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Development of a New Risk Assessment Methodology for Light Goods Vehicles on Two-Lane Road Sections

Marko Subotić [1], Veljko Radičević [2], Zoran Pavlović [2] and Goran Ćirović [3,*]

[1] Faculty of Transport and Traffic Engineering, University of East Sarajevo, Vojvode Mišića 52, 74000 Doboj, Bosnia and Herzegovina; marko.subotic@sf.ues.rs.ba
[2] Academy of Technical and Art Applied Studies Belgrade, Department School of Railroad Transport of Applied Studies in Belgrade, Zdravka Celara 14, 11000 Belgrade, Serbia; veljko.radicevic@vzs.edu.rs (V.R.); zoran.pavlovic@vzs.edu.rs (Z.P.)
[3] Faculty of Technical Sciences, University of Novi Sad, Trg Dositeja Obradovića 6, 21000 Novi Sad, Serbia
* Correspondence: cirovic@sezampro.rs

Abstract: Increasing mobility directly affects traffic frequency and thus increases the possible risk of traffic accident occurrences. Taking this into account, it is necessary to create models for determining risk and to act preventively based on these models; this is of great importance both to society and science. In this paper, six measuring sections of a road network are considered on the basis of eight geometric-exploitation road parameters, taking into account the data for light goods vehicles. An original methodology is proposed for identifying risk levels of road sections through their evaluation. For identifying risk levels, the Dombi Logarithmic Methodology of Additive Weights (D'LMAW) was used, which was combined with the Measurement Alternatives and Ranking according to the Compromise Solution (MARCOS) method. Statistical indicators were processed using a hybrid methodology based on the application of rough numbers and Dombi–Bonferroni functions. The performance of the presented methodology was verified on a real-world example, processing the statistical parameters of six two-lane road sections, with the sixth measuring section showing the best performance, since it had the minimum risk. Research has shown that measuring sections with increasing longitudinal gradients are safer. The analysis of measuring sections from fall to rise reduces the deviation of speeds from the speed limit on the roads. The effectiveness, rationality, and robustness of the solution of the proposed methodology was confirmed through a sensitivity analysis.

Keywords: traffic risk; traffic accidents; light goods vehicles; LMAW; MARCOS; Dombi; Bonferroni

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1. Introduction

In a real traffic flow, there are a large number of influential road and traffic indicators of potential traffic risk. If two-lane roads are analyzed, the traffic indicators that are especially significant are the AADT (Annual Average Daily Traffic), uneven distribution of traffic by different directions, vehicle structure, traffic flow density, exploitation speed, exceeding the speed in relation to the speed limit, and so on. Additionally, road and environmental conditions have great impacts on potential indicators of increased traffic risk, such as a longitudinal gradient (ascent/descent), road condition, radii of horizontal curves, number of accesses per kilometer, and so on. Potential road and traffic indicators often refer to the speed limit, which is imperative to limiting the speed of real traffic flow. Nevertheless, speed limit analysis and compliance with the speed limit are integral parts of speed control.

Speed control is an important segment in the traffic flow control system. Any posted speed limit is not always respected by road users, leading to speeding, and any non-adjusted speed is often a potential cause of increased traffic risk. In addition, studies have shown that the greater the difference between the free flow speed and the speed limit, the higher the percentage of drivers who do not comply with the speed limit for any class of vehicles [1,2]. It is very important to establish an optimum speed limit, which can enable maximum capacity and level of service with minimum costs and risks of traffic accidents. By analyzing risk on two-lane roads, it is certain that, as a function of different road characteristics and the influence of traffic indicators, there is a large percentage of vehicles that exceed the speed limit. Moreover, there are large dispersions of speeds on a case-by-case basis in a real traffic flow.

In this study, a multi-criteria model for identifying risk on two-lane road sections was developed. Rough numbers [3] and rough Dombi functions [4] were used to process statistical data by measuring road sections. The data were obtained over a five-year period. The rough Dombi Logarithmic Methodology of Additive Weights (D'LMAW) was used to determine the weight coefficients of criteria, while the rough Measurement Alternatives and Ranking according to the Compromise Solution (MARCOS) method [5] was used to determine the level of risk and evaluate the alternatives. The performance of the rough MARCOS methodology was improved through the implementation of the hybrid rough Dombi–Bonferroni function, which was used to calculate the sum of the weighted elements of the normalized matrix. The application of rough Dombi–Bonferroni functions enables a flexible definition of risk on two-lane road sections and consideration of mutual relations among attributes that define the level of risk on given measuring road sections.

Further in the paper, Section 2 presents the literature review of scholarly sources. Section 3 is related to rough numbers [6] and rough Dombi functions [7], with three definitions given. Subsequently, Section 4 presents the multi-criteria framework of the proposed methodology for determining the risk for light goods vehicles on the road sections. Section 5 provides the results obtained and discussion of the research results, with a general conclusion given in Section 6.

2. Literature Review

The analysis of the impact of geometric road parameters is of great importance in the adoption of measures to improve traffic safety. Based on the research [8] conducted for traffic safety assessment, it is necessary to identify environment elements that affect the functional status of drivers, the functional dependence between the status of drivers, and the statistical indicators of road safety. The research conducted in two studies [9] on the Northern Corridor in Kenya concluded that pavement rehabilitation on roads has led to improvements in the traffic safety level. This study showed that 24% of traffic accidents were fatal before the road rehabilitation. Improving traffic safety performance through engineering solutions has also been examined through Empirical Bayes (EB) models [10]. This research highlighted six engineering solutions for improving safety on two-lane roads. In order to improve safety on two-lane rural roads, significant studies were conducted, the outcomes of which formed the basis for revising guidelines for design, investment decision making, and implementation of traffic safety decisions [11–17]. The findings of these studies are limited by drivers' behavior, the quality of the infrastructure present, and the characteristics of the traffic. In practice, risk management is the basis for eliminating a potential adverse event [18–22].

Speed is extremely important in terms of efficiency (Level of Service (LOS) and travel time) and safety (occurrence and consequences of traffic accidents) [23]. The size and frequency of the exceeding of speed limits was given in the report Vehicle Speed Compliance Statistics, produced in Great Britain in 2018 by the Department for Transport, which shows that there is frequent speed limit exceeding of 53.00% for light commercial vehicles in free-flow conditions. Gao et al. [24] investigated the dispersion of traffic flow speed in relation to speed limits. The research was conducted on an expressway with speed limits of 80 km/h, 100 km/h, and 120 km/h, and showed that there was an increase in the speed of traffic flow and speed dispersion with an increase in the speed limit. The impact of posting an appropriate speed limit on increasing road capacity has also been described in a study on Indian expressways [25]. This study concluded that when increasing the speed limit, the compliance with the speed limit by traffic participants increases too. When a large number of drivers comply with the posted speed limit in the traffic conditions prevailing on roads in India, it was found that the travel time is slightly reduced and that the flow efficiency is improved. Based on a study [2] conducted in the Netherlands with 600 respondents, who were shown photographs of 27 road sections, large differences were found between the preferred speed of the respondents and the speed limit (80 km/h). These differences referred to a number of road and environment characteristics, such as the presence/absence of curves and characteristics related to the driver's field of vision. In addition, another study [26] showed large differences among respondents. The influence of horizontal signalization on the road network leads to the appearance of higher speeds, regardless of the presence of marked pedestrian paths, residential housing, or speed signs. To a lesser extent, an increase in speed with an increase in marking (greater demarcation) on rural two-lane roads was also noted [7].

3. Rough-Number-Based Bonferroni Operators Based on Dombi Operation Laws

3.1. Some Basic Concepts on Rough Numbers

Rough sets [6] represent an adequate tool for processing inaccuracies in information with additional influence of subjectivity when defining boundary intervals [27]. Zhai et al. [28] emphasize that the use of rough sets is quite appropriate for a decision-making process when there is uncertain and unavailable data. Given the performance of rough numbers in subjectivity manipulation, a multi-criteria framework based on information processing using rough numbers is proposed in this paper.

Rough numbers are essentially based on the concept of rough sets, which are based on defining the lower limit, the upper limit, and the rough boundary interval of a rough number. If we assume that Ψ is the universal set of objects divided into b classes that satisfy the condition $\varsigma_1 \leq \varsigma_2 \leq, \ldots, \leq \varsigma_b$, then $1 \leq i \leq b$. If we assume that Υ is the collection of $(\varsigma_1, \varsigma_2, , \ldots, \varsigma_b)$ and that Π is an arbitrary element of Ψ, then we can define the lower approximation of class ς_i as follows:

$$\underline{Apr}(\varsigma_i) = \cup\{\Pi \in \Psi / \Upsilon(\Pi) \leq \varsigma_i\} \tag{1}$$

In addition, based on the above, we can define the upper approximation as follows:

$$\overline{Apr}(\varsigma_i) = \cup\{\Pi \in \Psi / \Upsilon(\Pi) \geq \varsigma_i\} \tag{2}$$

Based on the lower and upper approximations (1) and (2), we can define the lower and upper limit of ς_i as follows:

$$\underline{Lim}(\varsigma_i) = \left(\frac{1}{N^-} \sum_{i,j=1}^{N^-} \varsigma_i^{\varepsilon_1} \left(\prod_{j=1}^{N^-} \varsigma_j^{\varepsilon_2} \right)^{\frac{1}{N^- - 1}} \right)^{\frac{1}{\varepsilon_1 + \varepsilon_2}} \left| \varsigma_i^{\varepsilon_1}, \varsigma_j^{\varepsilon_2} \in \underline{Apr}(\varsigma_i) \right. \tag{3}$$

$$\overline{Lim}(\varsigma_i) = \left(\frac{1}{N^+} \sum_{i,j=1}^{N^+} \varsigma_{il}^{\varepsilon_1} \left(\prod_{j=1}^{N^+} \varsigma_{jl}^{\varepsilon_2} \right)^{\frac{1}{N^+ - 1}} \right)^{\frac{1}{\varepsilon_1 + \varepsilon_2}} \left| \varsigma_{il}^{\varepsilon_1}, \varsigma_{jl}^{\varepsilon_2} \in \overline{Apr}(\varsigma_i) \right. \tag{4}$$

where N^- and N^+ represent the number of elements in $\underline{Apr}(\varsigma_i)$ and $\underline{Apr}(\varsigma_i)$, respectively; $\varepsilon_1, \varepsilon_2 \geq 0$ and $\varepsilon_1, \varepsilon_2 \in R$, where R represents a set of real numbers.

Based on Equations (1)–(4), we can define a rough number of ς_i as follows:

$$RN(\varsigma_i) = \left[\underline{Lim}(\varsigma_i), \overline{Lim}(\varsigma_i)\right] = \left[\varsigma_i^-, \varsigma_i^+\right] \tag{5}$$

The rough boundary interval of ς_i is defined as follows:

$$RNBnd(\varsigma_i) = \varsigma_i^+ - \varsigma_i^- \tag{6}$$

The rough boundary interval represents the uncertainty of ς_i. Arithmetic operations between rough numbers are performed as with classical interval numbers and can be seen in more detail in Djalic et al. [29].

3.2. Dombi Operations

Definition 1. *Let τ_1 and τ_2 be any two real numbers. Then, the Dombi T-norm and T-conorm between τ_1 and τ_2 are defined as follows* [4]*:*

$$T_D(\tau_1, \tau_2) = \frac{1}{1 + \left\{ \left(\frac{1-\tau_1}{\tau_1}\right)^{\alpha} + \left(\frac{1-\tau_2}{\tau_2}\right)^{\alpha} \right\}^{1/\alpha}} \tag{7}$$

$$T_D^c(\tau_1, \tau_2) = 1 - \frac{1}{1 + \left\{ \left(\frac{\tau_1}{1-\tau_1}\right)^{\alpha} + \left(\frac{\tau_2}{1-\tau_2}\right)^{\alpha} \right\}^{1/\alpha}} \tag{8}$$

where $\alpha > 0$ and $(\tau_1, \tau_2) \in [0, 1]$.

Based on the definition of Dombi T-norm and T-conorm, we can define Dombi operations with rough numbers.

Definition 2. *Assume that $\tau_1 = \left[\tau_1^-, \tau_1^+\right]$ and $\tau_2 = \left[\tau_2^-, \tau_2^+\right]$ are two rough numbers, $\alpha, \theta > 0$, and let $f(\tau_i) = \tau_i / \sum_{i=1}^{n} \tau_i$ be a rough function; then, based on the Dombi T-norm and T-conorm, we can define some operational laws with rough numbers as follows:*

(1) Addition "+"

$$\tau_1 + \tau_2 = \begin{bmatrix} (\tau_1^- + \tau_2^-) - \dfrac{\tau_1^- + \tau_2^-}{1 + \left\{ \left(\frac{f(\tau_1^-)}{1-f(\tau_1^-)}\right)^{\alpha} + \left(\frac{f(\tau_2^-)}{1-f(\tau_2^-)}\right)^{\alpha} \right\}^{1/\alpha}}, \\ (\tau_1^+ + \tau_2^+) - \dfrac{\tau_1^+ + \tau_2^+}{1 + \left\{ \left(\frac{f(\tau_1^+)}{1-f(\tau_1^+)}\right)^{\alpha} + \left(\frac{f(\tau_2^+)}{1-f(\tau_2^+)}\right)^{\alpha} \right\}^{1/\alpha}} \end{bmatrix} \tag{9}$$

(2) Multiplication "×"

$$\tau_1 \times \tau_2 = \left[\frac{\tau_1^- + \tau_2^-}{1 + \left\{ \left(\frac{1-f(\tau_1^-)}{f(\tau_1^-)}\right)^{\alpha} + \left(\frac{1-f(\tau_2^-)}{f(\tau_2^-)}\right)^{\alpha} \right\}^{1/\alpha}}, \frac{\tau_1^+ + \tau_2^+}{1 + \left\{ \left(\frac{1-f(\tau_1^+)}{f(\tau_1^+)}\right)^{\alpha} + \left(\frac{1-f(\tau_2^+)}{f(\tau_2^+)}\right)^{\alpha} \right\}^{1/\alpha}} \right] \tag{10}$$

(3) Scalar multiplication, where $\theta > 0$

$$\theta \times \tau_1 = \left[\tau_1^- - \frac{\tau_1^-}{1 + \left\{ \theta \left(\frac{f(\tau_1^-)}{1-f(\tau_1^-)}\right)^{\alpha} \right\}^{1/\alpha}}, \tau_1^+ - \frac{\tau_1^+}{1 + \left\{ \theta \left(\frac{f(\tau_1^+)}{1-f(\tau_1^+)}\right)^{\alpha} \right\}^{1/\alpha}} \right] \tag{11}$$

(4) Power, where $\gamma > 0$

$$\tau_1^{\theta} = \left[\frac{\tau_1^-}{1 + \left\{ \theta \left(\frac{1-f(\tau_1^-)}{f(\tau_1^-)}\right)^{\alpha} \right\}^{1/\alpha}}, \frac{\tau_1^+}{1 + \left\{ \theta \left(\frac{1-f(\tau_1^+)}{f(\tau_1^+)}\right)^{\alpha} \right\}^{1/\alpha}} \right] \tag{12}$$

3.3. Bonferroni Mean Operators

Definition 3 [30]**.** *Let the set (τ_1, τ_2, ..., τ_n) represent the set of rough numbers; let χ_1, $\chi_2 \geq 0$; and let the weight coefficients of rough numbers τ_i ($i = 1, 2, \ldots, n$) be denoted by $w_i \in [0, 1]$ (i = 1, 2, ... , n). If*

$$WBM^{\chi_1,\chi_2}(\tau_1, \tau_2, \ldots, \tau_n) = \left(\sum_{i,j=1}^{n} \frac{w_i w_j}{1 - w_i} \tau_i^{\chi_1} \tau_j^{\chi_2} \right)^{\frac{1}{\chi_1+\chi_2}} \tag{13}$$

then WBM^{χ_1,χ_2} represents the normalized weighted Bonferroni mean (WBM) operator.

4. A Hybrid Dombi–Bonferroni MARCOS Model Based on Rough Numbers

The multi-criteria model represents the application of the rough Dombi Logarithmic Methodology of Additive Weights (D'LMAW) for determining the weight coefficients of criteria and improving the rough Measurement Alternatives and Ranking according to the Compromise Solution (MARCOS) method [5]. The improvement of the rough MARCOS methodology is based on the integration of the Dombi T-norm (TN) and T-conorm (TCN) into the Bonferroni function, which was used to calculate the sum of the weighted elements of the normalized matrix in the rough Dombi–Bonferroni MARCOS method. The application of the hybrid rough Dombi–Bonferroni function enables nonlinear processing of the rough parameters of the initial matrix. In addition, the integration of the rough Dombi–Bonferroni function into the MARCOS model improves the flexibility of the traditional MARCOS method, thus enabling the perception of dynamic environmental conditions and risks that are an integral part of the real-world application of multi-criteria techniques. In addition, the rough Dombi–Bonferroni function enables the demonstration of mutual relations among the elements of the initial matrix, which significantly improves the performance of the MARCOS method. In the following section, a multi-criteria framework of the proposed methodology for determining the risk on road sections is presented.

4.1. Rough Dombi Logarithmic Methodology of Additive Weights

In the following section, a new approach is presented for determining weight coefficients, which is based on the application of the rough Dombi Logarithmic Methodology of Additive Weights (D'LMAW). The Rough D'LMAW methodology is implemented through the six steps presented below:

Step 1. Assume that b experts $E = \{E_1, E_2, \ldots, E_b\}$ participate in the research. Each expert defines a priority vector $\Theta^t = \left(\gamma_{C1}^t, \gamma_{C2}^t, \ldots, \gamma_{Cn}^t\right)$, $1 \leq t \leq b$ on the basis of a predefined scale. Thus, we get b priority vectors Θ^1, Θ^2, ... , Θ^t, ... , Θ^b. By applying Equations (1)–(4), the sequences of priority vectors γ_j^1, γ_j^2, ... , γ_j^b are transformed into interval rough sequences $\gamma_j^1 = \left[\gamma_j^{1-}, \gamma_j^{1+}\right]$, $\gamma_j^2 = \left[\gamma_j^{2-}, \gamma_j^{2+}\right]$, ... , $\gamma_j^t = \left[\gamma_j^{t-}, \gamma_j^{t+}\right]$, ... , $\gamma_j^b = \left[\gamma_j^{b-}, \gamma_j^{b+}\right]$.

By applying the Dombi function, Equation (14), we obtain an aggregated rough priority vector $\Theta = (\gamma_{C1}, \gamma_{C2}, \ldots, \gamma_{Cn})$, $\overline{\gamma}_j = \left[\gamma_j^-, \gamma_j^+\right]$.

$$\overline{\gamma}_j = \left[\frac{\sum_{j=1}^{b} \gamma_j^-}{1 + \left\{ \sum_{j=1}^{b} \frac{1}{b} \left(\frac{1 - f\left(\gamma_j^-\right)}{f\left(\gamma_j^-\right)} \right)^{\alpha} \right\}^{1/\alpha}}, \frac{\sum_{j=1}^{b} \gamma_j^+}{1 + \left\{ \sum_{j=1}^{b} \frac{1}{b} \left(\frac{1 - f\left(\gamma_j^+\right)}{f\left(\gamma_j^+\right)} \right)^{\alpha} \right\}^{1/\alpha}} \right] \tag{14}$$

where $f\left(\gamma_j\right) = \overline{\gamma}_j / \sum_{j=1}^{b} \overline{\gamma}_j$ represents a rough priority function, while b represents the total number of experts.

Step 2. Defining a rough vector of relations Ψ. Using Equation (15), the relations among the elements of the priority vector and the absolute anti-ideal point (β_{AIP}) are defined as follows:

$$RN(\rho_{Cn}) = \frac{RN(\gamma_{Cn})}{RN(\beta_{AIP})} \tag{15}$$

where $RN(\rho_{Cn})$ represents an element of the rough vector of relations $\Psi = (RN(\rho_{C1}), RN(\rho_{C2}), \ldots, RN(\rho_{Cn}))$, $1 \le t \le b$, while the absolute anti-ideal point is determined on the basis of condition $RN(\beta_{AIP}) < \min\left(\gamma^t_{C1}, \gamma^t_{C2}, \ldots, \gamma^t_{Cn}\right)$.

Step 3. Determination of weight coefficient vector. Using Equation (16), we determine the weight coefficients of the criteria:

$$RN(w_j) = \frac{\ln\left(RN\left(\rho_j\right)\right)}{\ln(RN(\nu_j))} \tag{16}$$

where $RN\left(\rho_j\right)$ represents the elements of the rough vector of relations $\Psi = (RN(\rho_{C1}), RN(\rho_{C2}), \ldots, RN(\rho_{Cn}))$, while the value of $RN(\nu)$ is obtained by applying Equation (17)

$$RN(\nu_j) = \left[\frac{\sum_{j=1}^{n} \rho_j^-}{1 + \left\{ \sum\limits_{j=1}^{n} \frac{1}{n} \left(\frac{1 - f\left(\rho_j^-\right)}{f\left(\rho_j^-\right)} \right)^{\alpha} \right\}^{1/\alpha}}, \frac{\sum_{j=1}^{n} \rho_j^+}{1 + \left\{ \sum\limits_{j=1}^{n} \frac{1}{n} \left(\frac{1 - f\left(\rho_j^+\right)}{f\left(\rho_j^+\right)} \right)^{\alpha} \right\}^{1/\alpha}} \right] \tag{17}$$

where $RN\left(\rho_j\right) = \left[\rho_j^-, \rho_j^+\right]$ represents the elements of the rough vector of relations.

4.2. Rough Dombi Bonferroni MARCOS Model

Based on the definitions of rough numbers, Dombi norms, and Bonferroni functions, the following section presents a hybrid rough Dombi–Bonferroni MARCOS model. The Rough Dombi–Bonferroni MARCOS model is based on the application of hybrid Dombi–Bonferroni functions and rough numbers to process inaccuracies in a multi-criteria framework.

Step 1. Assume that in the multi-criteria model, there are m alternatives and n criteria used to evaluate the alternatives. In addition, assume that the data obtained in the initial decision matrix (IDM) $\Omega = \left[\psi_{ij}\right]_{m \times n}$ were obtained by recording the traffic data over x recording periods. Based on the collected data, x IDMs can be formed, which we can denote by $\Omega^v = \left[\psi_{ij}^v\right]_{m \times n}$ $(1 \le v \le x)$. Based on $\Omega^v = \left[\psi_{ij}^v\right]_{m \times n}$ $(1 \le v \le x)$, we can form a matrix Ω^r that contains sequences from the matrices $(1 \le v \le x)$.

$$\Omega^r = \begin{bmatrix} \psi^1_{11}, \psi^2_{11}, \ldots, \psi^x_{11} & \psi^1_{12}, \psi^2_{12}, \ldots, \psi^x_{12} & , \ldots, & \psi^1_{1n}, \psi^2_{1n}, \ldots, \psi^x_{1n} \\ \psi^1_{21}, \psi^2_{21}, \ldots, \psi^x_{1} & \psi^1_{22}, \psi^2_{22}, \ldots, \psi^x_{22} & , \ldots, & \psi^1_{2n}, \psi^2_{2n}, \ldots, \psi^x_{2n} \\ \ldots & \ldots & , \ldots, & \ldots \\ \psi^1_{m1}, \psi^2_{m1}, \ldots, \psi^x_{m1} & \psi^1_{m2}, \psi^2_{m2}, \ldots, \psi^x_{m2} & , \ldots, & \psi^1_{mn}, \psi^2_{mn}, \ldots, \psi^x_{mn} \end{bmatrix} \tag{18}$$

where $\psi_{ij}^v = \left\{\psi^1_{11}, \psi^2_{11}, \ldots, \psi^x_{11}\right\}$, $(1 \le v \le x)$ represents sequences that demonstrate the relative importance of alternative i in relation to criterion j. By applying Equations (1)–(4), the sequences ψ_{ij}^v $(1 \le v \le x)$ are transformed into interval rough sequences. By averaging interval rough sequences, we obtain an aggregated rough sequence $RN\left(\psi_{ij}\right) = \left[\psi_{ij}^{-}, \psi_{ij}^{+}\right]$, which represents an element of an aggregated initial matrix $\Omega = \left[RN\left(\psi_{ij}\right)\right]_{m\times n}$:

$$\Omega = \begin{array}{c} \\ A_1 \\ A_2 \\ \ldots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \ldots & C_n \end{array} \\ \begin{bmatrix} RN(\psi_{11}) & RN(\psi_{12}) & \ldots & RN(\psi_{1n}) \\ RN(\psi_{21}) & RN(\psi_{22}) & \ldots & RN(\psi_{2n}) \\ \ldots & \ldots & \ddots & \ldots \\ RN(\psi_{m1}) & RN(\psi_{m2}) & \ldots & RN(\psi_{mn}) \end{bmatrix}_{m\times n} \end{array} \tag{19}$$

Step 2. Using Equation (20), the ideal alternative (*IA*) and the anti-ideal alternative (*AIA*) are defined as follows:

$$\begin{aligned} IA &= \max_{1\le i\le m} RN\left(\psi_{ij}\right) \quad if \quad j\in B \quad and \quad \min_{1\le i\le m} RN\left(\psi_{ij}\right) \quad if \quad j\in C \\ AIA &= \min_{1\le i\le m} RN\left(\psi_{ij}\right) \quad if \quad j\in B \quad and \quad \max_{1\le i\le m} RN\left(\psi_{ij}\right) \quad if \quad j\in C \end{aligned} \tag{20}$$

where B represents a benefit group of criteria, while C represents a non-benefit group of criteria.

Step 3. Normalization of the elements of matrix $\Omega = \left[RN\left(\psi_{ij}\right)\right]_{m\times n}$ is performed by applying Equation (21). The elements of normalized matrix $\Omega^N = \left[RN\left(\hat{\psi}_{ij}\right)\right]_{m\times n}$ are determined as follows:

$$RN\left(\hat{\psi}_{ij}\right) = \begin{cases} \left[\dfrac{\psi_{ij}^{-}}{\psi_{j}^{+}}, \dfrac{\psi_{ij}^{+}}{\psi_{j}^{+}}\right] if \quad j \in \text{Benefit} \\ \left[\dfrac{\psi_{j}^{-}}{\psi_{ij}^{+}}, \dfrac{\psi_{j}^{-}}{\psi_{ij}^{-}}\right] if \quad j \in \text{Non-benefit} \end{cases} \tag{21}$$

where $\hat{\psi}_j^{+} = \max_{1\le i\le m}\left\{RN\left(\psi_{ij}\right)\right\}$ and $\hat{\psi}_j^{-} = \min_{1\le i\le m}\left\{RN\left(\psi_{ij}\right)\right\}$.

Step 4: Calculation of the utility degree of alternatives (Λ_i). Using Equations (22) and (23), the utility degrees of the alternative in relation to *IA* and *AIA* are calculated:

$$\Lambda_i^{-} = \frac{RN(\theta_i)}{RN\left(\theta_i^{AAIA}\right)} \tag{22}$$

$$\Lambda_i^{+} = \frac{RN(\theta_i)}{RN\left(\theta_i^{IA}\right)} \tag{23}$$

where $RN(\theta_i)$ (i = 1, 2, … , m) represents the Dombi–Bonferroni weighted function that is used to calculate the sum of the weighted elements of the matrix $\Omega^N = \left[RN\left(\hat{\psi}_{ij}\right)\right]_{m\times n}$.

Theorem 1. *Let* $\left\{RN\left(\hat{\psi}_1\right)_1, RN\left(\hat{\psi}_2\right), \ldots, RN\left(\hat{\psi}_n\right)\right\}$ *be a set of normalized elements of matrix* $\Omega^N = \left[RN\left(\hat{\psi}_{ij}\right)\right]_{m\times n}$ *and let* χ_1, χ_2, $\alpha \ge 0$, *and let* $RN(w_j) = \left[w_j^{-}, w_j^{+}\right]$ *(j = 1, 2, … , n)* *represent rough weight coefficients; then, we can express the Dombi–Bonferroni weighted function* ($\theta_j^{\chi_1,\chi_2,\alpha}$) *as follows:*

$$\theta_j^{\chi_1,\chi_2,\alpha} = \left[\frac{\sum_{j=1}^{n} \hat{\psi}_j^-}{1+\left\{ \frac{1}{w_i^- w_j^- (\chi_1+\chi_2)} \sum_{\substack{i,j=1 \\ i\neq j}}^{n} \frac{1-w_i^-}{\mu_1\left(\frac{1-f(\hat{\psi}_j^-)}{f(\hat{\psi}_j^-)}\right)^{\alpha} + \mu_2\left(\frac{1-f(\hat{\psi}_j^-)}{f(\hat{\psi}_j^-)}\right)^{\alpha}} \right\}^{1/\alpha}}, \frac{\sum_{j=1}^{n} \hat{\psi}_j^-}{1+\left\{ \frac{1}{w_i^+ w_j^+ (\chi_1+\chi_2)} \sum_{\substack{i,j=1 \\ i\neq j}}^{n} \frac{1-w_i^+}{\mu_1\left(\frac{1-f(\hat{\psi}_j^+)}{f(\hat{\psi}_j^+)}\right)^{\alpha} + \mu_2\left(\frac{1-f(\hat{\psi}_j^+)}{f(\hat{\psi}_j^+)}\right)^{\alpha}} \right\}^{1/\alpha}} \right] \tag{24}$$

where χ_1 *and* χ_2 *represent the stabilization parameters of the Bonferroni function, and* α *represents the parameter of the Dombi norm, while* $f\left(\hat{\psi}_j^-\right) = \hat{\psi}_j^- / \sum_{j=1}^{n} \hat{\psi}_j^-$ *and* $f\left(\hat{\psi}_j^+\right) = \hat{\psi}_j^+ / \sum_{j=1}^{n} \hat{\psi}_j^+$. *Then,* $\theta_j^{\chi_1,\chi_2,\alpha}$ *represents the rough Dombi–Bonferroni weighted function. The proof for Theorem 1 is presented in Appendix A.*

Step 5. The compromise of the alternative in relation to *IA* and *AIA* is defined by the rough utility function $f(\Lambda_i)$, Equation (25)

$$f(\Lambda_i) = \frac{RN(\Lambda_i^+) + RN(\Lambda_i^-)}{1 + \frac{1-f(\Lambda_i^+)}{f(\Lambda_i^+)} + \frac{1-f(\Lambda_i^-)}{f(\Lambda_i^-)}}; \tag{25}$$

where $f(\Lambda_i^-) = RN(\Lambda_i^+)/(RN(\Lambda_i^+) + RN(\Lambda_i^-))$ represents the rough utility function in relation to *AIA*, while $f(\Lambda_i^+) = RN(\Lambda_i^-)/(RN(\Lambda_i^+) + RN(\Lambda_i^-))$ represents the utility function in relation to *IA*.

Step 6. Ranking of alternatives is performed on the basis of the values of utility functions ($f(\Lambda_i)$). It is desirable that the alternative has the lowest possible risk value, that is, $f(\Lambda_i)$.

5. Results and Discussion

The research was conducted on six measuring sections of two-lane roads (main roads of category I) in the territory of Bosnia and Herzegovina, with a total length of the road network of 60.918 km, which were analyzed as a function of longitudinal gradient. The Vrhovi-Šešlije (M-I-103) road section was analyzed for the longitudinal fall of −5.00% and −1.92%, so that a total of six measuring road sections (*D*1–*D*6) were considered in the case study. Moreover, at each measuring section, the value of the speed limit was visually identified, and the case study synthesized the obtained data on exceeding the speed limit at each of the measuring sections. The obtained data on the deviation of the real speed from the speed limit were synthesized and presented on the basis of the arithmetic mean of a representative sample of the obtained values for light goods vehicles, which is given in Table 1.

Table 1. Technical and exploitation characteristics of measuring sections with values of speeding.

Measuring Sections for Exceeding the Speed Limit by LGV		Section Mark	Section Length (m)	Ascent/Descent at 1000 m in %	Speed Limit (km/h)	Deviation of Speeds from the Speed Limit (km/h)
*D*1	Vrhovi-Šešlije	M-I-103	14.073	−5.00%	80	11.741
*D*2	Vrhovi-Šešlije	M-I-103	14.073	−1.92%	80	8.615
*D*3	Rudanka-Doboj	M-I-105	7.405	−0.017%	60	5.200
*D*4	Šepak-Karakaj 3	M-I-115	20.95	+1.00%	80	2.000
*D*5	Donje Caparde-Karakaj 1	M-I-110	15.35	+3.00%	80	0.000
*D*6	Border (RS/FBIH)-Donje Caparede	M-I-110	3.14	+7.00%	80	2.000

Further in the paper, eight criteria (*C*1–*C*8) are analyzed. The data for determining the level of risk of road sections are systematized in Table 1. The determination of the criteria included the criterion of optimality through: *C*1—length of the section (m); *C*2—ascent/descent at 1000 m in %; *C*3—credible deviation of the arithmetic mean of the real speed from the speed limit for light goods vehicles (km/h); *C*4—AADT (Annual Average Daily Traffic) (vehicles/day); *C*5–*C*8—number of accidents with fatalities, with severely injured persons, with slightly injured persons, and with material damage, respectively.

5.1. Determining Criteria Weights by Rough D'LMAW Methodology

In the previous section, eight criteria used to determine the level of risk on five road sections (six measuring sections) have been defined. The criteria are marked with codes *C*1–*C*8, as follows: *C*1—length of the section (m); *C*2—ascent/descent at 1000 m in %; *C*3—speed deviation from the limit speed; *C*4—AADT (Annual Average Daily Traffic) (vehicles/day); *C*5—number of traffic accidents with fatalities; *C*6—number of traffic accidents with severely injured persons; *C*7—number of traffic accidents with slightly injured persons; and *C*8—number of traffic accidents with material damage. The following section explains the application of the rough D'LMAW methodology for determining the weight coefficients of the criteria.

Step 1. Expert assessment consisting of a survey, the assessment of concordance of expert preferences, and the results obtained were used in the analysis. Methods of determining the weights of the criteria to describe risk management are considered to be subjective if they are evaluated by respondents or experts. The estimate of one highly qualified expert may be more important than the estimates made by a number of inexperienced specialists. The research involved four experts (two traffic engineers and two civil engineers, road experts) represented by a set. Eight experts were interviewed, and the result of the interviews for four experts were accepted. Based on experts' estimates, priority vectors for each expert were defined, as shown in Table 2. The experts' estimates of criteria in the priority vector were defined on the basis of a seven-point scale: very low (VL)—1; low (L)—2; medium low (ML)—3; medium (M)—4; medium high (MH)—5; high (H)—6; very high (VH)—7.

Table 2. Priority vectors of criteria.

Criteria	Expert 1	Expert 2	Expert 3	Expert 4
C1	L	ML	L	ML
C2	ML	L	VL	L
C3	M	M	ML	MH
C4	M	MH	H	M
C5	H	VH	VH	VH
C6	H	H	VH	MH
C7	MH	H	H	H
C8	MH	MH	M	MH

Using Equations (1)–(4), the sequences of the priority vectors from Table 2 are transformed into the rough sequences shown in Table 3.

Table 3. Rough priority vectors of criteria.

Criteria	Expert 1	Expert 2	Expert 3	Expert 4
C1	[2.00,2.46]	[2.46,3.00]	[2.00,2.46]	[2.10,3.00]
C2	[1.00,1.89]	[1.41,2.29]	[1.60,2.45]	[1.89,3.00]
C3	[3.00,3.95]	[3.46,4.31]	[3.64,4.47]	[3.95,5.00]
C4	[4.00,4.70]	[4.00,4.94]	[4.31,5.48]	[4.70,6.00]
C5	[6.00,6.74]	[6.48,7.00]	[6.65,7.00]	[6.74,7.00]
C6	[5.00,5.97]	[5.48,6.32]	[5.65,6.48]	[5.97,7.00]
C7	[5.00,5.74]	[5.48,6.00]	[5.65,6.00]	[5.74,6.00]
C8	[4.00,4.73]	[4.47,5.00]	[4.64,5.00]	[4.73,5.00]

An example of the transformation of experts' estimates from Table 3 for criterion $C1$ is presented in the following section. The experts' estimates for criterion $C1$ in the priority vector (Table 2) yielded the following values: $\gamma_1^1 = \gamma_1^3 = 2$ and $\gamma_1^2 = \gamma_1^4 = 3$. Using Equations (1)–(4), and provided that $\varepsilon 1 = \varepsilon_2 = 1$, we can define the lower and upper limit of rough numbers according to the following:

Lower limits:

$$\underline{Lim}(\gamma_1^1) = \underline{Lim}(\gamma_1^3) = 2;$$

$$\underline{Lim}(\gamma_1^2) = \underline{Lim}(\gamma_1^4)$$
$$= \left(\tfrac{1}{4}\left\{2\cdot(2\cdot 3\cdot 3)^{1/3} + 2\cdot(2\cdot 3\cdot 3)^{1/3} + 3\cdot(2\cdot 2\cdot 3)^{1/3} + 3\cdot(2\cdot 2\cdot 3)^{1/3}\right\}\right)^{\frac{1}{2}} = 2.461$$

Upper limits:

$$\underline{Lim}(\gamma_1^1) = \underline{Lim}(\gamma_1^3)$$
$$= \left(\tfrac{1}{4}\left\{2\cdot(2\cdot 3\cdot 3)^{1/3} + 2\cdot(2\cdot 3\cdot 3)^{1/3} + 3\cdot(2\cdot 2\cdot 3)^{1/3} + 3\cdot(2\cdot 2\cdot 3)^{1/3}\right\}\right)^{\frac{1}{2}} = 2.461$$

$$\underline{Lim}(\gamma_1^2) = \underline{Lim}(\gamma_1^4) = 3;$$

Based on the defined limit values, we can define a rough number, Equation (5):

$$RN(\gamma_1^1) = RN(\gamma_1^3) = [2, 2.46];$$

$$RN(\gamma_1^2) = RN(\gamma_1^4) = [2.46, 3]$$

The aggregated rough priority vector is obtained by applying Equation (14):

$$\overline{\gamma}_j = \begin{cases} \gamma_j^- = \dfrac{2+2+2.46+2.46}{1+\left\{\frac{1}{4}\left(\frac{1-0.224}{0.224}\right)^1+\frac{1}{4}\left(\frac{1-0.224}{0.224}\right)^1+\frac{1}{4}\left(\frac{1-0.276}{0.276}\right)^1+\frac{1}{4}\left(\frac{1-0.276}{0.276}\right)^1\right\}^{1/1}} = 2.21 \\ \gamma_j^+ = \dfrac{2.46+2.46+3+3}{1+\left\{\frac{1}{4}\left(\frac{1-0.225}{0.225}\right)^1+\frac{1}{4}\left(\frac{1-0.225}{0.225}\right)^1+\frac{1}{4}\left(\frac{1-0.276}{0.276}\right)^1+\frac{1}{4}\left(\frac{1-0.276}{0.276}\right)^1\right\}^{1/1}} = 2.70 \end{cases}$$
$$= [2.21, 2.70]$$

Based on the aggregated rough values, we obtain an aggregated priority vector:

$$\begin{aligned} RN(\gamma_1) &= [2.21,\ 2.70]; \\ RN(\gamma_2) &= [1.40,\ 2.34]; \\ RN(\gamma_3) &= [3.48,\ 4.40]; \\ RN(\gamma_4) &= [4.23,\ 5.23]; \\ RN(\gamma_5) &= [6.45,\ 6.93]; \\ RN(\gamma_6) &= [5.50,\ 6.42]; \\ RN(\gamma_7) &= [5.45,\ 5.93]; \\ RN(\gamma_8) &= [4.44,\ 4.93]. \end{aligned}$$

Step 2. By applying the condition that $\beta_{AIP} < \min\left(\gamma_{C1}^{t}, \gamma_{C2}^{t}, \ldots, \gamma_{Cn}^{t}\right)$, the absolute anti-ideal point β_{AIP} = [0.4,0.6] is defined. The vector of relations is obtained by applying Equation (15), as follows:

$$
\begin{gathered}
RN(\rho_1) = [3.68,\ 6.76] \\
RN(\rho_2) = [2.33,\ 5.86]; \\
RN(\rho_3) = [5.80,\ 11.01]; \\
RN(\rho_4) = [7.06,\ 13.08]; \\
RN(\rho_5) = [10.76,\ 17.33]; \\
RN(\rho_6) = [9.17,\ 16.05]; \\
RN(\rho_7) = [9.08,\ 14.83]; \\
RN(\rho_8) = [7.41,\ 12.33].
\end{gathered}
$$

Step 3. By applying Equation (16), we obtain a vector of weight coefficients:

$$
\begin{gathered}
RN(w_1) = [0.552,\ 1.125] \\
RN(w_2) = [0.358,\ 1.041]; \\
RN(w_3) = [0.744,\ 1.411]; \\
RN(w_4) = [0.827,\ 1.513]; \\
RN(w_5) = [1.006,\ 1.679]; \\
RN(w_6) = [0.938,\ 1.634]; \\
RN(w_7) = [0.934,\ 1.587]; \\
RN(w_8) = [0.848,\ 1.478].
\end{gathered}
$$

The weight coefficient for criterion $C1$ is obtained by applying Equation (16) as follows:

$$RN(w_1) = \left[\frac{\ln(3.68)}{\ln(10.60)}, \frac{\ln(6.76)}{\ln(5.47)}\right] = [0.552,\ 1.125]$$

The values of the remaining weight coefficients of the criteria are obtained in a similar way.

5.2. Determination of Risk on Road Sections Using Rough Dombi–Bonferroni MARCOS Methodology

The application of rough Dombi–Bonferroni MARCOS methodology is presented through a multi-criteria model for determining the risk on the measuring road sections. The applied multi-criteria framework is presented through the steps given below.

Step 1: In the case study, six measuring sections of the given road sections are considered, which are marked with the following codes: $D1$—Vrhovi-Šešlije I; $D2$—Vrhovi-Šešlije II; $D3$—Rudanka-Doboj; $D4$—Šepak-Karakaj 3; $D5$—Donje Caparde-Karakaj 1; $D6$—Border (RS/FBIH)-Donje Caparede. The data shown in Table 4 are used to determine the level of risk.

Table 4. Data for determining the level of risk of road sections.

		***D*1**	***D*2**	***D*3**	***D*4**	***D*5**	***D*6**
C1		14.07	14.07	7.41	20.95	15.35	3.14
C2		5.00	1.92	0.02	1.00	3.00	7.00
C3		11.74	8.62	5.20	2.00	0.00	2.00
*C*4	2012	4542.33	4542.33	12,825.33	5619.67	3113.00	3568.67
	2013	4880.00	4880.00	13,444.50	6107.00	3407.00	3901.00
	2014	4611.50	4611.50	13,231.00	6097.50	3433.00	3927.00
	2015	4416.00	4416.00	13,044.33	6022.00	3411.67	3942.67
	2016	4587.50	4587.50	13,670.00	6340.00	3642.00	4221.00
*C*5	2015	2.00	2.00	2.00	2.00	3.00	0.00
	2016	0.00	0.00	2.00	1.00	0.00	0.00
	2017	2.00	2.00	1.00	1.00	1.00	0.00
	2018	0.00	0.00	1.00	2.00	0.00	0.00
	2019	0.00	0.00	1.00	1.00	0.00	0.00

Table 4. *Cont.*

		D1	D2	D3	D4	D5	D6
C6	2015	5.00	5.00	5.00	3.00	2.00	1.00
	2016	3.00	3.00	3.00	6.00	5.00	1.00
	2017	3.00	3.00	10.00	9.00	3.00	0.00
	2018	1.00	1.00	2.00	3.00	3.00	0.00
	2019	1.00	1.00	5.00	8.00	3.00	0.00
C7	2015	3.00	3.00	7.00	19.00	5.00	3.00
	2016	3.00	3.00	12.00	23.00	11.00	0.00
	2017	4.00	4.00	17.00	18.00	7.00	0.00
	2018	7.00	7.00	17.00	19.00	6.00	1.00
	2019	2.00	2.00	20.00	18.00	3.00	1.00
C8	2015	11.00	11.00	47.00	43.00	17.00	1.00
	2016	11.00	11.00	43.00	65.00	20.00	3.00
	2017	6.00	6.00	55.00	48.00	22.00	1.00
	2018	14.00	14.00	58.00	65.00	18.00	2.00
	2019	6.00	6.00	46.00	46.00	29.00	3.00

Based on the data presented in Table 4, we can see that the data for criteria *C4*–*C8* are given for a five-year period. The values *C*1–*C*3 are obtained by empirical research, and the values *C*4–*C*8 are taken from AADT (Annual Average Daily Traffic) and accident databases. Therefore, the values for criteria *C*4–*C*8 are transformed into rough numbers, while the values of criteria C1–C3 are shown as crisp values. Using Equations (1)–(4), the sequences of criteria *C*4, *C*5, *C*6, *C*7, and *C*8 are transformed into interval rough sequences. The rough sequences are averaged using the rough Bonferroni operator [3,31–34], and an aggregated rough initial matrix is obtained, as shown in Table 5.

Table 5. Aggregated initial decision matrix.

Crit.	D1	D2	D3	D4	D5	D6
C1	[14.07,14.07]	[14.07,14.07]	[7.41,7.41]	[20.95,20.95]	[15.35,15.35]	[3.14,3.14]
C2	[5,5]	[1.92,1.92]	[0.02,0.02]	[1,1]	[3,3]	[7,7]
C3	[11.74,11.74]	[8.62,8.62]	[5.2,5.2]	[2,2]	[0,0]	[2,2]
C4	[4487,4742.03]	[4487,4742.03]	[12,981.6,13,504.84]	[5825.93,6220.79]	[3253.79,3535.94]	[3731.52,4080.96]
C5	[0,0.02]	[0,0.02]	[1.05,1.6]	[1.05,1.6]	[0,0.02]	[0,0]
C6	[1.3,3.07]	[1.3,3.07]	[2.76,5.79]	[3.59,6.87]	[2.44,3.49]	[0,0.01]
C7	[2.49,4.32]	[2.49,4.32]	[9.97,16.63]	[18.21,20.04]	[4.09,7.37]	[0,0.65]
C8	[6.88,10.9]	[6.88,10.9]	[45.08,52.66]	[45.75,58.08]	[17.99,22.89]	[1.21,2.39]

Step 2: Using Equation (20), the ideal alternative (*IA*) and the anti-ideal alternative (*AIA*) are defined for each criterion *j*. Since all criteria are of benefit type (B), the first part of Equation (20) is used to determine *IA* and *AIA*. *IA* and *AIA* are shown below:

$$\begin{aligned} IA^{C1} &= [20.95,\ 20.95], & AIA^{C1} &= [3.14,\ 3.14], \\ IA^{C2} &= [7,\ 7], & AIA^{C2} &= [0.02,\ 0.02], \\ IA^{C3} &= [11.74,\ 11.74], & AIA^{C3} &= [0,\ 0], \\ IA^{C4} &= [12981.6,\ 13504.84], & AIA^{C4} &= [3253.79,\ 3535.94], \\ IA^{C5} &= [1.05,\ 1.6], & AIA^{C5} &= [0,\ 0], \\ IA^{C6} &= [3.59,\ 6.87], & AIA^{C6} &= [0,\ 0.01], \\ IA^{C7} &= [18.21,\ 20.04], & AIA^{C7} &= [0,\ 0.65], \\ IA^{C8} &= [45.75,\ 58.08]. & AIA^{C8} &= [1.21,\ 2.39]. \end{aligned}$$

Step 3: Normalization of initial matrix elements (Table 5) is performed using Equation (21). The normalized rough matrix is shown in Table 6.

Table 6. Normalized rough matrix.

Alter.	*AIA*	*D*1	*D*2	*D*3	*D*4	*D*5	*D*6	*IA*
C1	[0.15,0.15]	[0.67,0.67]	[0.67,0.67]	[0.35,0.35]	[1.00,1.00]	[0.73,0.73]	[0.15,0.15]	[1.00,1.00]
C2	[0.00,0.00]	[0.71,0.71]	[0.27,0.27]	[0.00,0.00]	[0.14,0.14]	[0.43,0.43]	[1.00,1.00]	[1.00,1.00]
C3	[0.00,0.00]	[1.00,1.00]	[0.73,0.73]	[0.44,0.44]	[0.17,0.17]	[0.00,0.00]	[0.17,0.17]	[1.00,1.00]
C4	[0.24,0.27]	[0.33,0.37]	[0.33,0.37]	[0.96,1.04]	[0.43,0.48]	[0.24,0.27]	[0.28,0.31]	[0.96,1.04]
C5	[0.00,0.00]	[0.00,0.02]	[0.00,0.02]	[0.66,1.52]	[0.66,1.52]	[0.00,0.02]	[0.00,0.00]	[0.66,1.52]
C6	[0.00,0.00]	[0.19,0.86]	[0.19,0.86]	[0.40,1.61]	[0.52,1.91]	[0.36,0.97]	[0.00,0.00]	[0.52,1.91]
C7	[0.00,0.04]	[0.12,0.24]	[0.12,0.24]	[0.50,0.91]	[0.91,1.10]	[0.20,0.41]	[0.00,0.04]	[0.91,1.10]
C8	[0.02,0.05]	[0.12,0.24]	[0.12,0.24]	[0.78,1.15]	[0.79,1.27]	[0.31,0.50]	[0.02,0.05]	[0.79,1.27]

The normalization of the element at position *C*5–*D*4 in Table 6 is obtained by applying Equation (21) as follows:

$$RN\left(\hat{\psi}_{45}\right) = \left[\frac{\psi_{45}^{-}}{\psi_{5}^{+}}, \frac{\psi_{45}^{+}}{\psi_{5}^{+}}\right] = \left[\frac{1.05}{1.60}, \frac{1.60}{1.05}\right] = [0.66, 1.52]$$

The remaining elements from Table 6 are obtained in a similar way.

Step 4: Using Equations (22) and (23), the utility degrees of alternatives in relation to *IA* and *AIA* are calculated. The utility levels of the alternatives are shown below:

$$\Lambda_i{}^{-} = \begin{bmatrix} [6.757,\ 9.605] \\ [5.300,\ 7.464] \\ [9.422,\ 12.633] \\ [10.657,\ 14.143] \\ [4.965,\ 6.924] \\ [2.227,\ 4.487] \end{bmatrix}; \Lambda_i{}^{+} = \begin{bmatrix} [0.318,\ 0.346] \\ [0.249,\ 0.269] \\ [0.443,\ 0.455] \\ [0.501,\ 0.509] \\ [0.234,\ 0.249] \\ [0.105,\ 0.162] \end{bmatrix}$$

The calculation of the utility degree of alternative *D*1 is explained below:

(1) By applying Equation (24), we obtain the sum of the weighted elements of the normalized matrix:

$$RN(\theta)_i = \begin{array}{c} AIA \\ D1 \\ D2 \\ D3 \\ D4 \\ D5 \\ D6 \\ IA \end{array} \begin{bmatrix} [0.333,\ 0.438] \\ [2.962,\ 3.202] \\ [2.323,\ 2.488] \\ [4.131,\ 4.211] \\ [4.672,\ 4.715] \\ [2.177,\ 2.308] \\ [0.976,\ 1.496] \\ [9.261,\ 9.318] \end{bmatrix}$$

The sum calculation of the weighted elements of the normalized matrix for alternative *D*1 is obtained as follows:

$$
RN(\theta)_1{}^{\chi_1=\chi_2=\alpha=1} = \left\{ \begin{array}{l}
RN(\theta)_1{}^{-} = \dfrac{0.67+0.71+1.00+0.33+0.00+0.19+0.12+0.12}{1+\left\{\frac{1}{1+1}\left(\begin{array}{c}
\frac{0.552\cdot 0.358}{1-0.552}\frac{1}{1\cdot\left(\frac{1-0.21}{0.21}\right)^1+1\cdot\left(\frac{1-0.23}{0.23}\right)^1}+ \\
\frac{0.552\cdot 0.744}{1-0.744}\frac{1}{1\cdot\left(\frac{1-0.21}{0.21}\right)^1+1\cdot\left(\frac{1-0.32}{0.32}\right)^1}+ \\
\frac{0.552\cdot 0.827}{1-0.827}\frac{1}{1\cdot\left(\frac{1-0.21}{0.21}\right)^1+1\cdot\left(\frac{1-0.11}{0.11}\right)^1}+\ldots+ \\
\frac{0.848\cdot 0.934}{1-0.848}\frac{1}{1\cdot\left(\frac{1-0.04}{0.04}\right)^1+1\cdot\left(\frac{1-0.04}{0.04}\right)^1}
\end{array}\right)^{-1}\right\}^{1/1}} = 2.962 \\
RN(\theta)_1{}^{+} = \dfrac{0.67+0.71+1.00+0.33+0.00+0.19+0.12+0.12}{1+\left\{\frac{1}{1+1}\left(\begin{array}{c}
\frac{1.125\cdot 1.041}{1-1.125}\frac{1}{1\cdot\left(\frac{1-0.21}{0.21}\right)^1+1\cdot\left(\frac{1-0.23}{0.23}\right)^1}+ \\
\frac{1.125\cdot 1.411}{1-1.125}\frac{1}{1\cdot\left(\frac{1-0.21}{0.21}\right)^1+1\cdot\left(\frac{1-0.32}{0.32}\right)^1}+ \\
\frac{1.125\cdot 1.513}{1-1.513}\frac{1}{1\cdot\left(\frac{1-0.21}{0.21}\right)^1+1\cdot\left(\frac{1-0.11}{0.11}\right)^1}+\ldots+ \\
\frac{1.478\cdot 1.587}{1-1.478}\frac{1}{1\cdot\left(\frac{1-0.038}{0.038}\right)^1+1\cdot\left(\frac{1-0.04}{0.04}\right)^1}
\end{array}\right)^{-1}\right\}^{1/1}} = 3.202 \\
\quad = [2.962,\ 3.202]
\end{array} \right.
$$

(2) Then, by applying Equations (22) and (23), we obtain the utility degrees of alternative $D1$ in relation to IA and AIA:

$$
\Lambda_1{}^{-} = \frac{RN(\theta_1)}{RN\left(\theta^{AIA}\right)} = \left[\frac{2.962}{0.438}, \frac{3.202}{0.333}\right] = [6.757,\ 9.605]
$$

$$
\Lambda_1{}^{+} = \frac{RN(\theta_1)}{RN\left(\theta^{IA}\right)} = \left[\frac{2.962}{9.318}, \frac{3.202}{9.261}\right] = [0.318,\ 0.346]
$$

Steps 5 and 6: Ranking of alternatives is performed on the basis of the values of the utility function $f(\Lambda_i)$, Equation (25). The utility functions of alternatives are presented below:

$$
\begin{array}{cc}
f(\Lambda_i) & Rank \\
\left[\begin{array}{c} [0.673,\ 0.935] \\ [0.402,\ 0.559] \\ [1.273,\ 1.781] \\ [1.638,\ 2.296] \\ [0.347,\ 0.483] \\ [0.099,\ 0.135] \end{array}\right] &
\left[\begin{array}{c} 4 \\ 3 \\ 5 \\ 6 \\ 2 \\ 1 \end{array}\right]
\end{array}
$$

It is desirable that the road section has the lowest possible value of risk, so the following rank is obtained: $D6 > D5 > D2 > D1 > D3 > D4$. Further in the paper, the stability of the solution is tested in the case of a change in the stabilization parameters of the Dombi–Bonferroni hybrid function Equation (24), which has been used to calculate the utility degree of the alternatives. The Dombi–Bonferroni function has three stabilization parameters, χ_1, χ_2, and α. During the risk calculation of the considered road sections, the values of the parameter $\chi_1 = \chi_2 = \alpha = 1$ are obtained. Further, the application of parameters χ_1, χ_2, and α are simulated through 100 scenarios ($1 \leq \chi_1, \chi_2, \alpha \leq 100$). Figure 1 shows the dependence of the Dombi–Bonferroni function on the change of parameters χ_1, χ_2, and α; for alternative $D1$ (Figure 1a), for alternative $D2$ (Figure 1b), for alternative $D3$ (Figure 1c), for alternative $D4$ (Figure 1d), for alternative $D5$ (Figure 1e) and for alternative $D6$ (Figure 1f).

The results from Figure 1 indicate that an increase in the values of parameters $1 \leq \alpha \leq 100$ causes a decrease in the value of the Dombi–Bonferroni function of all alternatives. However, the question arises as to whether these changes affect the change in the ranks of alternatives. In order to consider the influence of the mentioned parameters on the road section ranks, Figure 2 provides a comparative overview of the changes in the utility functions of alternatives $f(\Lambda_i)$ depending on the changes in parameters χ_1, χ_2, and α.

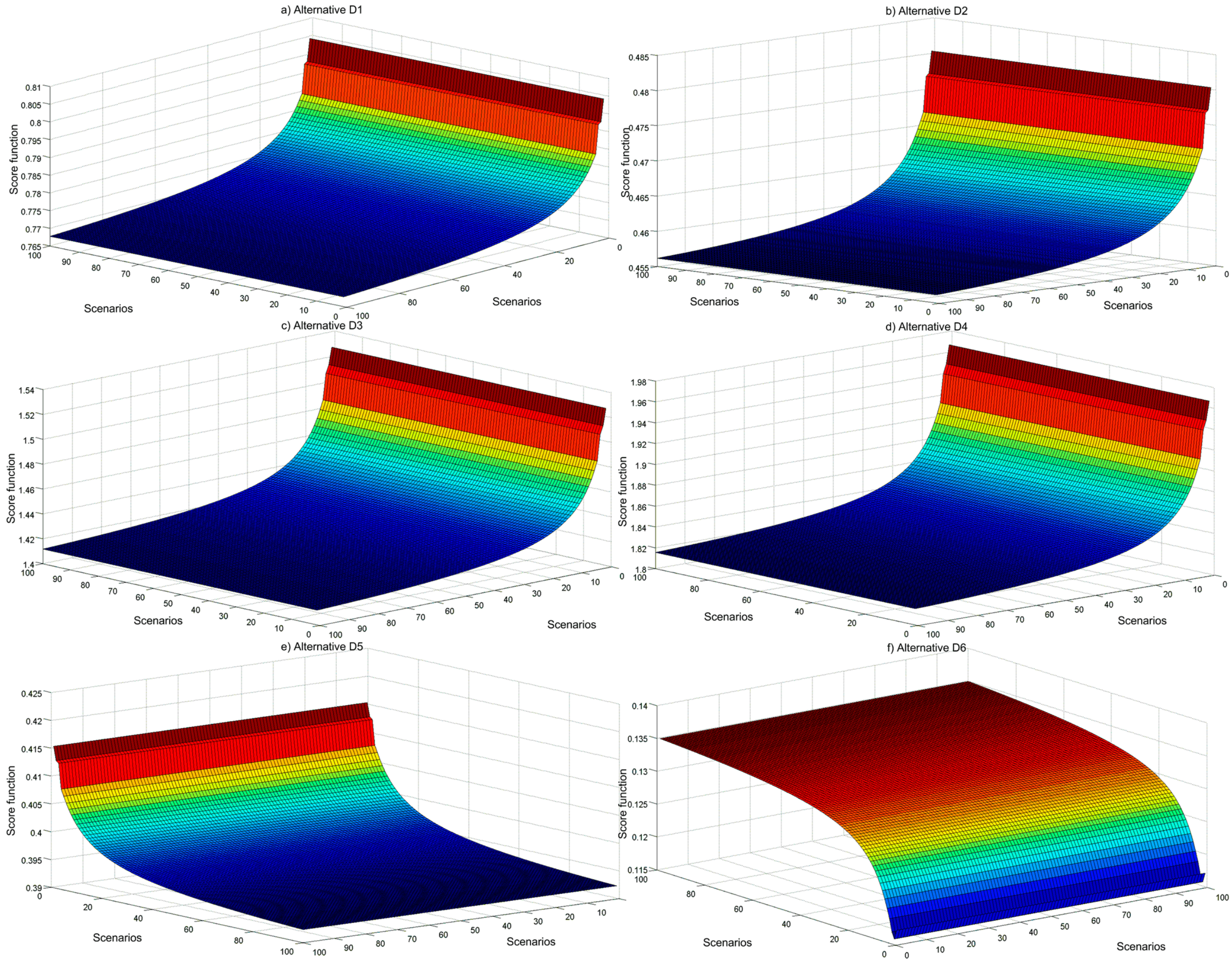

Figure 1. Dependence of Dombi–Bonferroni function on a change in parameter χ_1, χ_2, and α.

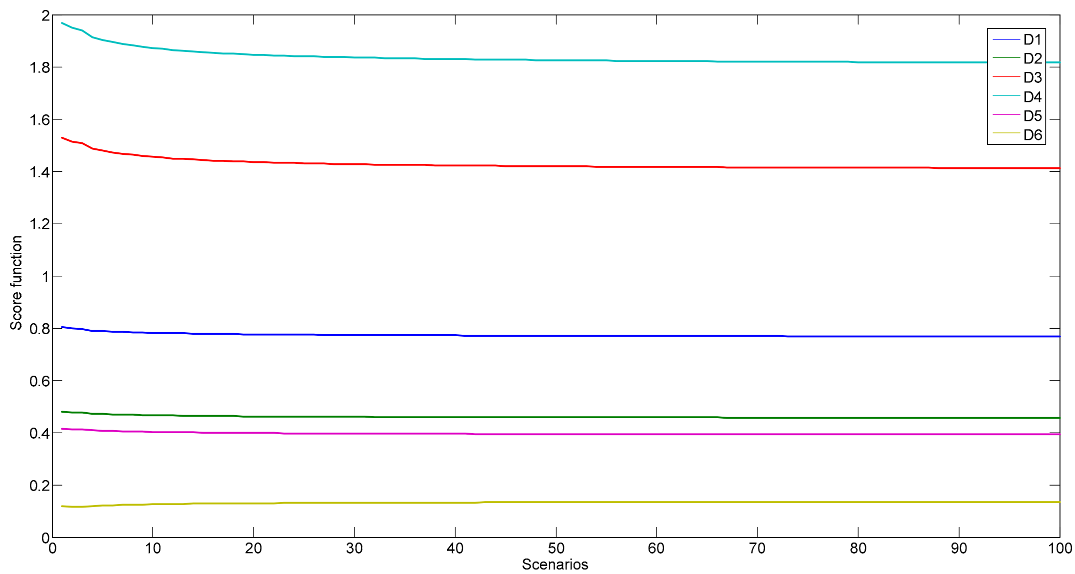

Figure 2. Comparative influence of change in coefficient $1 \leq \chi_1, \chi_2, \alpha \leq 100$ on a change in value of $f(\Lambda_i)$.

The increase in the value of the considered parameters leads to a change in the utility functions; however, these changes are not sufficient to lead to the change of the ranks of alternatives. From the presented analysis, we can conclude that the initial rank $D6 > D5 > D2 > D1 > D3 > D4$ has been confirmed, and that the road section $D6$ has the lowest value of risk, and therefore represents the best solution from the considered set.

6. Conclusions

By applying rough Dombi–Bonferroni MARCOS methodology on six measuring sections of the given road sections, the assessment of risk was performed using a multi-criteria evaluation of eight significant criteria, on the basis of which the measuring sections were ranked from the least to the most risky. Additionally, using experts' assessment, it was transformed into rough sequences, and after that, into a risk assessment of measuring sections for light goods vehicles using rough Dombi–Bonferroni MARCOS methodology in six steps. In addition, stability testing of the solution in case of a change in the stabilization parameters of the Dombi–Bonferroni hybrid function was used to calculate the utility degree of alternatives. The research was conducted with an assumption that the sections have the lowest possible level of risk of potential accidents for light goods vehicles. The results obtained by analyzing the existing criteria and alternatives show the most ($D4$) and the least risky ($D6$) road sections on the given measuring two-lane road sections. The conducted research showed that the road section $D6$, Border (RS-BIH)-Donje Caparde (M-I-110), with the smallest road section length (3.14 km) and the largest ascent (7.00%), shows the lowest level of risk. In this section, the speed deviation for light goods vehicles from the limit value is 2 km/h. According to the analysis, the measuring section with an extremely high level of risk is $D4$, Šepak-Karakaj (M-I-115); for this section, the length is 20.95 km, and the deviation of speeds for light goods vehicles from the limit value is 2 km/h. Both sections, $D4$ and $D6$, have the same level of speed deviation for light goods vehicles, which is 2 km/h. In addition, the functional dependence of the changes was identified in the value of the Dombi–Bonferroni function on the change of the parameters χ_1, χ_2, and α. An increase in the value of the considered parameters leads to a change in utility functions, but these changes are not sufficient to lead to a change in the ranks of the alternatives. This research can be conducted to select a risky section in local conditions. However, the research needs to be conducted on a larger sample of measuring sections.

In future research endeavors, it will be necessary to take a systematic approach to the assessment of ranks and alternatives on a much larger number of sections and to analyze, through extensive research, a significantly larger number of input parameters for risk assessment for light goods vehicles. This kind of approach needs to include constant monitoring of speed deviations from speed limits, the number of accidents, the volume of traffic, and so on, of the measuring sections.

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Appendix A

The proof for Theorem 1 is presented below.

Proof. Equation (13) is decomposed into segments in order to gradually derive Equation (24).

From Equation (7), we obtain the following:

$$RN\left(\hat{\psi}_i^{\chi_1}\right) = \left(\frac{\hat{\psi}_i^-}{1+\left\{\chi_1\left(\frac{1-f\left(\hat{\psi}_i^-\right)}{f\left(\hat{\psi}_i^-\right)}\right)^{\alpha}\right\}^{1/\alpha}}, \frac{\hat{\psi}_i^+}{1+\left\{\chi_1\left(\frac{1-f\left(\hat{\psi}_i^+\right)}{f\left(\hat{\psi}_i^+\right)}\right)^{\alpha}\right\}^{1/\alpha}} \right) \text{ and}$$

$$RN\left(\hat{\psi}_j^{\chi_2}\right) = \left(\frac{\hat{\psi}_j^-}{1+\left\{\chi_2\left(\frac{1-f\left(\hat{\psi}_j^-\right)}{f\left(\hat{\psi}_j^-\right)}\right)^{\alpha}\right\}^{1/\alpha}}, \frac{\hat{\psi}_j^+}{1+\left\{\chi_1\left(\frac{1-f\left(\hat{\psi}_j^+\right)}{f\left(\hat{\psi}_j^+\right)}\right)^{\alpha}\right\}^{1/\alpha}} \right)$$

Then, we obtain that

$$RN\left(\hat{\psi}_i^{\chi_1}\right)\cdot RN\left(\hat{\psi}_i^{\chi_2}\right)$$

$$= \left(\frac{\hat{\psi}_i^- + \hat{\psi}_j^-}{1+\left\{\chi_1\left(\frac{1-f\left(\hat{\psi}_i^-\right)}{f\left(\hat{\psi}_i^-\right)}\right)^{\alpha} + \chi_2\left(\frac{1-f\left(\hat{\psi}_j^-\right)}{f\left(\hat{\psi}_j^-\right)}\right)^{\alpha}\right\}^{1/\alpha}}, \frac{\hat{\psi}_i^+ + \hat{\psi}_j^+}{1+\left\{\chi_1\left(\frac{1-f\left(\hat{\psi}_i^+\right)}{f\left(\hat{\psi}_i^-\right)}\right)^{\alpha} + \chi_2\left(\frac{1-f\left(\hat{\psi}_j^+\right)}{f\left(\hat{\psi}_j^+\right)}\right)^{\alpha}\right\}^{1/\alpha}} \right)$$

After that, we obtain that

$$\sum_{\substack{i,j=1\\ i\neq j}}^{n} RN\left(\hat{\psi}_i^{\chi_1}\right) RN\left(\hat{\psi}_i^{\chi_2}\right)$$

$$= \left(\begin{array}{c} \sum_{j=1}^{n}\hat{\psi}_j^- - \frac{\sum_{j=1}^{n}\hat{\psi}_j^-}{1+\left\{\sum_{\substack{i,j=1\\ i\neq j}}^{n} \frac{1}{\chi_1\left(\frac{1-f\left(\hat{\psi}_i^-\right)}{f\left(\hat{\psi}_i^-\right)}\right)^{\alpha} + \chi_2\left(\frac{1-f\left(\hat{\psi}_j^-\right)}{f\left(\hat{\psi}_j^-\right)}\right)^{\alpha}}\right\}^{1/\alpha}}, \\ \sum_{j=1}^{n}\hat{\psi}_j^+ - \frac{\sum_{j=1}^{n}\hat{\psi}_j^+}{1+\left\{\sum_{\substack{i,j=1\\ i\neq j}}^{n} \frac{1}{\chi_1\left(\frac{1-f\left(\hat{\psi}_i^+\right)}{f\left(\hat{\psi}_i^+\right)}\right)^{\alpha} + \chi_2\left(\frac{1-f\left(\hat{\psi}_j^+\right)}{f\left(\hat{\psi}_j^+\right)}\right)^{\alpha}}\right\}^{1/\alpha}} \end{array} \right)$$

Further, we obtain that

$$\frac{RN(w_i)RN(w_j)}{1-RN(w_i)}\sum_{\substack{i,j=1\\ i\neq j}}^{n} RN\left(\hat{\psi}_i^{\chi_1}\right)RN\left(\hat{\psi}_i^{\chi_2}\right)$$

$$=\left(\begin{array}{c}\sum\limits_{j=1}^{n}\hat{\psi}_j^{-}-\dfrac{\sum\limits_{j=1}^{n}\hat{\psi}_j^{-}}{\left\{1+\dfrac{w_i^{-}w_j^{-}}{1-w_i^{-}}\sum\limits_{\substack{i,j=1\\ i\neq j}}^{n}\dfrac{1}{\chi_1\left(\frac{1-f\left(\hat{\psi}_i^{-}\right)}{f\left(\hat{\psi}_i^{-}\right)}\right)^{\alpha}+\chi_2\left(\frac{1-f\left(\hat{\psi}_j^{-}\right)}{f\left(\hat{\psi}_j^{-}\right)}\right)^{\alpha}}\right\}^{1/\alpha}},\\ \sum\limits_{j=1}^{n}\hat{\psi}_j^{+}-\dfrac{\sum\limits_{j=1}^{n}\hat{\psi}_j^{+}}{\left\{1+\dfrac{w_i^{+}w_j^{+}}{1-w_i^{+}}\sum\limits_{\substack{i,j=1\\ i\neq j}}^{n}\dfrac{1}{\chi_1\left(\frac{1-f\left(\hat{\psi}_i^{+}\right)}{f\left(\hat{\psi}_i^{+}\right)}\right)^{\alpha}+\chi_2\left(\frac{1-f\left(\hat{\psi}_j^{+}\right)}{f\left(\hat{\psi}_j^{+}\right)}\right)^{\alpha}}\right\}^{1/\alpha}}\end{array}\right)$$

Finally, we obtain the Dombi–Bonferroni weighted function ($\theta_j^{\chi_1,\chi_2,\alpha}$)

$$\theta_j^{\chi_1,\chi_2,\alpha}=\left[\begin{array}{c}\dfrac{\sum\limits_{j=1}^{n}\hat{\psi}_j^{-}}{\left\{1+\dfrac{1}{w_i^{-}w_j^{-}(\chi_1+\chi_2)}\sum\limits_{\substack{i,j=1\\ i\neq j}}^{n}\dfrac{1-w_i^{-}}{\frac{1}{\mu_1\left(\frac{1-f\left(\hat{\psi}_j^{-}\right)}{f\left(\hat{\psi}_j^{-}\right)}\right)^{\alpha}+\mu_2\left(\frac{1-f\left(\hat{\psi}_j^{-}\right)}{f\left(\hat{\psi}_j^{-}\right)}\right)^{\alpha}}}\right\}^{1/\alpha}},\\ \dfrac{\sum\limits_{j=1}^{n}\hat{\psi}_j^{-}}{\left\{1+\dfrac{1}{w_i^{+}w_j^{+}(\chi_1+\chi_2)}\sum\limits_{\substack{i,j=1\\ i\neq j}}^{n}\dfrac{1-w_i^{+}}{\frac{1}{\mu_1\left(\frac{1-f\left(\hat{\psi}_j^{+}\right)}{f\left(\hat{\psi}_j^{+}\right)}\right)^{\alpha}+\mu_2\left(\frac{1-f\left(\hat{\psi}_j^{+}\right)}{f\left(\hat{\psi}_j^{+}\right)}\right)^{\alpha}}}\right\}^{1/\alpha}}\end{array}\right]$$

□

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