

Table 4. Ranking of variants using the TOPSIS & VIKOR methods

Variants	Ranking of VIKOR method	Ranking of TOPSIS method
variant 1	1	1
variant 2	3	3
variant 3	2	2
variant 4	7	6
variant 5	4	7
variant 6	6	5
variant 7	8	8
variant 8	7	4

The convergence of results obtained from both approaches enhances the reliability of the multi-criteria evaluation. Although based on different methodological foundations, TOPSIS and VIKOR lead to similar conclusions, thereby reinforcing the validity of the final choice. This complementarity is well-documented in the literature, which highlights the value of using multiple decision-making techniques to better address trade-offs between criteria. Their combined application helps minimize biases inherent in relying on a single method, while providing a more nuanced interpretation of the outcomes.

Moreover, the sensitivity analysis confirmed the robustness of the rankings, demonstrating that this integrated approach significantly improves decision quality, especially in complex contexts such as infrastructure planning.

This hybrid framework enables effective management of trade-offs and ensures a transparent and traceable decision-making process with two essential aspects of engineering projects. Ultimately, the classification produced in this study stands out for its realism and methodological rigor. The integration of multi-criteria methods with BIM tools facilitated the identification of the most suitable solution, while ensuring a comprehensive assessment of performance criteria. This rigorous and innovative approach aligns with current trends in intelligent infrastructure planning and provides a solid foundation for future research in engineering and project management.

6. Conclusions

The development of a road infrastructure project remains a multidimensional undertaking, marked by technical, environmental and decision-making challenges, particularly during the preliminary design phase. This study proposes an innovative approach to selecting the best route option to replace a section of road that is vulnerable to flooding. Unlike traditional practices based on 2D cartographic data, the integration of the InfraWorks BIM tool enabled realistic and dynamic modeling of the alternatives, thereby enriching the multi-criteria analysis.

The evaluation was carried out using the TOPSIS and VIKOR decision-making methods, selected for their complementarity. Their application to eight route variants, evaluated according to ten geometric, topographic and economic criteria, made it possible to objectively rank the alternatives and identify an optimal solution, validated by both methods. This methodological synergy provides decision-makers with robust decision-making support, fostering more rational planning adapted to the constraints of the terrain.

The method developed in this article differs from traditional techniques through the incorporation of a realistic 3D environment, facilitating accurate representation of the alternatives and their potential effects. The two multi-criteria methods were applied to eight variants, evaluated according to ten geometric, topographical and economic criteria. Their combined application made it possible to rank the alternatives objectively and reliably. The convergence of the results, particularly in favor of Variant 1, provides decision-makers with a solid basis for an informed and technically justified choice. This research provides a twofold contribution: first, it demonstrates the value of integrating BIM tools into multi-criteria analysis during the early design stages of infrastructure projects; second, it paves the way for the standardization of route selection processes. Future work should focus on defining a unified methodological framework, applicable at the national level, to objectivize the choice of criteria and promote the harmonization of practices among the various public works stakeholders.

Finally, although this methodology has been applied to a

specific case of replacing a flood-prone section, it can easily be applied to other infrastructure projects, such as the optimal location of engineering structures or culverts, tunnels, railway infrastructure, etc. This approach thus contributes to an overall improvement in the quality and efficiency of road projects from the early stages, while strengthening the resilience of networks to natural hazards.

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