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Integrating Cultural Norms and Behavioral Risk Factors into Traffic Accident Mitigation: A Hybrid MCDM Approach for Libya

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Abstract: The mitigation of road traffic accidents remains a critical global challenge, particularly in regions where cultural norms and behavioral risk factors significantly influence driving practices. This study employs a hybrid Multi-Criteria Decision-Making (MCDM) approach, integrating Grey Theory, the Full Consistency Method (FUCOM), and the Evaluation based on Distance from Average Solution (EDAS), to systematically assess four strategic interventions: Infrastructure Improvements, Educational Programs, Policy Amendments, and Technology Integration. These strategies are evaluated based on a set of criteria that encompass attitudes toward speeding, perceptions of traffic laws, the use of safety equipment, and the prevalence of high-risk driving behaviors. The findings indicate that while Infrastructure Improvements and Technology Integration enhance the physical and technological dimensions of road safety, Educational Programs and Policy Amendments play an indispensable role in shaping driver behavior and reinforcing compliance with traffic regulations. The necessity of a comprehensive and integrated strategy that leverages both technological advancements and behavioral interventions is underscored, ensuring a holistic and sustainable reduction in traffic-related fatalities and injuries. The outcomes of this study provide valuable insights for policymakers and road safety authorities, offering a structured framework for the prioritization and implementation of road safety measures tailored to the socio-cultural and behavioral dynamics of Libya.

Keywords: MCDM; EDAS; FUCOM; Grey theory; Traffic safety; Behavioral risk factors; Cultural norms

1 Introduction

Transportation accidents can have severe consequences, including loss of life, injuries, property damage, and economic costs. Road accidents are particularly common and represent a significant portion of transportation-related fatalities worldwide [1]. Contributing factors to these accidents include speeding, driver fatigue, distracted driving, and poor road infrastructure. To mitigate these risks, it is essential to enforce strict safety regulations and protocols. Transportation operators must also implement robust safety measures and provide comprehensive training to their staff. Moreover, advances in technology and infrastructure improvements can further enhance safety on the roads and reduce the incidence of accidents [2].

Car accidents are a significant global public health concern, causing millions of deaths and injuries each year [3]. According to the World Health Organization (WHO), road traffic accidents are the eighth leading cause of death worldwide and the leading cause of death for individuals aged 5 to 29 years. Data from 2020 indicates that approximately 1.35 million people died in road traffic accidents globally [4]. Notably, over 90% of these deaths occurred in low- and middle-income countries [5]. Despite advances in road safety and the adoption of safe systems over the last decade, no low-income country has experienced a reduction in road traffic accidents since 2013 [6]. Contributing factors may include inadequate road infrastructure, substandard vehicles, and limited access to driver education and safety programs in these regions. Car accidents are influenced by a variety of factors such as driver behavior, infrastructure quality, vehicle safety, and environmental conditions. Addressing this issue requires a comprehensive approach that involves these elements and collaboration between policymakers, road safety experts, and the community.

This paper aims to develop a comprehensive framework for mitigating road traffic accidents by integrating various influencing factors such as driver behavior, vehicle safety, road infrastructure, and environmental conditions. The objective is to provide a systematic approach for evaluating and ranking mitigation strategies that can effectively reduce the incidence of traffic accidents, particularly in low- and middle-income countries where the majority of road fatalities occur. To achieve this, the study will employ a novel hybrid decision-making model that combines Grey Theory, FUCOM, and the EDAS. Grey Theory will be utilized to handle the uncertainty and incompleteness often present in data concerning traffic accidents. FUCOM will aid in determining the relative importance of various criteria affecting road safety, ensuring a consistent and robust weighting process. Finally, the EDAS method will be applied to rank the potential strategies based on their effectiveness, using the weighted criteria. This hybrid approach is expected to offer a clear and actionable pathway for policymakers and road safety specialists to prioritize interventions and enhance road safety outcomes.

2 Methodology

The use of MCDM methods has become increasingly prevalent in transportation research, offering a robust framework for navigating the complex decision-making processes associated with this field [7]. Specifically, in traffic accident research, MCDM methods have proven invaluable for dissecting and prioritizing the myriad factors that contribute to road safety challenges [8, 9]. By accommodating multiple, often conflicting criteria, such as driver behavior, vehicle safety features, and environmental conditions, MCDM facilitates a deeper understanding and more effective management of the factors leading to accidents, thus enhancing the development and implementation of targeted safety interventions [10].

2.1 Grey Theory

Grey systems theory, pioneered by Deng in the early 1980s, addresses problems characterized by incomplete information or small data samples [11]. This methodology is particularly effective in managing uncertain systems where only partial information is known, enabling the extraction and synthesis of valuable data from limited inputs. Grey theory posits that even with minimal data, complex systems exhibit inherent laws that govern their functioning and structure. Central to this theory is the concept of the grey number, a type of data that defines not a specific value, but a range within which the value lies, reflecting the uncertainty of information. This approach has been applied across a diverse range of fields, utilizing a spectrum metaphor of Black-Grey-White to represent different degrees of system knowledge and complexity. The grey number, fundamental to grey systems theory, mirrors the role of the fuzzy number in fuzzy mathematics, encapsulating the uncertainties within these systems (Figure 1) [12].

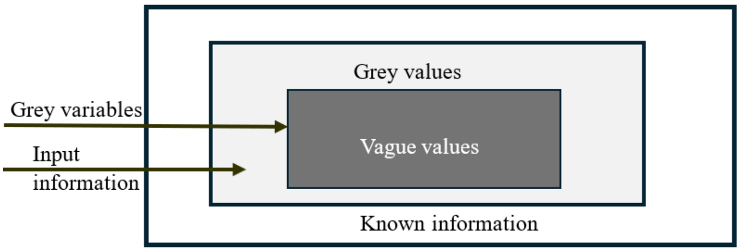

Figure 1. Concept of grey system

The Grey model involves the following steps:

Step 1: Identify and select the most significant attributes that describe the alternatives.

Step 2. Determine the criteria weights: Attribute weight W_j can be calculated as follows:

$$\otimes W_j = \frac{1}{K}\left[\otimes W_j^1 + \otimes W_j^2 + \cdots + \otimes W_j^K\right] \tag{1}$$

$$\otimes W_j^K = \left[\underline{W}_j^K, \underline{W}_j^K\right] \tag{2}$$

2.2 FUCOM Method

FUCOM is an innovative approach used in decision-making processes to determine the relative importance of criteria in a systematic and consistent manner [13]. Developed to address some of the shortcomings of traditional pairwise comparison methods, FUCOM ensures that the criteria weights derived are fully consistent with the initial judgments provided by the decision-makers. This method starts by soliciting expert inputs on the importance of one criterion relative to another through pairwise comparisons. The key advantage of FUCOM lies in its algorithm, which optimizes the consistency of these comparisons by minimizing the deviations from a fully consistent matrix. This results in more reliable and precise weighting, making it particularly valuable in complex decision-making scenarios where criteria are interdependent, and judgments must be precise. FUCOM's structured approach reduces subjective biases and enhances the objectivity of the decision-making process, making it a preferred method in various fields, including engineering, management, and healthcare [14–16].

The subsequent section outlines the process for determining the weighting coefficients of criteria using the FUCOM method:

Step 1. The first step is to rank the criteria from a predefined set of evaluation criteria $C = \{C_1, C_2, \ldots, C_n\}$.

$$C_{j_{(1)}} > C_{j_{(2)}} > \cdots > C_{j_{(k)}} \tag{3}$$

where, k represents the rank of the observed criterion.

Step 2. In the second step, a mutual comparison of ranked criteria is made and comparative significance $(\varphi_{k/(k+1)})$, $k = 1, 2, \ldots, n$, is determined, where k represents the ranking of the evaluation criteria.

$$\Phi = (\varphi_{1/2}, \varphi_{2/3}, \ldots, \varphi_{k/(k+1)}) \tag{4}$$

Step 3. In the third step, the final values of the weighting coefficients of the evaluation criteria $(w_1, w_2, \ldots, w_n)^T$ are calculated. The final values of the weighting coefficients should satisfy two conditions: (1) The ratio of the weighting coefficients is equal to the comparative significance among the observed criteria $(\varphi_{k/(k+1)})$, which is defined in Step 2, i.e., that the following condition is fulfilled:

$$\frac{w_k}{w_{k+1}} = \varphi_{k/(k+1)} \tag{5}$$

In addition, the final values of the weighting coefficients should satisfy the condition of mathematical transitivity, i.e., that $\varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} = \varphi_{k/(k+2)}$. Since $\varphi_{k/(k+1)} = \frac{w_k}{w_{k+1}}$ and $\varphi_{(k+1)/(k+2)} = \frac{w_{k+1}}{w_{k+2}}$, we obtain that $\frac{w_k}{w_{k+1}} \otimes \frac{w_{k+1}}{w_{k+2}} = \frac{w_k}{w_{k+2}}$. Thus, we gain a second condition that should be satisfied by the final values of the weighting coefficients of the evaluation criteria:

$$\frac{w_k}{w_{k+2}} = \varphi_{\frac{k}{k+1}} \otimes \varphi_{\frac{k+1}{k+2}} \tag{6}$$

Based on the defined settings, we can define a final model for determining the final values of the weighting coefficients of the evaluation criteria:

$$\begin{aligned}
&\min \chi \\
&\text{s.t.} \\
&\left| \frac{w_{j(k)}}{w_{j(k+1)}} - \varphi_{k/(k+1)} \right| = \chi, \forall j \\
&\left| \frac{w_{j(k)}}{w_{j(k+2)}} - \varphi_{k(k+1)} \otimes \varphi_{(k+1)(k+2)} \right| = \chi, \forall j \\
&\sum_{j=1}^{n} w_j = 1, \\
&w_j \geq 0, \forall j
\end{aligned}$$

2.3 EDAS Method

The EDAS method is a robust decision-making tool used to rank alternatives based on their performance relative to an average solution [17, 18]. This method calculates the positive and negative distances of each alternative from the average performance across all criteria, thus determining their relative superiority or inferiority. EDAS focuses on how each alternative deviates from the normative average, integrating these deviations into a comprehensive scoring system [19]. The simplicity and effectiveness of the EDAS method make it particularly suitable for multi-criteria decision analysis in areas ranging from supply chain management to policy evaluation, where clear differentiation between options based on aggregate criteria performance is crucial.

2.4 Proposed Hybrid Grey-FUCOM-EDAS Method

In this study, we introduce a hybrid MCDM approach that integrates Grey Theory, the FUCOM, and the EDAS to address complex decision-making scenarios with incomplete or uncertain information. The following pseudo code provides a detailed procedural outline of how these methods are sequentially applied to evaluate and rank different strategies or solutions, illustrating the practical application of the integrated MCDM model.

1. Input:
- S: Set of alternatives $\mathrm{S} = \{\mathrm{s1},\ \mathrm{s2}, \ldots, \mathrm{sn}\}$
- C: Set of criteria $C = \{c1, c2, \ldots,\ \mathrm{cm}\}$
- M: Decision matrix of size $\mathrm{n} \times \mathrm{m}$, with incomplete data

2. Process Grey Data:
- Use Grey Theory to estimate missing values in M
- Normalize decision matrix M using linear normalization

3. Calculate Criteria Weights with FUCOM:
- Initialize pairwise comparison matrix based on expert judgment or derived from normalized M
- Solve for weights W using FUCOM ensuring consistency and priorities among criteria

4. Apply EDAS Method:
- Calculate average solution A for each criterion from the completed M
- Initialize S+ and S- for positive and negative distances

for i from 1 to n:

for j from 1 to m:

if $\mathrm{mij}^{>} = \mathrm{A[j]}$:

$$\mathrm{S} + [\mathrm{i}] = \mathrm{S} + [\mathrm{i}] + \mathrm{W[j]} * (\mathrm{mij} - \mathrm{A[j]})$$

else:

$$\mathrm{S} - [\mathrm{i}] = \mathrm{S} - [\mathrm{i}] + \mathrm{W[j]} * (\ \mathrm{A[j]} - \mathrm{mij})$$

5. Compute Appraisal Scores and Rank Alternatives:
- AS[i] = S+[i] - S-[i] for each alternative si
- Rank alternatives based on AS from highest to lowest

6. Output:
- Return ranked list of alternatives

3 Results

Libya's transportation infrastructure is predominantly supported by airplanes, automobiles, and trucks, heavily emphasizing road transport for domestic travel. The extensive use of trucks and private vehicles has precipitated various adverse effects, including environmental concerns such as air pollution and noise pollution, as well as a high incidence of accidents and significant land use. These impacts are magnified by the country's reliance on such modes of transportation. For instance, Libya's accident fatality rate stands at 26.1 per 100,000 population—one of the highest globally—which can be attributed to deteriorating road conditions and a surge in vehicle registrations, with over 3.55 million vehicles registered by 2013 [20]. Data spanning from 1995 to 2021, presented in Table 1, highlights a concerning upward trend in accident-related fatalities. Moreover, the absence of advanced transportation systems and effective traffic management, such as functional traffic signals and sufficient road signage, exacerbates the situation, complicating efforts to enhance road safety.

Table 1. Number of deaths and injuries caused by traffic accidents in Libya during 1995-2021

Injury Severity	Category	Count
Deaths	No. of Accidents	41,476
	No. of Persons	51,672
Serious injuries	No. of Accidents	62,497
	No. of Persons	102,091
Slight injuries	No. of Accidents	56,769
	No. of Persons	117,105

The primary aim of this study is to identify and prioritize the critical risk factors contributing to transport accidents using an MCDM approach, specifically designed to address the nuances of transportation safety. Our research focuses on evaluating several key criteria that broadly influence accident rates. These include behavioral aspects such as attitudes toward speeding, perceptions of traffic laws, and the frequency of risky behaviors like running red lights and erratic lane changing. We also consider technological factors such as the use of safety equipment and mobile devices while driving. Environmental and infrastructural elements are analyzed through criteria like road conditions, traffic signage, and road markings. Additionally, we examine the effectiveness of traffic law enforcement and the historical data on traffic violations and accidents. Table 2 displays the criteria used in this study, as recommended by experts in the field.

Table 2. List of the criteria used

Criteria No.	Description
C1	Attitudes toward speeding
C2	Perceptions of traffic laws
C3	Use of safety equipment (e.g., seat belts)
C4	Frequency of risky behaviors (e.g., running red lights, erratic lane changing)
C5	Use of mobile devices while driving
C6	Road conditions and design
C7	Traffic signage and road markings
C8	Enforcement of traffic laws
C9	History of traffic violations or accidents

Four experts have been asked to assess the importance of each criterion in evaluating proposed techniques. They used linguistic variables, which are represented as grey numbers, detailed in Table 3. Table 4 presents the linguistic assessment of attributes by the experts, including the upper and lower bounds, and the weighting value for each criterion.

Table 3. The importance of grey numbers for the weights of the criteria

Importance	Abbreviation	Scale of Grey Number (⊗W)
Very Low	VL	[0.0, 0.1]
Low	L	[0.1, 0.3]
Medium Low	ML	[0.3, 0.4]
Medium	M	[0.4, 0.5]
Medium High	MH	[0.5, 0.6]
High	H	[0.6, 0.8]
Very High	VH	[0.8, 1.0]

Table 4. The linguistic assessment of the attributes by experts

Ci	Expert #1	Expert #2	Expert #3	Expert #4	$\otimes W$		Whitening Degree
C1	H	H	VH	MH	0.63	0.80	0.7125
C2	MH	MH	M	H	0.50	0.63	0.5625
C3	MH	MH	MH	M	0.48	0.58	0.5250
C4	H	VH	H	VH	0.70	0.90	0.8000
C5	VH	VH	VH	H	0.75	0.95	0.8500
C6	M	ML	H	ML	0.40	0.53	0.4625
C7	H	MH	MH	M	0.50	0.63	0.5625
C8	VH	VH	H	VH	0.75	0.95	0.8500
C9	H	H	H	MH	0.58	0.75	0.6625

Based on the results obtained from the Grey method, the next step in the analysis involves applying the FUCOM method to determine the relative weights of the criteria. The linguistic assessments provided by experts have been converted into numerical values, representing the importance of each criterion in decision-making.

Based on the FUCOM analysis, the final weights for each criterion have been determined, ensuring a fully consistent allocation of importance, as shown in Table 5. The highest-weighted criteria are use of mobile devices while driving (0.145) and enforcement of traffic laws (0.145), indicating their critical role in traffic accident mitigation. Frequency of risky behaviors (0.132) and attitudes toward speeding (0.121) also hold significant importance. Conversely, road conditions and design (0.077) and use of safety equipment (0.086) received the lowest weights, suggesting they have relatively less impact compared to other criteria. The consistency of the weight distribution is confirmed by the DFC(γ) value of 0.000, demonstrating that the expert judgments were fully aligned and internally consistent.

Table 5. Weights of the criteria

Ci	C1	C2	C3	C4	C5	C6	C7	C8	C9
Weight	0.121	0.091	0.086	0.132	0.145	0.077	0.091	0.145	0.112

Social and behavioral factors, accounting for 48.9% of the total weight, are the most significant contributors to road accidents. Enforcement and regulatory factors, representing 34.3%, also play a crucial role. In contrast, environmental and infrastructure factors, which hold the lowest weight at 16.8%, indicate that while road conditions and signage are important, they are not as critical as behavioral and enforcement-related aspects in mitigating accidents.

These weights will now be used in the EDAS method to rank the proposed strategies based on their effectiveness in addressing the prioritized factors influencing road safety. Table 6 serves as the decision matrix for the study, representing the average weights assigned to various strategies against each criterion. These weights have been derived from the assessments provided by the experts, who evaluated the efficacy of each strategy in addressing the key factors associated with road safety. The four strategies evaluated in this study for mitigating road traffic accidents are Infrastructure Improvements (S1), Educational Programs (S2), Policy Amendments (S3), and Technology Integration (S4). Each targets different aspects of road safety, from enhancing physical road infrastructure and educating road users to revising traffic laws and incorporating advanced technologies. These strategies aim to collectively reduce the incidence and severity of traffic accidents by addressing the varied dimensions of road safety.

Table 6. Decision matrix

Ci	C1	C2	C3	C4	C5	C6	C7	C8	C9
Weight	0.121	0.091	0.086	0.132	0.145	0.077	0.091	0.145	0.112
S1	80	75	75	70	75	95	95	90	75
S2	90	85	85	75	80	80	65	80	65
S3	80	80	85	65	80	80	65	90	60
S4	80	65	80	85	90	65	70	80	75

The appraisal score (AS) values for all proposed strategies are obtained as follows:

$$\text{AS1} = 1/2(1.000 + 0.875) = 0.938$$
$$\text{AS2} = 1/2(0.463 + 0.796) = 0.629$$
$$\text{AS3} = 1/2(0.834 + 1.000) = 0.917$$
$$\text{AS4} = 1/2(0.102 + 0.000) = 0.051$$

By arranging the AS values obtained in descending order, the ranking of the proposed strategies can be obtained as follows: S1>S2>S3>S4.

4 Discussion

In this study, we explored the effectiveness of four strategies—Infrastructure Improvements, Educational Programs, Policy Amendments, and Technology Integration—aimed at reducing road traffic accidents. Our findings indicate that while each strategy has its unique strengths, they collectively contribute to a comprehensive approach to road safety. Infrastructure Improvements and Technology Integration, in particular, scored highly on criteria related to the physical and technological enhancements necessary for safer road environments. These strategies directly impact the physical conditions that drivers encounter daily, suggesting that improvements such as better road layouts, robust traffic signals, and advanced safety features in vehicles can significantly decrease the likelihood of accidents.

On the other hand, Educational Programs and Policy Amendments are crucial in addressing the behavioral and regulatory aspects of road safety. Educational initiatives that focus on the dangers of risky behaviors, like speeding and distracted driving, are vital for long-term cultural changes in driving habits. Simultaneously, Policy Amendments that enforce stricter regulations and penalties serve as both a deterrent and a framework for safer driving practices. The interaction between these strategies highlights the need for an integrated road safety policy that combines physical, technological, behavioral, and regulatory elements to effectively reduce traffic accidents. This multifaceted approach ensures that while infrastructure and technology provide the necessary tools for safety, education and policy solidify the behavioral foundation required for their effective utilization.

5 Conclusions

In conclusion, this study underscores the necessity of adopting a multi-faceted approach to mitigate road traffic accidents effectively. By analyzing the impact of four strategic avenues—Infrastructure Improvements, Educational Programs, Policy Amendments, and Technology Integration—we demonstrate that each strategy plays a vital role in enhancing road safety. Infrastructure Improvements and Technology Integration are critical in upgrading the physical and technological framework of transportation, thereby directly reducing accident-prone scenarios on the road. Concurrently, Educational Programs and Policy Amendments address the behavioral and legislative aspects, shaping safer driving behaviors and creating a regulatory environment that enforces these behaviors.

The synergy between these strategies forms the backbone of an effective road safety system. As such, it is recommended that policymakers and road safety officials adopt an integrated strategy that leverages the strengths of physical infrastructure, technology, education, and robust legal frameworks. By doing so, it becomes possible to create a sustainable and significant reduction in road traffic accidents, ultimately saving lives and reducing economic costs associated with these accidents. Moving forward, continuous evaluation and adaptation of these strategies should be pursued to respond to evolving road safety challenges and technological advancements.

Data Availability

The data used to support the research findings are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflict of interest.

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