HOLOS
ISSN 1807 - 1600

ENHANCING ECONOMIC VIABILITY OF ROAD WORKS THROUGH A MULTICRITERIA MODEL BASED ON FUZZY LOGIC

G. H. N. SILVA, L. O. GEISENHOFF, R. C. SANTOS*, A. V. A. MOTOMIYA, E. P. GOMES, R. A. JORDAN
Universidade Federal da Grande Dourados (UFGD)[1, 2, 3, 4, 5, 6]
ORCID ID: https://orcid.org/0000-0003-4585-9305[3]
rodrigocouto@ufgd.edu.br[3]

Submitted 27/07/2023 - Accepted 16/05/2025

DOI: 10.15628/holos.2025.15774

ABSTRACT

Due to its significance, transport infrastructure has been the subject of extensive research. In Brazil, road transport interconnects the entire production chain and incurs substantial costs. Thus, this study aimed to propose a multicriteria model based on fuzzy logic to assist in reducing construction costs for road works. The input variables considered in the model were the number of factors that add cost to construction, length of the segment to be built, and levels of environmental thermal stress suffered by workers during work. The output variable represented the economic viability of the road project. The results demonstrated the effectiveness of the proposed model in evaluating the viability of highway construction, contributing in an interdisciplinary way with Brazil's productive, economic, and social sectors. Each variable involved in the model played an important role in the overall cost composition.

KEYWORDS: Applied economics, engineering 4.0, simulation, expert system

AUMENTO DA VIABILIDADE ECONÔMICA DE OBRAS RODOVIÁRIAS POR MEIO DE UM MODELO MULTICRITÉRIO BASEADO EM LÓGICA FUZZY

RESUMO

Devido à sua relevância a infraestrutura de transportes tem sido objeto de extensas pesquisas. No Brasil, o transporte rodoviário interliga toda a cadeia produtiva e incorre em custos substanciais. Assim, este estudo teve como objetivo propor um modelo multicritério baseado em lógica fuzzy para auxiliar na redução dos custos de construção de obras rodoviárias. As variáveis de entrada consideradas no modelo foram o número de o número de fatores que agregam custo à construção, a extensão do trecho a ser construído e os níveis de estresse térmico ambiental sofridos pelos trabalhadores durante o trabalho. A variável de saída representou a viabilidade econômica do projeto rodoviário. Os resultados demonstraram a eficiência do modelo proposto na avaliação da viabilidade da construção de rodovias, contribuindo de forma interdisciplinar com os setores produtivo, econômico e social do Brasil. Cada variável envolvida no modelo desempenhou um papel relevante na composição geral do custo.

PALAVRAS-CHAVE: Economia aplicada, engenharia 4.0, simulação, sistema especialista

1 INTRODUCTION

Road transport, as highlighted by Oliveira and Araujo (2023), serves as the main mode of transportation in Brazil, accounting for over 58% of the country's cargo movement. Although the Brazilian road network is 1.72 million kilometers long, it faces significant challenges, with only 12.4% of the roads being paved. Such an insufficient expansion of the road network has hindered the country's ability to meet the demand for paved roads, resulting in discrepancies compared to other developing nations and hampering efficient cargo and passenger transport (Gao & Zhu, 2022).

Paving and maintenance of roads are driven by the demands of people and vehicles for movement. They involve numerous factors such as costs, production capacity, deadlines, and equipment, particularly in the public sector. Therefore, effectiveness in road works is dependent on selection of suitable materials, proper equipment, adherence to deadlines, and expertise of trained technicians (Kassa, 2020).

Due to the exponential growth of the global population, investments in transport infrastructure aimed at improving efficiency and sustainability have become a subject of extensive research. Studies focusing on road transport have a positive impact on productivity, accessibility, flow of goods and people, and inter-regional connectivity (Acheampong, Opoku, Dzator & Kufuor, 2022).

Aside from infrastructure investments, crucial considerations include maintenance, conservation, and restoration costs throughout the lifespan of highways. Such costs tend to increase over time due to pavement deterioration. Therefore, it is vital to maintain the quality of road systems from their initial implementation to ensure long-lasting and suitable infrastructure (Palit, Bari & Karmaker, 2022).

Integrating advanced technologies in road construction can enhance project quality and durability, resulting in reduced maintenance costs and future repairs. Constructing well-designed highways contributes to improved production and logistics, thereby fostering regional and national development. Thus, research involving the use of computational modeling is important to ensure high-quality projects and economic efficiency, which justifies its realization.

The digital transformation driven by the integration of 4.0 technologies, the Internet of Things (IoT), and Artificial Intelligence (AI) models has had a significant impact on improving the efficiency and quality of projects, raising global standards to levels never achieved in terms of constructive sustainability (Santos et al., 2023). In this sense, the adoption of emerging technologies such as modeling aimed at road construction represents a promising opportunity to optimize processes, reduce costs, and promote sustainable regional development.

Thus, research involving computational modeling is essential to ensure high-quality projects and achieve economic efficiency, as it allows simulating and testing different construction scenarios before physical execution, identifying potential problems that may arise, and facilitating their timely, efficient, and cost-effective resolution (Patcharachavalit, Limsawasd & Athigakunagorn, 2023).

The application of intelligent systems in road construction planning can significantly reduce construction costs, directly impacting freight costs for consumer goods and stimulating market growth and progress (Jahani, Sepehri, Vandchali & Tirkolaee, 2021).

Expert systems and basic concepts of road transport play a crucial role in scientific and technological advancements by supporting strategic decision-making, optimizing resources, and reducing costs. These contributions make regional development more accessible while improving the efficiency of financial resource utilization. According to Da Silva Júnior, Martins and Librantz (2021), modeling with Fuzzy Logic is recommended to enhance flexibility in comprehending responses, thereby supporting various management aspects in interdisciplinary studies.

The proposed model in this study aimed to aid feasibility studies through a rational structure and systematic multicriteria decision-making process. Conceptual cost estimation during the initial project stages is vital for making financial viability decisions, establishing budgets, and forecasting actual expenditures.

Chen and Zheng (2021) emphasized the prominent level of uncertainty in road construction, which increases the risk of losses and makes it challenging to produce reliable budgets. Excess costs can arise from scope changes, unforeseen conditions, market fluctuations, and other factors. Project profiles encompass multiple components such as material costs, equipment expenses, team requirements, and construction management, among others.

In this context, this study evaluated variables related to the initial costs of budgeting for paved highways, mainly focusing on their structural aspects. Our aim was to develop an intelligent modeling system based on Fuzzy Logic that can estimate the feasibility of highway construction more accurately based on project characteristics.

The main objective was to construct an expert system using Fuzzy Logic that incorporates key variables associated with the construction of paved highways, enhancing your economic viability and aiding decision-making in these projects. Our specific objectives included identifying the main variables influencing the cost of paved roads, fuzzifying the economic viability of road works, and testing the expert system in real-world scenarios.

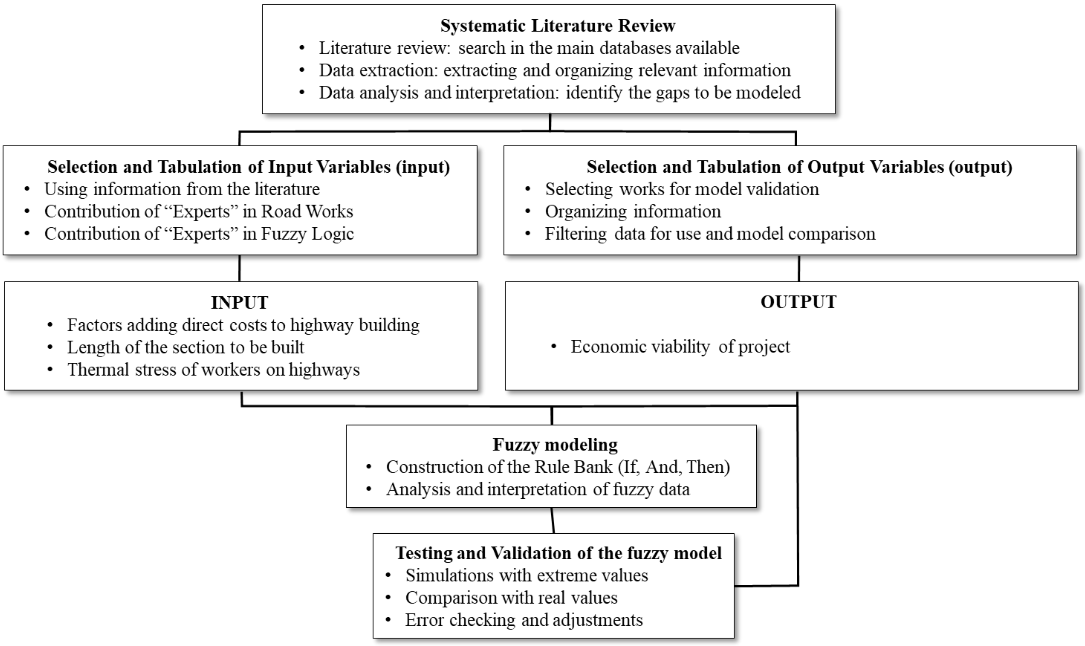
2 MATERIAL AND METHODS

2.1 Overview of the experiment

To provide a concise visual representation of the research methodology, Figure 1 displays the detailed description of the investigation.

Figure 1.

General flowchart for conducting the research.



The research was conducted by the Post-Graduate Program in Agricultural Engineering at the Federal University of Grande Dourados (UFGD), located in Dourados/MS, Brazil (latitude 22°11'38.66" S, longitude 54°55'53.26" W). The average altitude of the region is 464 meters, with an annual rainfall of 1400 mm. The climate is classified as Cwa, which stands for a humid mesothermal climate with hot summers and dry winters, according to the Köppen's classification (Alvares, Stape, Sentelhas & Gonçalves, 2013; Cesca et al., 2021).

This step was included because, according to Lovatto et al. (2020), who studied programming as a constructive decision-making tool, there is a direct relationship between information available in the literature, observations at work, and the optimization of time and resources involved.

2.2 Systematic Literature Review

To establish the research database, a systematic literature review was conducted using multiple platforms including Google Scholar, Science Direct, Web of Science, and Scopus. Additionally, records provided by the *Associação Brasileira de Normas Técnicas* – ABNT (Brazilian Technical Standards Association) and the *Departamento Nacional de Infraestrutura de Transportes* – DNIT (Brazilian Department of Transport Infrastructure) were also included. The search encompassed the period from 2010 onwards, focusing on keywords related to the research objectives. Key topics included road transport, transport infrastructure, decision making, economic viability, modeling, highways, construction costs, and fuzzy logic.

For instance, Barreto and Amorim (2020) investigated the technical performance of different mixtures for road construction and made reference to ABNT standards and legislation established by DNIT.

2.3 Selection and Tabulation of Input Variables

Following the literature review, factors directly impacting the cost of a highway were identified and grouped into three main interacting variables These variables included the direct cost factors in highway construction, complexity related to the Segment-Length, and levels of environmental thermal stress experienced by workers during construction.

2.3.1 Factors adding direct costs to highway building

Lanzaro and Andrade (2023) proposed a modeling method using fuzzy logic to assist in the construction of geometric road projects in developing countries. The method considers factors such as topography, road class, width, length, driving speed, materials, and services involved to achieve a more cost-effective project.

Given the numerous variables that influence the final cost of a highway, this investigation analyzed the variables identified in the literature with the input of specialists working in road construction. Their expertise helped identify the most significant parameters for cost forecasting.

To compose the "input" related to the number of Attended-Questions during road construction, a pertinence function was developed. This function assigned grades from 0 to 10 to the variables included in the project, using the concepts of bad, average, and good. Table 1 presents the pertinence function for the Attended-Questions, along with the corresponding ranges of values.

Table 1.

Relevance Functions for Met Requirements.

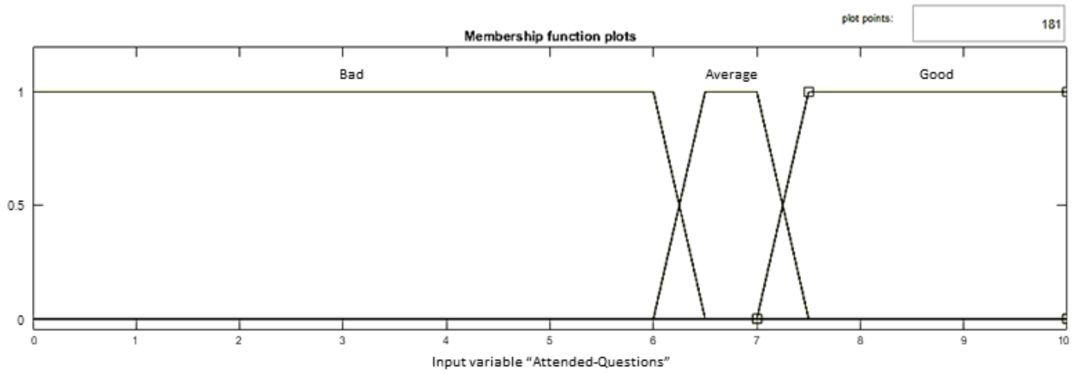
Interval	Membership Function	Curve
Good	[7 7.5 10 10]	Trapezoidal
Average	[6 6.5 7 7.5]	Trapezoidal
Bad	[0 0 6 6.5]	Trapezoidal

Using the MATLAB™ Fuzzy simulator (MATLAB, 2017), Figure 2 represents the input variable along with its corresponding membership functions.

HOLOS
ISSN 1807 - 1600

Figure 2.

Input variable for Attended-Questions



2.3.2 Length of the segment to be built

The length of the segment is a crucial parameter in road design as it directly influences the cost per kilometer of construction. The topography of the land, whether flat, undulating, or mountainous, has a direct impact on the overall budget. Additionally, the Design Speed, which is determined for each project and its class, plays a significant role in establishing the technical conditions necessary for ensuring trafficability, safety, and the desired outcome.

In this model, the input variable considered was a combination of Road Class and Design Speed, considering flat, undulating, and mountainous terrains. Furthermore, minimum and ideal distances were taken into consideration to facilitate safe vehicle overtaking based on the specified Design Speed outlined by DNIT (DNIT, 2010). Using this information, the linguistic intervals for the "Segment-Length" membership function were defined as in Table 2.

Table 2.

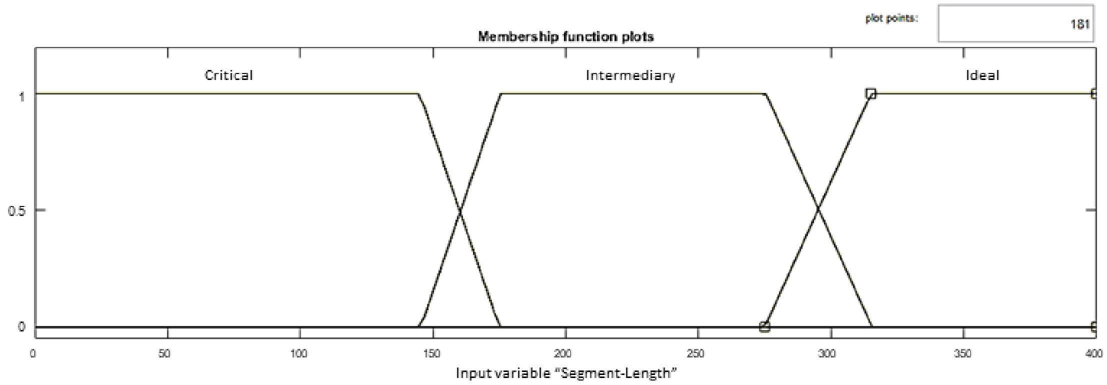
Membership Functions for the Segment-Length

Interval	Membership Function	Curve
Critical	[0 0 145 175]	Trapezoidal
Intermediary	[145 175 275 315]	Trapezoidal
Ideal	[275 315 400 400]	Trapezoidal

Figure 3 depicts the input variable, along with its corresponding membership functions, using the MATLAB™ Fuzzy simulator.

Figure 3.

Segment-Length Input Variable



2.3.3 Thermal stress of workers on highways

According to Cesca et al. (2021), temperature variations in environments with thermal exposure are closely linked to relative humidity. Therefore, it was determined that the Human Discomfort Index (HDI) would serve as an input variable to assess the levels of heat and cold stress experienced by workers. This index incorporates both temperature and relative humidity, allowing for a comprehensive evaluation of thermal comfort conditions.

The membership function associated with HDI and its corresponding thermal comfort conditions are outlined in Table 3.

Table 3.

Pertinence functions for the HDI

Interval of HDI	Membership Function	Effects
HDI > 80	[79 81 100 100]	Heat-Stress
75 > HDI > 80	[74 76 79 81]	Uncomfortable-Heat
60 > HDI > 75	[59 61 74 76]	Comfortable
55 > HDI > 60	[54 56 59 61]	Uncomfortable-Cold
HDI < 55	[40 40 54 56]	Cold-Stress

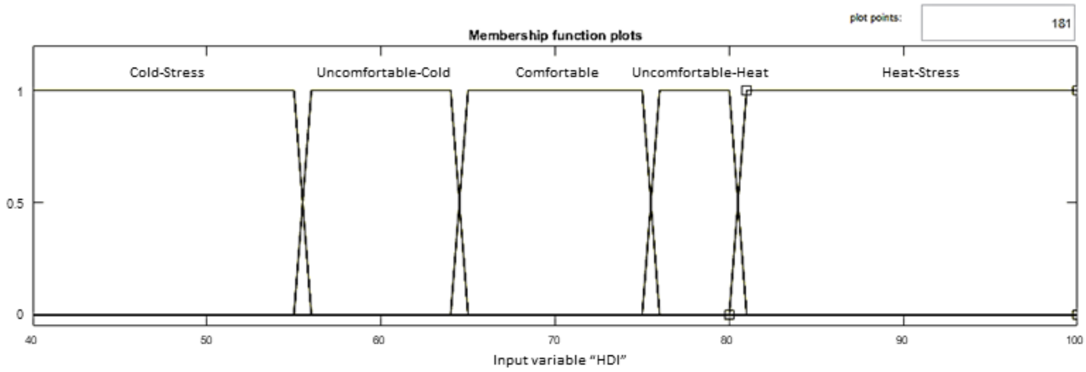
Notice. Gomes, Silva and Silva (2019), adapted

The thermal stress variable was represented using a trapezoidal membership function in the MATLAB™ Fuzzy simulator. Figure 4 visually depicts this variable, showing the linguistic terms and their respective membership functions.

HOLOS
ISSN 1807 - 1600

Figure 4.

HDI input variable



2.4 Selection and Tabulation of the Output Variable

The output variable, "Economic Viability," was constructed based on information provided by DNIT specialists, who provided the necessary data from 20 projects to evaluate the model. This variable enabled the users to assess the impact of the combined input variables on potential profitability or loss of road construction projects.

To establish the range of "Economic Viability," a domain of [0.100] was chosen. This range was divided into intervals (Table 4) with equal distribution. According to Bektaş and Kegyes-Brassai (2023), the output of a fuzzy system can be represented on a scale from 0 to 100, with equally distributed functions, thus improving precision in the representation of the system's result.

Table 4.

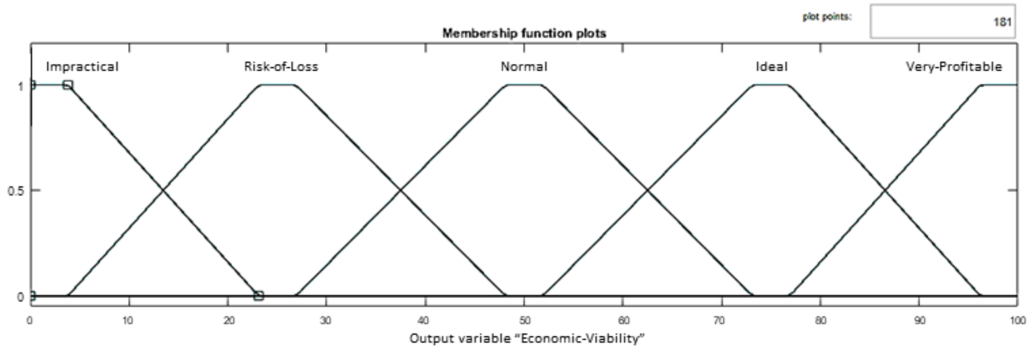
Pertinence Functions for Economic-Viability

Interval	Membership Function	Curve
Very-Profitable	[76.9 96.2 100 100]	Trapezoidal
Ideal	[51.9 73.1 76.9 96.2]	Trapezoidal
Normal	[26.9 48.1 51.9 73.1]	Trapezoidal
Risk-of-Loss	[3.8 23.1 26.9 48.1]	Trapezoidal
Impractical	[0 0 3.8 23.1]	Trapezoidal

Figure 5 illustrates the output variable and its corresponding membership functions, using the MATLAB™ Fuzzy simulator.

Figure 5.

Economic-Viability output variable

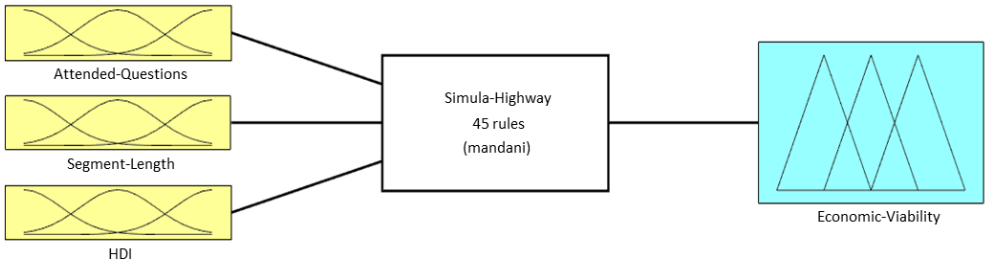


2.5 System Inference Rules

The Fuzzy model was developed in the MATLAB R2017a™ software (MATLAB, 2017). The program facilitated the setting rules, visualization, and simulation of various algorithm scenarios, as well as data processing and activation functions. Figure 6 illustrates the initial screen displaying the structure of the built simulator.

Figura 6.

Basic configuration of the fuzzy logic toolbox.



Notice. MATLAB R2017a®.

In this study, the Mamdani inference method was employed to combine input values using minimum and maximum operators, resulting in an expert system. The fuzzy rule bank consisted of 45 sentences and was generated based on the literature, incorporating the connectives IF, AND, and THEN. The rules were weighted according to the knowledge and expertise of specialists in the field.

For the defuzzification step, the "Center of Gravity" method was utilized. This method considered all possible output values and transformed the fuzzy model into a numerical set (Zhang, Li, Liu & Zhang, 2021).

2.6 Model Testing and Validation

The developed fuzzy model was evaluated and validated following the approach proposed by Olowosulu, Kaura, Murana and Adeke (2022). These authors recommended comparing simulations with field observations to ensure the accuracy and reliability of the model. For validation, data provided by DNIT were utilized, including execution time, work size, material distances (such as sand, cement, and steel), excavation and landfill volumes, Hot Mix Asphalt Concrete (HMAC), special structures, land coverage, and thermal stress measurements using HDI. These data were analyzed and discussed with specialists to verify the accuracy and effectiveness of the model

The quality evaluation of the fuzzy system followed the approach proposed by Patel, Patel, Patel and Shah (2022). Mean Absolute Error (MAE) and Correlation Coefficient (CC) were calculated using the MATLAB R2017a™ software (MATLAB, 2017). MAE measured the average deviation between the model's predictions and actual data, while CC evaluated the linear relationship between the predicted and observed values.

As proposed by Reges, Silva, Bezerra and Alexandria (2017), simulations, model training, and testing were performed to generate results and identify areas for improvement. This iterative process aimed to refine the intelligent simulator to closely resemble real-world scenarios.

The obtained results enabled the application of interdisciplinary concepts, integrating engineering, computer science, environmental management, applied economics, and sustainability. These findings subsequently facilitated in-depth discussions on the current scenario and proposed solutions to mitigate road construction costs, thereby enhancing their economic viability. The ultimate goal was to contribute to the productivity sector and improve transport logistics in Brazil.

3 RESULTS AND DISCUSSION

This investigation resulted in probabilistic models for assessing the economic viability of highway implementation. These models, based on Fuzzy Logic and multicriteria methods, contribute to enhanced resource management.

3.1 Multicriteria Modeling Based on Fuzzy Logic

Figure 7 graphically illustrates the relationship between the input variables, Segment Length and HDI, in relation to the output function, Economic Viability, within the proposed Fuzzy model of this research.

HOLOS
ISSN 1807 - 1600

Figure 7.

Representation of Economic-Viability as a function of Segment-Length and HDI

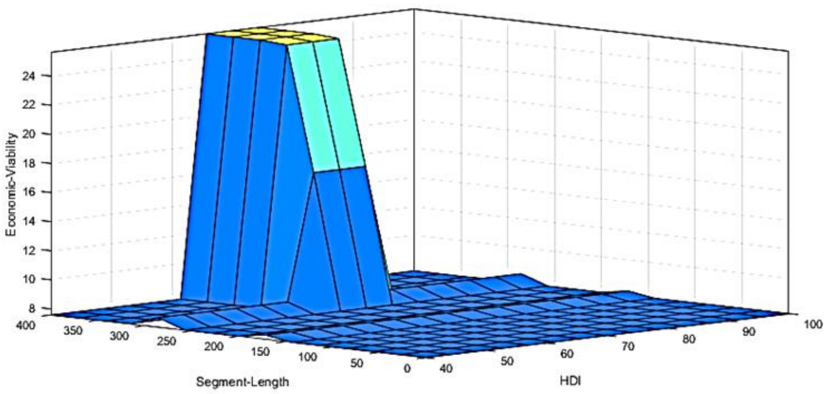


Figure 7 demonstrates the significant role of HDI in assessing human comfort in different environmental conditions. An HDI above 80 indicates high heat stress, while an HDI below 55 suggests cold stress (Moghbel, 2020). These findings align with the presented membership functions in the model.

As for Segment-Length, studies such as the one by Broniewicz and Ogrodnik (2020) have highlighted the theory of fuzzy sets as a valuable tool for multicriteria analysis. These authors recommended carefully evaluating different sections of a project, as even smaller spaces can compose complex landscapes and significantly influence its feasibility.

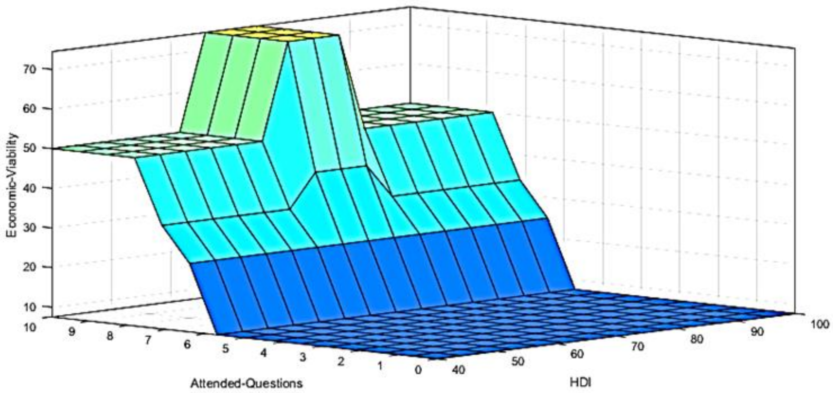
In Figure 7, it is evident that critical-length segments are prone to safety issues and increased operating costs, while intermediate lengths require further analysis in conjunction with other variables. When the segment length is between 0 and 250 meters, regardless of the HDI value, the viability is deemed unfeasible and assigned a value of 8. Factors such as existing infrastructure capacity, accessibility, and terrain complexity play a significant role in this outcome (Zhao, Sun & Webster, 2022).

The interaction between HDI, segment length, and feasibility is complex and project-specific. A comprehensive assessment of road work feasibility requires an integrated, multidisciplinary approach considering technical, environmental, social, and economic aspects (Harbiankova & Gertsberg, 2022).

Figure 8 illustrates the relationship between the input variables, Questions Attended and HDI, with Economic Viability as the output function in the proposed Fuzzy model of this research.

Figure 8.

Representation of Economic-Viability in terms of Questions- Attended and HDI



The results of Figure 8 for fuzzy simulation reveals complex relationships between Attended-Questions, Human Discomfort Index (HDI), and the resulting Economic Viability of the highway. Initially, it is observed that the HDI alone does not significantly impact Viability when up to 5.5 Questions are met. However, if close to 8 Questions are met, the HDI starts to have a high impact on Viability, because if it is in the comfort region, it returns to the ideal classification, while in regions of stress due to heat or cold, it still promotes normal Viability.

The highlighted result in Figure 8 indicates an Economic Viability close to the maximum value of 75% (ideal) when the HDI corresponds to a comfort level and approximately 78% of the Questions are met. This demonstrates that both factors are essential for achieving ideal Viability. Wang et al. (2019) support this conclusion, emphasizing the importance of considering the thermal environment in road projects planning and feasibility.

When the HDI is at a thermal comfort level, but only up to 5.5 Questions are met, Viability is drastically reduced to approximately 9%. This underscores the significance of meeting an adequate number of requirements in road projects to ensure Viability, even under favorable thermal comfort conditions. Kalra and Al-Qassem (2023) support this statement, emphasizing the need to consider appropriate variables in road section design to ensure Viability.

Lima, Amorim, Oliveira and Moura (2021) also reinforced this study when they shared concerns about sustainability regarding the use of Hot Mix Asphalt Concrete (HMAC), since this material is unique and essential in road works, has a high cost, and impacts the environment throughout the process.

However, according to Figure 8, when the HDI is outside the thermal comfort zone, even with ideal Question values, the Feasibility is reduced to 50%. This indicates that Economic Viability of road projects may be compromised if workers' thermal comfort is not taken into account. In this context, studies have emphasized the significance of considering workers' thermal exposure conditions in road projects to reduce the impact of absences and illnesses caused by adverse climates (Karthick, Kermanshachi, Pamidimukkala & Namian, 2023).

3.2 Viability Simulator Testing and Validation

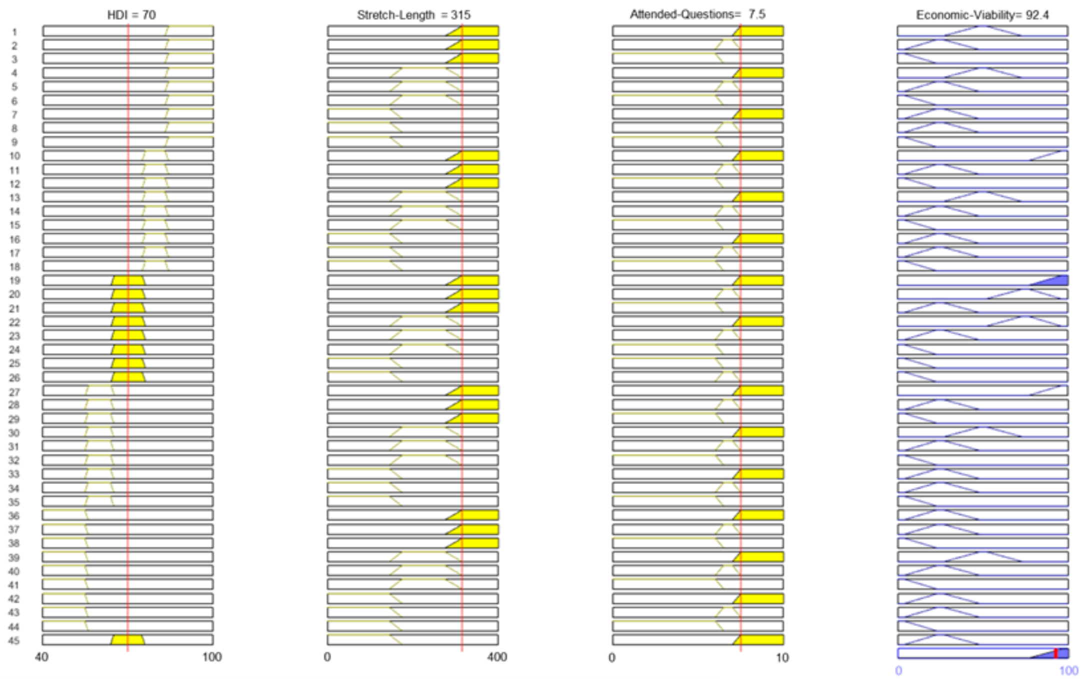
The constructed fuzzy model was validated through simulations using information from literature and real-life situations, which were verified by specialists. The analysis of the highway's output variable, "Economic Viability," was conducted by evaluating different configurations of the input variables, emphasizing both ideal and extreme positions.

To validate the model, the protocol proposed by experts in fuzzy modeling Agrawal, Bansal, Kumar and Sisodia (2022) and Wang, Chen, Jin and Zhang (2022) was followed, who recommended the combination of optimal and extreme values in simulations with intelligent systems aimed at validation after overcoming possible limitations presented by the model.

Figure 9 illustrates the activated rule base of the fuzzy model, considering the three input variables: HDI, Segment-Length, and Attended Questions, within their respective best intervals. In this case, the fuzzy model yielded an Economic Viability of 92.4% for the project's output, classified as "Very Profitable." This result demonstrates the consistency of the simulator.

Figure 9.

Activated Rules Base of the Fuzzy Model, considering all Inputs and Output in ideal values



Elmousalami (2020) surveyed studies on AI modeling practices and procedures to determine an optimal approach for predicting road construction costs based on information from the literature. Among the 20 AI techniques tested, the most accurate and suitable method yielded an absolute mean percentage error of 9.091% and a precision of 92.9%. These results demonstrate the high accuracy of the simulator, as depicted in Figure 9, and can therefore be recommended to estimate the viability of highways when involving the same variables used in the model.

The analysis of economic feasibility in infrastructure and road construction projects is a complex process involving multiple factors (Khanani, Adugbila, Martinez & Pfeffer, 2021). Inadequate levels or fluctuations in any of these variables during project execution can compromise the budget. Feng and Zhang (2022) investigated the financial return on highway investments and suggested that if the project's viability indicator is already above 90%, the likelihood of venture success is high.

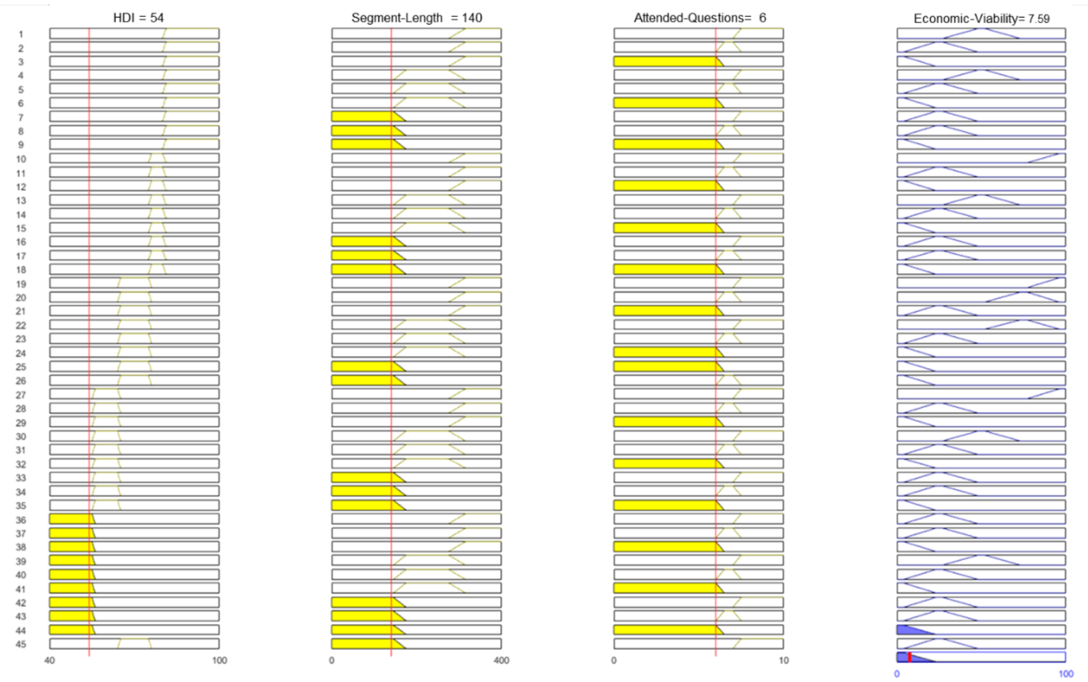
In simulations where two input variables were maintained within the ideal range while one was adjusted to an inappropriate value, Economic-Feasibility also changed, following the model's behavior. Adjusting Stretch-Length, Answered-Questions or HDI to inappropriate values led to an Economic-Viability of up to 25.6%, indicating risk-loss. Štilić and Puška (2023) endorse these findings in their discussion of applying multicriteria analysis techniques, such as fuzzy logic, to address uncertainty and subjectivity in factors associated with construction projects. They assert that complex variables, including the distance from the construction site and the environmental exposure of workers, are interconnected.

The significance of Questions in determining Economic Viability is affirmed by Costa, Cruz, Sarmento and Sousa (2023), who highlighted the influence of each factor in the cost composition of road works at the project level. The authors emphasized the need to consider the specific characteristics of each construction project and identify the variables that exert the most noteworthy influence on costs, considering all of them, respecting the significant individual importance of each one.

Figure 10 displays the activated rule base of the fuzzy model when the three input variables (HDI, Segment-Length, and Attended-Questions) are in opposite positions from the ideal ones. In this scenario, the fuzzy model predicts an Economic Viability of the project at 7.89%, classified as "Unfeasible," aligning again with real-world observations.

Figure 10.

Activated Rules Base of the Fuzzy Model considering all Inputs with unsatisfactory values.



The results presented in Figure 10 demonstrate that when the HDI is high, the Segment-Length is critical, and only six Questions are met, the Economic-Viability of the project is Impractical. This information holds significant importance for decision-making, as it highlights the interplay of variables that, if poorly managed, can jeopardize the success of the enterprise (Prado Lima, Mendonça, Vergilio & Assunção, 2022).

When it comes to expert systems for cost estimation and budgeting, Patcharachavalit et al. (2023) asserted that advantages such as time reduction, increased precision, and lower investment are evident. According to the authors, these expert systems also contribute to better project management by supporting decision-making and fostering sustainability.

Alvand, Mirhosseini, Ehsanifar, Zeighami and Mohammadi (2023) and Rezaee Arjroody, Hosseini, Akhbari, Safa and Asadpour (2023) recommended considering as many variables as possible during the planning stage of a highway project since the exclusion of any variable can have a negative impact on project viability. In this context, evaluating the economic risks associated with these variables becomes an integral part of the budgetary process, and several methods have been developed to assess project complexity, with special emphasis on those using Fuzzy Logic.

Considering the fuzzy simulations encompassing the three input variables—Human Discomfort Index (HDI), Segment-Length, and Attended-Questions—in various scenarios with optimal and extreme values, the obtained results consistently align with the Economic-Viability output variable. The consistency and coherence between the simulated results and the model's objectives confirm that this model has undergone thorough testing and validation, establishing its reliability as an interdisciplinary tool to support decision-making for professionals who need to evaluate road projects. Furthermore, well-designed roads can significantly contribute to the logistics of agribusiness in Brazil.

4 CONCLUSIONS

The proposed simulation model has demonstrated its effectiveness in evaluating the economic viability of highway construction projects. The inclusion of the Fuzzy simulator has significantly enhanced the accuracy and efficiency of decision-making in cost estimation prior to highway construction.

Each variable involved in the budgeting process holds immense relevance in the final cost composition and should not be underestimated by the designer.

The use of Fuzzy Logic in this research marks a substantial interdisciplinary advancement toward sustainable decision-making in highway planning and construction. This advancement has a positive impact on Brazil's productive, economic, and social sectors.

The interdisciplinary nature of the model, drawing on knowledge from applied economics, engineering 4.0, and expert systems, contributes to the long-term sustainability of the road and logistics sectors. It represents a valuable fusion of expertise that furthers a holistic and accurate view of the economic viability of road projects.

Acknowledgment

To the Post-Graduate Program in Agricultural Engineering at the Federal University of Grande Dourados (PGEA/UFGD) and to the Group of Applied Technologies for Agricultural Sustainability (TASA). To the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES - Public Notice PDPG 2022) for the financial support provided to realize this study.

5 REFERENCES

Acheampong, A. O., Opoku, E. E. O., Dzator, J., & Kufuor, N. K. (2022). Enhancing human development in developing regions: Do ICT and transport infrastructure matter? *Technological Forecasting and Social Change*, *180*, 121725. https://doi.org/10.1016/j.techfore.2022.121725

Agrawal, H. P., Bansal, H. O., Kumar, R., & Sisodia, Y. S. (2022). Design and real-time validation of PI and Fuzzy Logic tuned photovoltaic integrated DSTATCOM to improve power quality. *Environmental Science and Pollution Research*, *29*(60), 90158–90177. https://doi.org/10.1007/s11356-022-21910-7

Alvand, A., Mirhosseini, S. M., Ehsanifar, M., Zeighami, E., & Mohammadi, A. (2023). Identification and assessment of risk in construction projects using the integrated FMEA-SWARA-WASPAS model under fuzzy environment: A case study of a construction project in Iran. *International Journal of Construction Management*, *23*(3), 392–404. https://doi.org/10.1080/15623599.2021.1877875

Alvares, C. A., Stape, J. L., Sentelhas, P. C., & de Moraes Gonçalves, J. L. (2013). Modeling monthly mean air temperature for Brazil. *Theoretical and Applied Climatology*, *113*(3), 407–427. https://doi.org/10.1007/s00704-012-0796-6

Barreto, A. C., & Amorim, E. F. (2020). Avaliação do desempenho técnico de diferentes misturas de solo com resíduos de construção (RCD) para uso em obras viárias. *HOLOS*, *7*, 1–20. https://doi.org/10.15628/holos.2020.9696

Bektaş, N., & Kegyes-Brassai, O. (2023). Development in Fuzzy Logic-Based Rapid Visual Screening Method for Seismic Vulnerability Assessment of Buildings. *Geosciences*, *13*(1), Artigo 1. https://doi.org/10.3390/geosciences13010006

Broniewicz, E., & Ogrodnik, K. (2020). Multi-criteria analysis of transport infrastructure projects. *Transportation Research Part D: Transport and Environment*, *83*, 102351. https://doi.org/10.1016/j.trd.2020.102351

Cesca, R. S., Santos, R. C., Goes, R. H. de T. e B. de, Favarim, A. P. C., Oliveira, M. S. G. de, & Silva, N. C. da. (2021). Thermal comfort of beef cattle in the state of Mato Grosso do Sul, Brazil. *Ciência e Agrotecnologia*, *45*, e008321. https://doi.org/10.1590/1413-7054202145008321

Chen, W., & Zheng, M. (2021). Multi-objective optimization for pavement maintenance and rehabilitation decision-making: A critical review and future directions. *Automation in Construction*, *130*, 103840. https://doi.org/10.1016/j.autcon.2021.103840

Costa, Á., Cruz, C. O., Sarmento, J. M., & Sousa, V. F. (2023). Bundling Road and Railway Infrastructure Operators: Analysis of the Impact on Efficiency. *Journal of Infrastructure Systems*, *29*(1), 04023001. https://doi.org/10.1061/JITSE4.ISENG-2106

Da Silva Júnior, W. da S., Martins, F. S., & Librantz, A. F. H. (2021). Resistance in processes of change in information technology: A Fuzzy AHP approach. *HOLOS*, *3*, 1–17. https://doi.org/10.15628/holos.2021.10355

DNIT. (2010). *Manual de Implantação Básica de Rodovia. 3. Ed. - Rio de Janeiro, (IPR. Publ. 742), 617p*. IPR. Publ.

Elmousalami, H. H. (2020). Artificial Intelligence and Parametric Construction Cost Estimate Modeling: State-of-the-Art Review. *Journal of Construction Engineering and Management*, *146*(1), 03119008. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001678

Feng, H., & Zhang, Y. (2022). Research on the Multi-attribute Evaluation Model for the Investment Results of County-level Highways in New Urbanization. *KSCE Journal of Civil Engineering*, *26*(12), 4893–4911. https://doi.org/10.1007/s12205-022-1687-8

Gao, Y., & Zhu, J. (2022). Characteristics, Impacts and Trends of Urban Transportation. *Encyclopedia*, *2*(2), Artigo 2. https://doi.org/10.3390/encyclopedia2020078

Gomes, C., Silva, M. L., & Silva, A. C. da. (2019). Monitoramento da qualidade do ar e conforto ambiental urbano da avenida treze de maio em Fortaleza, Ceará / Air quality monitoring and urban environmental comfort from may thirteen avenue in Fortaleza, Ceará. *Brazilian Journal of Development*, *5*(10), Artigo 10. https://doi.org/10.34117/bjdv5n10-373

Harbiankova, A., & Gertsberg, L. (2022). Information Model for Sustainable Rural Development. *Energies*, *15*(11), Artigo 11. https://doi.org/10.3390/en15114009

Jahani, N., Sepehri, A., Vandchali, H. R., & Tirkolaee, E. B. (2021). Application of Industry 4.0 in the Procurement Processes of Supply Chains: A Systematic Literature Review. *Sustainability*, *13*(14), Artigo 14. https://doi.org/10.3390/su13147520

Kalra, D., & Al-Qassem, A. (2023). Assessing the environmental and economic feasibility of using recycled materials in urban cities projects for sustainable development. *Journal of Namibian Studies: History Politics Culture*, *33*, 1772–1787. https://doi.org/10.59670/jns.v33i.815

Karthick, S., Kermanshachi, S., Pamidimukkala, A., & Namian, M. (2023). A review of construction workforce health challenges and strategies in extreme weather conditions. *International Journal of Occupational Safety and Ergonomics*, *29*(2), 773–784. https://doi.org/10.1080/10803548.2022.2082138

Kassa, Y. F. (2020). *Determinants of Infrastructure Project Delays and Cost Escalations: The Cases of Federal Road and Railway Construction Projects in Ethiopia*. *63*(1).

Khanani, R. S., Adugbila, E. J., Martinez, J. A., & Pfeffer, K. (2021). The Impact of Road Infrastructure Development Projects on Local Communities in Peri-Urban Areas: The Case of Kisumu, Kenya and Accra, Ghana. *International Journal of Community Well-Being*, *4*(1), 33–53. https://doi.org/10.1007/s42413-020-00077-4

Lanzaro, G., & Andrade, M. (2023). A fuzzy expert system for setting Brazilian highway speed limits. *International Journal of Transportation Science and Technology*, *12*(2), 505–524. https://doi.org/10.1016/j.ijtst.2022.05.003

Lima, C. E. de, Amorim, E. F., Oliveira, H. da S., & Moura, L. F. de. (2021). Concreto asfáltico a quente dosado com resíduos de construção e demolição (RCD) aplicado em pavimento flexível. *HOLOS*, *1*, 1–18. https://doi.org/10.15628/holos.2021.9576

Lovatto, J., Santos, R. C., Souza, C., Zucca, R., Lovatto, F., & Geisenhoff, L. O. (2020). Use of linear programming for decision making: An analysis of cost, time and comfort of rural housing dwellings. *Revista Brasileira de Engenharia Agrícola e Ambiental*, 24, 622-629. https://doi.org/10.1590/1807-1929/agriambi.v24n9p622-629

MATLAB. (2017). *MATLAB [Computer software]. Version 9.2 R2017a. Natick, Massachusetts: The MathWorks Inc., 2017* (9.2) [Win]. The MathWorks Inc.

Moghbel, M. (2020). Evaluation of the human thermal discomfort index in different phases of North-Caspian Sea Patterns (NCP) in southern coasts of Caspian Sea, Iran. *Climate Change Research*, *1*(4), 1–9. https://doi.org/10.30488/ccr.2020.236996.1007

Oliveira, A. L., & Araujo, R. da C. de. (2023). Estabilização do solo com adição de cimento para fins de pavimentação em vias de baixo volume de tráfego. *Revista de Engenharia e Tecnologia*, *15*(1), Artigo 1. https://revistas.uepg.br/index.php/ret/article/view/21120

Olowosulu, A. T., Kaura, J. M., Murana, A. A., & Adeke, P. T. (2022). Development of framework for performance prediction of flexible road pavement in Nigeria using Fuzzy logic theory. *International Journal of Pavement Engineering*, *23*(11), 3809–3818. https://doi.org/10.1080/10298436.2021.1922907

Palit, T., Bari, A. B. M. M., & Karmaker, C. L. (2022). An integrated Principal Component Analysis and Interpretive Structural Modeling approach for electric vehicle adoption decisions in sustainable transportation systems. *Decision Analytics Journal*, *4*, 100119. https://doi.org/10.1016/j.dajour.2022.100119

Patcharachavalit, N., Limsawasd, C., & Athigakunagorn, N. (2023). Multiobjective Optimization for Improving Sustainable Equipment Options in Road Construction Projects. *Journal of Construction Engineering and Management*, *149*(1), 04022160. https://doi.org/10.1061/JCEMD4.COENG-12544

Patel, D., Patel, S., Patel, P., & Shah, M. (2022). Solar radiation and solar energy estimation using ANN and Fuzzy logic concept: A comprehensive and systematic study. *Environmental Science and Pollution Research*, *29*(22), 32428–32442. https://doi.org/10.1007/s11356-022-19185-z

Prado Lima, J. A., Mendonça, W. D. F., Vergilio, S. R., & Assunção, W. K. G. (2022). Cost-effective learning-based strategies for test case prioritization in continuous integration of highly-configurable software. *Empirical Software Engineering*, *27*(6), 133. https://doi.org/10.1007/s10664-021-10093-3

Reges, J. P., Silva, J. L. N. da, Bezerra, L. C. da S., & Alexandria, A. R. de. (2017). Controle fuzzy de robô diferencial. *Holos*, *7*, 98–109. https://doi.org/10.15628/holos.2017.3089

Rezaee Arjroody, A., Hosseini, S. azim, Akhbari, M., Safa, E., & Asadpour, J. (2023). Accurate estimation of cost and time utilizing risk analysis and simulation (case study: Road construction projects in Iran). *International Journal of Construction Management*, 1–12. https://doi.org/10.1080/15623599.2023.2210476

Santos, R. C., Lopes, A. L. N., Sanches, A. C., Gomes, E. P., Silva, E. A. S. da, & Silva, J. L. B. da. (2023). Intelligent automated monitoring integrated with animal production facilities. *Engenharia Agrícola*, 43, e20220225. https://doi.org/10.1590/1809-4430-Eng.Agric.v43n2e20220225/2023

Štilić, A., & Puška, A. (2023). Integrating Multi-Criteria Decision-Making Methods with Sustainable Engineering: A Comprehensive Review of Current Practices. *Eng*, *4*(2), Artigo 2. https://doi.org/10.3390/eng4020088

Wang, T., Qu, Z., Yang, Z., Nichol, T., Dimitriu, D., Clarke, G., & Bowden, D. (2019). How can the UK road system be adapted to the impacts posed by climate change? By creating a climate adaptation framework. *Transportation Research Part D: Transport and Environment*, *77*, 403–424. https://doi.org/10.1016/j.trd.2019.02.007

Wang, X., Chen, Y., Jin, J., & Zhang, B. (2022). Fuzzy-clustering and fuzzy network based interpretable fuzzy model for prediction. *Scientific Reports*, *12*(1), Artigo 1. https://doi.org/10.1038/s41598-022-20015-y

Zhang, W., Li, B., Liu, Z., & Zhang, B. (2021). Application of improved fuzzy comprehensive evaluation method in karst groundwater quality evaluation: A case study of Cengong county. *Earth Science Informatics*, *14*(2), 1101–1109. https://doi.org/10.1007/s12145-021-00611-8

Zhao, J., Sun, G., & Webster, C. (2022). Does China-Pakistan Economic Corridor improve connectivity in Pakistan? A protocol assessing the planned transport network infrastructure. *Journal of Transport Geography*, *100*, 103327. https://doi.org/10.1016/j.jtrangeo.2022.103327

HOW TO CITE THIS ARTICLE:

Silva, G. H. N., Geisenhoff, L. O., Santos, R. C., Motomiya, A. V. de A., Gomes, E. P., & Jordan, R. A. Enhancing economic viability of road works through a multicriteria model based on fuzzy logic. *Holos*, *6*(41), 1-21. https://doi.org/10.15628/holos.2025.15774

ABOUT THE AUTHORS:

Guth Halley Nogueira Silva
Master in Agricultural Engineering from the Federal University of Grande Dourados (UFGD); Civil Engineer Contract Manager at RR Terraplenagem: BRASILIA, DF (Brazil); Member of the CNPq Certified Group Tecnologias Aplicadas à Sustentabilidade Agrícola (TASA). Email: guthhalley.eng@gmail.com
ORCID ID: https://orcid.org/0009-0006-1304-2500

Luciano Oliveira Geisenhoff
PhD in Agricultural Engineering from the Federal University of Lavras (UFLA); Professor of the Postgraduate Program in Agricultural Engineering at the Federal University of Grande Dourados/PPGEA-UFGD (Brazil); Member of the CNPq Certified Group Tecnologias Aplicadas à Sustentabilidade Agrícola (TASA). Email: lucianogeisenhoff@ufgd.edu.br
ORCID ID: https://orcid.org/0000-0002-5907-5870

Rodrigo Couto Santos
PhD in Agricultural Engineering from the State University of Campinas (UNICAMP); Professor of the Postgraduate Program in Agricultural Engineering at the Federal University of Grande Dourados/PPGEA-UFGD (Brazil); Leader of the CNPq Certified Group Tecnologias Aplicadas à Sustentabilidade Agrícola (TASA). Email: rodrigocouto@ufgd.edu.br
ORCID ID: https://orcid.org/0000-0003-4585-9305

Anamari Viegas de Araújo Motomiya

PhD in Phytotechnics from the University of São Paulo (USP); Post-Doctorate at USP; Professor of the Graduate Program in Agricultural Engineering at the Federal University of Grande Dourados/PPGEA-UFGD (Brazil); Member of the CNPq Certified Group Tecnologias Aplicadas à Sustentabilidade Agrícola (TASA). Email: anamarimotomiya@ufgd.edu.br
ORCID ID: https://orcid.org/0000-0003-2170-8676

Eder Pereira Gomes
PhD in Agricultural Engineering from the State University of Campinas (UNICAMP); Professor of the Postgraduate Program in Agricultural Engineering at the Federal University of Grande Dourados/PPGEA-UFGD (Brazil); Member of the CNPq Certified Group Tecnologias Aplicadas à Sustentabilidade Agrícola (TASA). Email: edergomes@ufgd.edu.br
ORCID ID: https://orcid.org/0000-0002-4049-790X

Rodrigo Aparecido Jordan
PhD in Agricultural Engineering from the State University of Campinas (UNICAMP); Professor of the Postgraduate Program in Agricultural Engineering at the Federal University of Grande Dourados/PPGEA-UFGD (Brazil); Member of the CNPq Certified Group Tecnologias Aplicadas à Sustentabilidade Agrícola (TASA). Email: rodrigojordan@ufgd.edu.br
ORCID ID: https://orcid.org/0000-0002-2479-4461

Editor: Francinaide de Lima Silva Nascimento

***Ad Hoc* Reviewer:** Maikon Alexandre Kremer

Submitted: July 27, 2023

Accepted: May 16, 2025

Published: December 26, 2025