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PREDICTION AND CONTROL OF SURFACE ROUGHNESS FOR END MILLING PROCESS USING ANFIS

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Abstract: *In this paper, we have applied an Adaptive Neuro-Fuzzy Inference System (ANFIS) approach to the prediction of workpiece surface roughness for end milling process. A small number of fuzzy rules are used for building an ANFIS model with the help of the subtractive clustering method (ANFIS-Subtractive clustering model). The predicted values are found to be in an excellent agreement with the experimental data with average error values in the range of 3.47-3.49%. Also, we have compared the proposed ANFIS model to other Artificial Intelligence (AI) approaches. The results show that the proposed model has high accuracy in comparison to the other AI approaches in literature. Therefore, we can use the ANFIS model to predict and control workpiece surface roughness for end milling process.*

Key Words: *ANFIS, Surface Roughness, Computer Numerical Control (CNC) Machine*

1 Introduction

Nowadays, accuracy is one of the most important characteristics of current manufacturing, which is manifested not only in the dimensions of a workpiece, but also in the surface roughness of the workpiece to be manufactured. The workpiece surface roughness has been an important factor in predicting the performance measure of any machining process (Chandrasekaran, Muralidhar, Krishna, & Dixit, 2010). Artificial Intelligence (AI) techniques can be used in the machining area for prediction and control of the performance parameters as well as for optimization of the process (Chandrasekaran, et al., 2010). For instance, researchers have attempted to control surface roughness by using artificial neural networks (Khorasani & Yazdi, 2017; Markopoulos, Manolakos, & Vaxevanidis, 2008), fuzzy logic (Kovac, Rodic, Pucovsky, Savkovic, & Gostimirovic, 2013) and ANFIS (Dong & Wang, 2011; Ho, Tsai, Lin, & Chou, 2009; Lo, 2003; Maher, Eltaib, Sarhan, & El-Zahry, 2014; Sharkawy, 2011), mostly for end milling operations (Lo, 2003; Tangjitsitcharoen, Thesniyom, &

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Ratanakuakangwan, 2017). In milling, the surface roughness is influenced by machining parameters such as spindle speed, feedrate, depth of cut, etc. These parameters can be considered as inputs to model the workpiece surface roughness.

Lo (Lo, 2003) used an ANFIS model to predict workpiece surface roughness after end milling process. Spindle speed, feed rate, and depth of cut were considered as input variables. The triangular and trapezoidal functions were used to describe the membership degree of these inputs. The number of the membership functions was three for each input and, in total, 27 rules were obtained to define their relationship with surface roughness. The average error of the surface roughness prediction by the ANFIS with the triangular membership function was only 4%, reaching an accuracy of 96%. In contrast, the average error by the ANFIS with the trapezoidal membership function was relatively higher at 6.7%, with a lower accuracy of 93.3%.

Ho et al. (Ho, et al., 2009) also used the ANFIS with the GA algorithm to control workpiece surface roughness. Based on the same experimental data of Lo (Lo, 2003), a total of 48 samples were used for training purpose, and other 24 samples were used for testing stage. The results show that their approach using the Gaussian membership function gives similar results as the ANFIS model with the triangular membership function obtained by Lo (Lo, 2003) (average error was 4.06%). Sharkawy (Sharkawy, 2011) used three types of AI approaches to model surface roughness in the end milling process with the same dataset presented in (Lo, 2003) (Ho, et al., 2009). Three models were built using radial basis function neural network RBFNs, ANFIS, and genetically evolved fuzzy inference systems G-FISs. The average error of the surface roughness prediction by these three models was in the range of 4-5%. A later work by (Paturi, Devarasetti, Fadare, & Narala, 2018) used ANN model and response surface methodology (RSM) in modeling of surface roughness. The outcome of their study demonstrates that both statistical and AI modeling can make a potential alternative to time-consuming experimental work, while minimizing costly machining test trials. Clearly, using a neural network involves a moderately tedious trial and error effort for obtaining the network structure, especially involving the middle layer nodes. Instead, the nodes and the hidden layers can be determined precisely by the fuzzy inference techniques in the ANFIS approach.

Dong et al. (Dong & Wang, 2011) used the ANFIS with a leave-one-out cross-validation (LOO-CV) approach to predict workpiece surface roughness. Based on the same experimental data, the predictive result of their ANFIS model outperforms the models reported recently in the literature with average error of 3.62%. Therefore, the ANFIS can be taken as an alternative promising method for future modeling and control of surface roughness for end milling process.

The ANFIS model construction requires the division of the input-output data into rule patches. This can be achieved by using a number of methods such as grid partitioning, subtractive clustering method and fuzzy c-means (FCM) (Guillaume, 2001). According to Jang (Jang, 1993), the grid partition is only suitable for problems with a small number of input variables (e.g. fewer than 6). In this paper, the proposed models have three inputs. It is reasonable to apply the ANFIS-Grid partition method. A model with three inputs with three fuzzy sets per input produces a complete rule set of 27 rules as in above-mentioned studies. It is important to note that an effective partition of the input space can decrease the number of rules and thus increase speed in both the learning and the application phases. Therefore, using the subtractive clustering with the ANFIS can be regarded as knowledge extraction from the experimental data. This is important since knowledge can be easily gathered in linguistic terms as a collection of "IF-THEN" rules. This is significant because the learning strategies can start from the point where the risk of entrapment in a local minimum is reduced in comparison to that when the initial parameters are chosen at random (which is often the case for ANNs).

The goal of this work is to make the intelligent system readily applicable to predict and control workpiece surface roughness with minimal effort. In this article, the ANFIS will be used for building two surface roughness prediction models: ANFIS by dividing the data space into rectangular sub-spaces (ANFIS-Grid) and ANFIS by using the subtractive clustering method (ANFIS-SCM). This combined methodology can help us improve robustness of the proposed model, and reduce the number of rules. Data needed for development of the ANFIS models are obtained from the literature. Comparisons of the predicted surface roughness with that using other AI techniques have also been made in this paper. This paper is organized as follows: in the next section, i.e. Section 2, the theoretical background of ANFIS is described. Section 3 shows the data we use for our investigations. In Section 3.2, we test and validate the proposed models in Section 3.1. Finally, conclusions and further research aspects are discussed in Section 4.

2 Adaptive Neuro Fuzzy Inference System (ANFIS)

The Adaptive Neuro Fuzzy Inference System (ANFIS), was first introduced by Jang (Jang, 1993). According to Jang, the ANFIS is a neural network that is functionally the same as the Takagi-Sugeno type inference model. The ANFIS is a hybrid intelligent system that takes advantages of both the ANN and the fuzzy logic theory in a single system. By employing the ANN technique to update the parameters of the Takagi-Sugeno type inference model, the ANFIS is given the ability to learn from training data, the same as ANN. The solutions mapped out onto a Fuzzy Inference System (FIS) can therefore be described in linguistic terms. In order to explain the concept of ANFIS structure, five distinct layers are used to describe the structure of an ANFIS model. The first layer in the ANFIS structure is the fuzzification one; the second layer acts as the rule base layer; the third layer performs the normalization of membership functions (MFs); the fourth and fifth layers are the defuzzification and summation ones, respectively. More information about the ANFIS structure is given in (Jang, 1993). Fig. 1 shows basic structure of the ANFIS with two inputs.

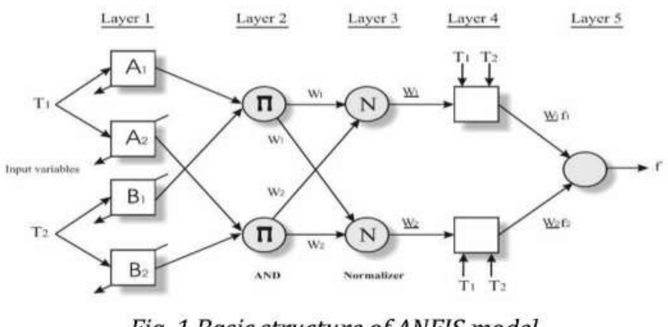

Fig. 1 Basic structure of ANFIS model

2.1 Extraction of the initial fuzzy model

In order to start the modeling process, an initial fuzzy model has to be derived. This model is required for selecting input variables and for input space partitioning (or clustering), for choosing the number and type of membership functions of the inputs as well as for creating fuzzy rules, their premise and conclusion parts. For a given dataset, different ANFIS models can be constructed using different identification methods such as grid partitioning and fuzzy subtractive clustering (Guillaume, 2001).

A. The ANFIS-Grid partition method is the combination of grid partition and ANFIS. The data space is divided into rectangular sub-spaces using axis-paralleled partitions based on a pre-defined number of MFs and their types in each dimension (Haddad & Al Kobaisi, 2012). The limitation of this method is that the number of rules rises rapidly as the number of input variables increases. For example, if the number of input sensors is n and the partitioned fuzzy subset for each input sensor is m, then the number of possible fuzzy rules is m^n. While the number of variables raises, the number of fuzzy rules increases exponentially; this requires a large computer memory. According to Jang (Jang 1993), the grid partition is only suitable for problems with a small number of input variables (e.g. fewer than 6).

B. The ANFIS-Subtractive clustering method combines the subtractive clustering method and the ANFIS. The subtractive clustering initially proposed by Chiu (Chiu, 1994) considers data points as candidates for the centre of clusters and computes the density at each point. One of the important aspects of the subtractive clustering algorithm is the determination of the cluster radius (R) which defines the number of clusters and, consequently, the number of rules. A small radius leads to many smaller clusters in the data space, which results in more rules. After clustering the data space, the number of fuzzy rules is determined and so is that of premise fuzzy MFs. Then the linear squares estimate is used to determine the consequence in the output MFs, resulting in a valid FIS.

In order to obtain a small number of fuzzy rules, a fuzzy rule generation technique that integrates ANFIS with the subtractive clustering method can be used, where the SCM is used to systematically identify the fuzzy MFs and the fuzzy rule base for the ANFIS model. In this paper, to identify premise membership functions, two afore-mentioned methods are used and compared.

3 Results and discussion

In order to build the proposed ANFIS models, spindle speed (Sp), feed rate (Fe), and depth of cut (Dep) are considered as input variables (see Table 1, Figs. 2 and 3, respectively). Fig. 2 shows experimental data used for training stage (48 samples), and Fig. 3 shows separate experimental data used for testing stage (24 samples). In this Section, the aim is to use the structure of the data-driven models described in the previous subsections in order to predict workpiece surface roughness. Moreover, comparison will be made between the estimates provided by the proposed models and the other models presented in literature. Based on the same experimental data of Lo (Lo, 2003), the available data set in Table 2 is divided into two sets; one is used for the ANFIS training (48 samples, about 66%, see Fig. 2), while the other for testing performance (24 samples, about 34%, see Fig.). The optimized ANFIS models are selected based on the minimal Root-Mean-Square Error (RMSE) value as will be discussed in the next section.

Table 1: The symbols used in the tables

Parameter	Definition	Unit
Sp	Spindle speed	Revolutions per minute (rpm)
Fe	Feed rate	Inch per minute (ipm)
Dep	Depth of cut	Inch (in)
Ra	Roughness	Micro inch (μin.)

Table 2: Experimental data (Lo, 2003)

Experimental results (training data set)					Experimental results (training data set)				
T no	Sp	Fe	Dep	Ra	T no	Sp	Fe	Dep	Ra
1	750	6	0.01	65	1	750	9	0.01	109
2	750	6	0.03	63	2	750	9	0.05	95
3	750	6	0.05	72	3	750	15	0.03	122
4	750	12	0.01	144	4	750	15	0.05	104
5	750	12	0.03	102	5	750	21	0.01	178
6	750	12	0.05	94	6	750	21	0.03	163
7	750	18	0.01	185	7	750	21	0.05	150
8	750	18	0.03	147	8	1000	9	0.01	92
9	750	18	0.05	121	9	1000	15	0.03	108
10	750	24	0.01	187	10	1000	21	0.01	149
11	750	24	0.03	170	11	1000	21	0.03	145
12	750	24	0.05	172	12	1000	21	0.05	112
13	1000	6	0.01	58	13	1250	15	0.01	106
14	1000	6	0.03	78	14	1250	15	0.03	96
15	1000	6	0.05	62	15	1250	21	0.01	125
16	1000	12	0.01	130	16	1250	21	0.03	100
17	1000	12	0.03	84	17	1250	21	0.05	105
18	1000	12	0.05	92	18	1500	9	0.03	73
19	1000	18	0.01	138	19	1500	15	0.01	106
20	1000	18	0.03	124	20	1500	15	0.03	83
21	1000	18	0.05	86	21	1500	15	0.05	99
22	1000	24	0.01	163	22	1500	21	0.01	118
23	1000	24	0.03	153	23	1500	21	0.03	102
24	1000	24	0.05	142	24	1500	21	0.05	113
25	1250	6	0.01	50					
26	1250	6	0.03	63					
27	1250	6	0.05	71					
28	1250	12	0.01	101					
29	1250	12	0.03	99					
30	1250	12	0.05	85					
31	1250	18	0.01	115					
32	1250	18	0.03	92					
33	1250	18	0.05	95					

34	1250	24	0.01	155
35	1250	24	0.03	109
36	1250	24	0.05	121
37	1500	6	0.01	37
38	1500	6	0.03	56
39	1500	6	0.05	56
40	1500	12	0.01	88
41	1500	12	0.03	82
42	1500	12	0.05	94
43	1500	18	0.01	119
44	1500	18	0.03	87
45	1500	18	0.05	104
46	1500	24	0.01	119
47	1500	24	0.03	103
48	1500	24	0.05	109

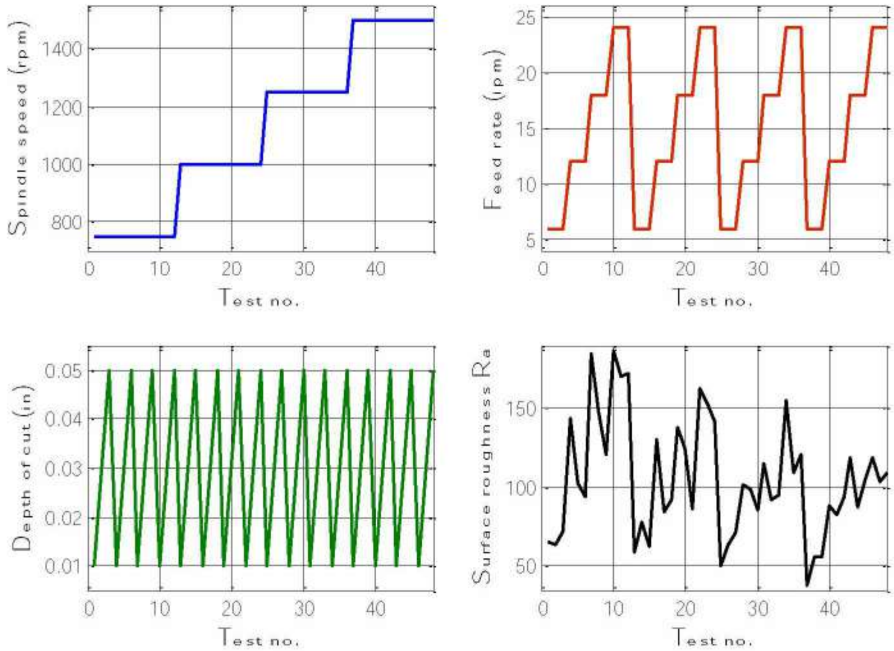

Fig. 2: Experimental results for training data

3.1 Development of the ANFIS models

In the ANFIS-Grid partition model structure, we can only use the Sugeno fuzzy rules, where the output is a linear combination of inputs. Different ANFIS models are evaluated using the RMSE in order to measure the deviation between the measured and the predicted values. By testing various ANFIS structures with a different number of MFs, we have obtained the optimal structure with 2 MFs for the spindle speed variable, 2 MFs for the feed rate variable, and 3 MFs for depth of cut variable, which adds up to the total of 12 rules. Also, we have tested all types of MFs such as Bell, Sigmoid, Triangle, Trapezoid and Gaussian. The Bell membership function in comparison with the others has the least error value. It is also observed that after using 5 epochs, the performance does not improve any further. The final ANFIS architecture used in this study is illustrated in Table 3. The corresponding rules of the optimal model are provided in Table 4.

Table 3: ANFIS-Grid model parameters

Parameters	ANFIS model
Type	Sugeno/ANFIS-Grid
Inputs/Outputs	3-1
Number of input membership function	2×2×3 for Sp, Fe and Dep, respectively
Number of output membership function	12
Input membership function Types	Bell
Output membership function Types	Linear
Rules Weight	1
Number of fuzzy rules	12
Number of epochs	5

Table 4: Linguistic rules

Linguistic rules
1. If (Sp is Low) and (Fe is Low) and (Dep is Low) then (Ra is out1mf1)
2. If (Sp is Low) and (Fe is Low) and (Dep is Medium) then (Ra is out1mf2)
3. If (Sp is Low) and (Fe is Low) and (Dep is High) then (Ra is out1mf3)
4. If (Sp is Low) and (Fe is High) and (Dep is Low) then (Ra is out1mf4)
5. If (Sp is Low) and (Fe is High) and (Dep is Medium) then (Ra is out1mf5)
6. If (Sp is Low) and (Fe is High) and (Dep is High) then (Ra is out1mf6)
7. If (Sp is High) and (Fe is Low) and (Dep is Low) then (Ra is out1mf7)
8. If (Sp is High) and (Fe is Low) and (Dep is Medium) then (Ra is out1mf8)
9. If (Sp is High) and (Fe is Low) and (Dep is High) then (Ra is out1mf9)
10. If (Sp is High) and (Fe is High) and (Dep is Low) then (Ra is out1mf10)
11. If (Sp is High) and (Fe is High) and (Dep is Medium) then (Ra is out1mf11)
12. If (Sp is High) and (Fe is High) and (Dep is High) then (Ra is out1mf12)

Next, different ANFIS models are constructed using the subtractive clustering method. In the ANFIS-SCM model, it is essential to obtain an optimal number of clusters. For this purpose, several ANFIS models can be constructed with a different number of cluster radiuses (R). The ANFIS model with R=0.8 is found to exhibit the lowest error after 5 epochs. The characterization of the ANFIS model is illustrated in Table 5. The corresponding rules of the optimal model are provided in Table 6.

Table 5: ANFIS-SCM model parameters

Parameters	ANFIS model
Type	Sugeno
Inputs/Outputs	3-1
Number of input membership function	8 for all inputs
Number of output membership function	8
Input membership function Types	Gaussian
Output membership function Types	Linear
Rules Weight	1
Number of fuzzy rules	8
Number of epochs	5

Table 6: Linguistic rules for ANFIS-SCM

Linguistic rules
1. If (Sp is SpCluster1) and (Fe is FeCluster1) and (Dep is DepCluster1) then (Ra is RaCluster1)
2. If (Sp is SpCluster2) and (Fe is FeCluster2) and (Dep is DepCluster2) then (Ra is RaCluster2)
3. If (Sp is SpCluster3) and (Fe is FeCluster3) and (Dep is DepCluster3) then (Ra is RaCluster3)
4. If (Sp is SpCluster4) and (Fe is FeCluster4) and (Dep is DepCluster4) then (Ra is RaCluster4)
5. If (Sp is SpCluster5) and (Fe is FeCluster5) and (Dep is DepCluster5) then (Ra is RaCluster5)
6. If (Sp is SpCluster6) and (Fe is FeCluster6) and (Dep is DepCluster6) then (Ra is RaCluster6)
7. If (Sp is SpCluster7) and (Fe is FeCluster7) and (Dep is DepCluster7) then (Ra is RaCluster7)
8. If (Sp is SpCluster8) and (Fe is FeCluster8) and (Dep is DepCluster8) then (Ra is RaCluster8)

3.2 Validation of the proposed models

In this section, the aim is to use the structure of the ANFIS models described in the previous section to predict the surface roughness. With the purpose of evaluating the prediction performance of the models, the remaining data set (testing data set) is used for running the proposed models. The performance of the models used in this study is computed using percentage error E_i and average percentage error E_{av} defined in equations (1) and (2), respectively, as follows:

$$E_i\% = \frac{|Ra_{Exp} - Ra_{Pre}|}{Ra_{Exp}} \times 100$$

$$E_{av}\% = \frac{1}{m}\sum_{i=1}^{m} E_i$$

where 'Ra_{Exp}' and 'Ra_{Pre}' stand for experimental values and predicted values, respectively; *m* is the samples number to be predicted.

It is observed from Table 6 that for the best models obtained by Lo (Lo, 2003), Ho et al. (Ho, et al., 2009), and Dong et al. (Dong & Wang, 2011), the maximum average errors are approximately 4.65% (for Triangular MF) and 7.31% (for Trapezoidal MF), 4.06%, and 3.62%, respectively; therefore, the error values are in the range of 3.62-7.31%. For the best ANFIS configuration obtained in this study, the maximum average errors are approximately 3.47% (for an ANFIS-Grid model, see Fig. 3) and 3.49% (for ANFIS-SCM model, see see Figure 4), respectively; therefore, the average error values are in the range of 3.47-3.49%.

From these results, it is clear that the surface roughness prediction by using the proposed ANFIS models outperforms the models presented in (Lo, 2003) (Ho, et al., 2009) (Dong & Wang, 2011), with the benefit of lower rules.

In this work, it can be clearly seen that the ANFIS model structure demonstrates several advantages. It provides a natural framework to include expert human being knowledge in the form of linguistic fuzzy "IF-THEN" rules. This knowledge can be easily gathered with the rules, which are automatically obtained from the data sets that describe the system. Therefore, the two main objectives to be addressed in this article are interpretability and accuracy. Generally speaking, the ideal model should satisfy both the criteria (interpretability and accuracy) to a high degree but since they are contradictory issues, this is generally impossible. Under the circumstances, one of them can be selected depending on the nature of the problem to be solved.

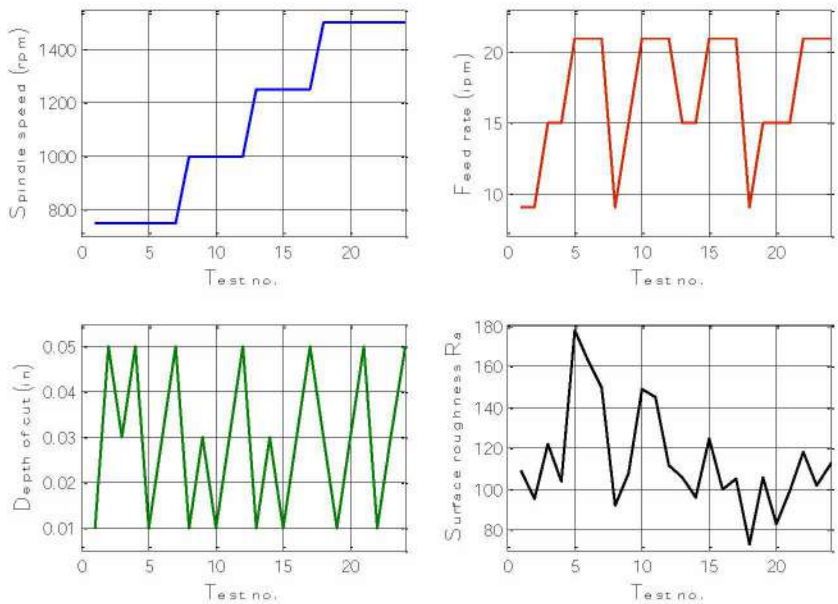

Fig. 3: Experimental results for testing data

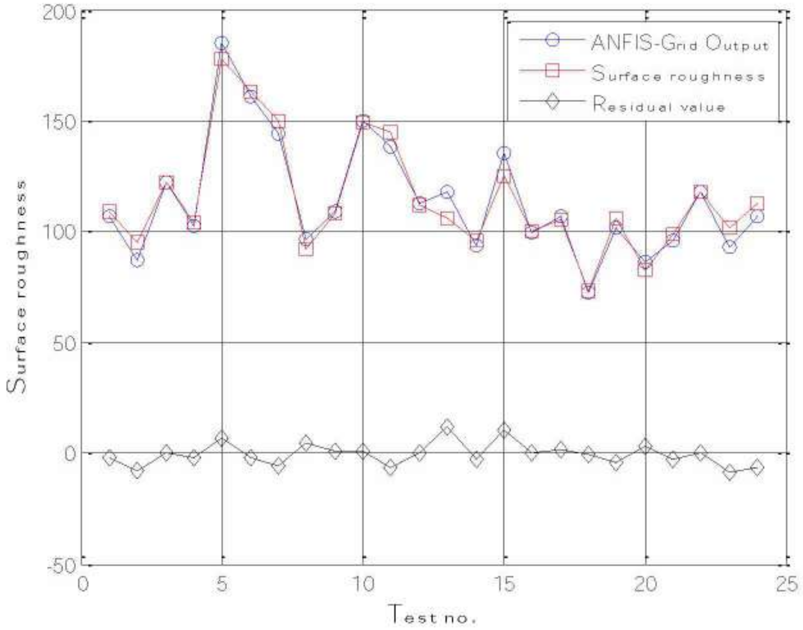

Fig. 4: The measured Ra and predicted Ra for testing dataset using ANFIS-Grid

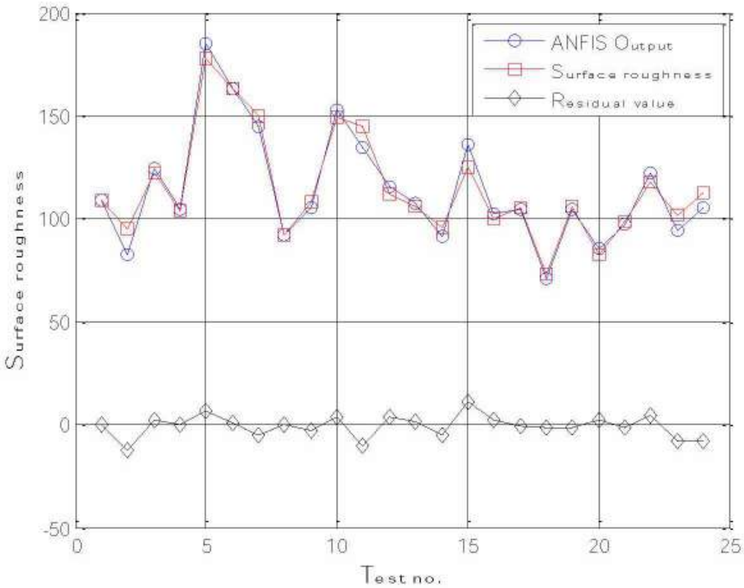

Fig. 5 The measured Ra and predicted Ra for testing dataset using ANFIS-SCM

4 Conclusions

In this paper, an adaptive Neuro-Fuzzy inference system for the modeling and control of workpiece surface roughness for end milling process is presented. The comparison between the experimental and the predicted values of the proposed ANFIS models shows that there is an excellent agreement between the predicted surface roughness and the experimental results with average error values in the range of 3.47-3.49%. This means that the proposed model can simulate workpiece surface roughness for end milling process with an excellent level of accuracy and lower rules. The results obtained with the proposed ANFIS models are superior to the Lo (Lo, 2003), Ho et al. (Ho, et al., 2009), and Dong et al. (Dong & Wang, 2011) models. Further work is required to validate the model using disparate cycles on multiple machines.

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EVALUATION AND SELECTION OF THE PVC CARPENTRY MANUFACTURER USING THE FUCOM-MABAC MODEL

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Abstract: *Solving real-life problems using multi-criteria decision-making methods is now an everyday challenge. These methods represent a very useful tool and support for decision-making in all areas. Therefore, this paper comprises evaluation and selection of the PVC carpentry manufacturers using a combined multi-criteria model. Five potential manufacturers are evaluated on the basis of seven criteria. For the determination of criteria weights, the FUCOM (FUll COnsistency Method) is used, while the Multi-Attributive Border Approximation Area Comparison (MABAC) method is used for evaluating and selecting the PVC manufacturer. The results show that the third alternative is the most suitable solution, as demonstrated by the sensitivity analysis. Four other methods are used in the sensitivity analysis, namely, ARAS (Additive Ratio Assessment), WASPAS (Weighted Aggregated Sum Product Assessment), EDAS (Evaluation based on Distance from Average Solution), and SAW (Simple Additive Weighting). The obtained results using all the methods show the complete correlation of the ranks obtained using the MABAC method.*

Key Words: *PVC Manufacturer, FUCOM, MABAC, Criteria Weights*

1 Introduction

In solving real-life problems, there is a large number of influencing factors that can affect the final decision. In the case of a larger number of criteria involved in the decision-making process, according to Zavadskas et al. (2018), it is practically impossible to avoid the use of multi-criteria decision-making (MCDM) methods. According to Kumar, (2010) the MCDM can be perceived as a process of evaluating real-world situations based on various qualitative/quantitative criteria in certain/uncertain/risky environments in order to find a suitable course of action/choice/strategy/policy among several available options. According to Chen et al. (2015), the MCDM is an effective systematic and quantitative way of dealing with vital real-life problems in the presence of a number of alternatives and several usually conflicting criteria. A great number of works applying diverse MCDM

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techniques for engineering problems have recently been published (Zavadskas et al. 2016). Everyday use of MCDM methods (Petrović et al. 2016; Shetwan et al. 2018; Eshtaiwi et al. 2018; Karabašević et al. 2018) has certainly contributed to the rise in popularity of this area.

The main objective of the paper is to evaluate and select the PVC carpentry manufacturer using the FUCOM-MABAC model. The way of reaching the given goal is by satisfying a number of criteria such as: selection of a high-quality manufacturer at the lowest possible price, a short time for delivery and montage, possibility of deferred payment and a longer warranty period with the manufacturer's reliability.

In addition to the Introduction, the paper is structured through four more sections. The second section (Section 2) presents the FUCOM and MABAC methods with their detailed steps. In the third section (Section 3), a multi-criteria model is formed and the previously described methods for evaluating and selecting PVC manufacturers are applied. The fourth section (Section 4) presents a sensitivity analysis in which the stability of the applied model is proved. The paper ends with the conclusions along with the guidelines for future research.

2 Methods

2.1 FUll COnsistency Method - FUCOM

This method is a new MCDM method proposed in (Pamučar et al. 2018). The problems of multi-criteria decision-making are characterized by the choice of the most acceptable alternative out of a set of the alternatives presented on the basis of the defined criteria. A model of multi-criteria decision-making can be presented by a mathematical equation $\max\left[c_1(x), c_2(x), ..., c_n(x)\right]$, $n \geq 2$, on the condition that $x \in A = \left[a_1, a_2, ..., a_m\right]$; where n represents the number of the criteria, m is the number of the alternatives, c_j represents the criteria ($j = 1,2,...,n$) and A represents the set of the alternatives a_i ($i = 1,2,...,m$). Values f_{ij} of each considered criterion c_j for each considered alternative a_i are known, namely $f_{ij} = c_j(a_i)$, $\forall(i,j)$; $i = 1,2,...,m$; $j = 1,2,...,n$. The relation shows that each value of the attribute depends on the j^{th} criterion and the i^{th} alternative.

Real problems do not usually have the criteria of the same degree of significance. It is, therefore, necessary that the significance factors of particular criteria should be defined by using appropriate weight coefficients for the criteria so that their sum is one. Determining the relative criteria weights in multi-criteria decision-making models is always a specific problem inevitably accompanied by subjectivity. This process is very important and has a significant impact on the final decision-making result since the weight coefficients in some methods crucially influence the solution. Therefore, particular attention in this paper is paid to the problem of determining the criteria weights, and the new FUCOM model for determining the weight coefficients of criteria is proposed. This method enables precise determination of the values of the weight coefficients of all of the elements mutually compared at a certain level of the hierarchy, simultaneously satisfying the conditions of the comparison consistency, too.

In real life, pairwise comparison values $a_{ij} = w_i / w_j$ (where a_{ij} shows the relative preference of criterion *i* to criterion *j*) are not based on accurate measurements, but rather on subjective estimates. There is also a deviation of values a_{ij} from ideal ratios w_i / w_j (where w_i and w_j represent criteria weights of criterion *i* and criterion *j*). If, for example, it is determined that A is of much greater significance than B, B of greater importance than C, and C of greater importance than A, there is inconsistency in the problem solving and the reliability of the results decreases. This is especially true when there is a large number of pairwise comparisons of criteria. The FUCOM reduces the possibility of errors in comparison to the least possible extent due to: (1) a small number of comparisons (*n-1*) and (2) the constraints defined when calculating the optimal values of criteria. The FUCOM provides the ability to validate the model by calculating the error value for the obtained weight vectors by determining DFC. On the other hand, in the other models for determining criteria weights (the BWM, the AHP models), the redundancy of the pairwise comparison appears, which makes them less vulnerable to errors in judgment, while the FUCOM methodological procedure eliminates this problem.

In the following section, the procedure for obtaining the weight coefficients of criteria by using the FUCOM is presented.

Step 1 In the first step, the criteria from a predefined set of the evaluation criteria $C = \{C_1, C_2, ..., C_n\}$ are ranked. The ranking is performed according to the significance of the criteria, i.e. starting from the criterion which is expected to have the highest weight coefficient down to the criterion of the least significance. Thus, the criteria ranked according to the expected values of the weight coefficients are obtained:

$$C_{j(1)} > C_{j(2)} > ... > C_{j(k)} \tag{1}$$

where *k* represents the rank of the observed criterion. If there is a judgment of the existence of two or more criteria with the same significance, the sign of equality is placed instead of ">" between these criteria in expression (1).

Step 2 In the second step, comparison of the ranked criteria is carried out and the *comparative priority* ($\varphi_{k/(k+1)}$, $k = 1, 2, ..., n$, where *k* represents the rank of the criteria) of the evaluation criteria is determined. The comparative priority of evaluation criteria ($\varphi_{k/(k+1)}$) is an advantage of the criterion of the $C_{j(k)}$ rank compared to the criterion of the $C_{j(k+1)}$ rank. Thus, the vector of the comparative priorities of the evaluation criteria is obtained, as in expression: (2)

$$\Phi = \left(\varphi_{1/2}, \varphi_{2/3}, ..., \varphi_{k/(k+1)}\right) \tag{2}$$

where $\varphi_{k/(k+1)}$ represents the significance (priority) of the criterion of the $C_{j(k)}$ rank in comparison with the criterion of the $C_{j(k+1)}$ rank.

The comparative priority of the criteria is defined in one of the two ways defined in the following part:

a) Pursuant to their preferences, the decision-makers define comparative priority $\varphi_{k/(k+1)}$ among the observed criteria. Thus, for example, if two stones A and B, which, respectively, have the weights of $w_A = 300$ grams and $w_B = 250$ grams are observed, comparative priority ($\varphi_{A/B}$) of Stone A in relation to Stone B is $\varphi_{A/B} = 300/250 = 1.2$. Also, if weights A and B cannot be determined precisely, but a predefined scale is used, e.g. from 1 to 9, then it can be said that Stones A and B have weights $w_A = 8$ and $w_B = 7$, respectively. Then comparative priority ($\varphi_{A/B}$) of Stone A in relation to Stone B can be determined as $\varphi_{A/B} = 8/7 = 1.14$. This means that Stone A in relation to Stone B has a greater priority (weight) by 1.18 (in the case of precise measurements), i.e. by 1.14 (in the case of application of measuring scale). In the same manner, the decision-makers define the comparative priority among observed criteria $\varphi_{k/(k+1)}$. When solving real problems, the decision-makers compare the ranked criteria based on internal knowledge so that they determine comparative priority $\varphi_{k/(k+1)}$ based on subjective preferences. If the decision-maker thinks that the criterion of the $C_{j(k)}$ rank has the same significance as the criterion of the $C_{j(k+1)}$ rank, then the comparative priority is $\varphi_{k/(k+1)} = 1$.

b) Based on a predefined scale for comparing criteria, the decision-makers compare the criteria and thus determine the significance of each individual criterion in expression (1). The comparison is made with respect to the first-ranked (the most significant) criterion. Thus, the significance of criteria ($\varpi_{C_{j(k)}}$) for all of the criteria ranked in Step 1 is obtained. Since the first-ranked criterion is compared with itself (its significance is $\varpi_{C_{j(1)}} = 1$), the conclusion can be drawn that the *n-1* comparison of the criteria should be performed.

For example: a problem with three criteria ranked as C2>C1>C3 is being subjected to consideration. Suppose that scale $\varpi_{C_{j(k)}} \in [1,9]$ is used to determine the priorities of the criteria and that, based on the decision-maker's preferences, the following priorities of criteria $\varpi_{C_2} = 1$, $\varpi_{C_1} = 3.5$ and $\varpi_{C_3} = 6$ are obtained. On the basis of the obtained priorities of the criteria and condition $\frac{w_k}{w_{k+1}} = \varphi_{k/(k+1)}$ we obtain the following calculations $\frac{w_2}{w_1} = \frac{3.5}{1}$, i.e. $w_2 = 3.5 \cdot w_1$, $\frac{w_1}{w_3} = \frac{6}{3.5}$ i.e. $w_1 = 1.714 \cdot w_3$. In that way, the following comparative priorities are calculated: $\varphi_{C_2/C_1} = 3.5/1 = 3.5$ and $\varphi_{C_1/C_3} = 6/3.5 = 1.714$ (expression (2)).

As we can see from the example shown in Step 2b, the FUCOM model allows the pairwise comparison of the criteria by means of integer, decimal values or values from the predefined scale for the pairwise comparison of the criteria.

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

$$\frac{w_k}{w_{k+1}} = \varphi_{k/(k+1)} \tag{3}$$

(2) In addition to the condition (3), the final values of the weight 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 $\varphi_{(k+1)/(k+2)} = \frac{w_{k+1}}{w_{k+2}}$, that $\frac{w_k}{w_{k+1}} \otimes \frac{w_{k+1}}{w_{k+2}} = \frac{w_k}{w_{k+2}}$ is obtained. Thus, yet another condition that the final values of the weight coefficients of the evaluation criteria need to meet is obtained, namely:

$$\frac{w_k}{w_{k+2}} = \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} \tag{4}$$

Full consistency, i.e. minimum DFC (χ) is satisfied only if transitivity is fully respected, i.e. when the conditions of $\frac{w_k}{w_{k+1}} = \varphi_{k/(k+1)}$ and $\frac{w_k}{w_{k+2}} = \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)}$ are met. In that way, the requirement for maximum consistency is fulfilled, i.e. DFC is $\chi = 0$ for the obtained values of the weight coefficients. In order for the conditions to be met, it is necessary that the values of weight coefficients $(w_1, w_2, ..., w_n)^T$ meet the condition of $\left|\frac{w_k}{w_{k+1}} - \varphi_{k/(k+1)}\right| \le \chi$ and $\left|\frac{w_k}{w_{k+2}} - \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)}\right| \le \chi$, with the minimization of value χ. In that manner the requirement for maximum consistency is satisfied. Based on the defined settings, the final model for determining the final values of the weight coefficients of the evaluation criteria can be defined.

$$\begin{aligned}
&\min \chi \\
&s.t. \\
&\left|\frac{w_{j(k)}}{w_{j(k+1)}} - \varphi_{k/(k+1)}\right| \le \chi, \ \forall j \\
&\left|\frac{w_{j(k)}}{w_{j(k+2)}} - \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)}\right| \le \chi, \ \forall j \\
&\sum_{j=1}^{n} w_j = 1, \ \forall j \\
&w_j \ge 0, \ \forall j
\end{aligned} \tag{5}$$

By solving the model (5), the final values of evaluation criteria $(w_1, w_2, ..., w_n)^T$ and the degree of DFC (χ) are generated.

2.2 MABAC method

The MABAC Method (Multi-Attributive Border Approximation Area Comparison) was developed by Pamučar and Ćirović, (2015). The basic setting of the MABAC Method is reflected in defining the distance of the criterion function of each observed alternative from the boundary approximation domain. In the following section, the implementation procedure for the MABAC Method consisting of 6 steps is shown.

Step 1 Forming initial decision matrix (X)

As the first step, *m* alternatives are evaluated by *n* criteria. Alternatives are shown with vectors $A_i=(x_{i1}, x_{i2,...,} x_{in})$, where x_{ij} is the value of i-... alternative by j-... criteria (i=1,2,...,m; j=1,2,...,n)

$$X = \begin{matrix} & C_1 & C_2 & \dots & C_n \\ A_1 & x_{11} & x_{12} & \dots & x_{1n} \\ A_2 & x_{21} & x_{22} & & x_{2n} \\ \dots & \dots & \dots & \dots & \dots \\ A_m & x_{m1} & x_{m2} & \dots & x_{mn} \end{matrix} \quad (6)$$

where *m* denotes the number or alternative, while *n* is the total number of criteria.

Step 2 Normalization of the elements of starting matrix *(X)*

$$N = \begin{matrix} & C_1 & C_2 & \dots & C_n \\ A_1 & t_{11} & t_{12} & \dots & t_{1n} \\ A_2 & t_{21} & t_{22} & & t_{2n} \\ \dots & \dots & \dots & \dots & \dots \\ A_m & t_{m1} & t_{m2} & \dots & t_{mn} \end{matrix} \quad (7)$$

The elements of normalized matrix (N) are determined using the expression:

For the criteria belonging to a "benefit" type (greater value of criteria is more desirable):

$$t_{ij} = \frac{x_{ij} - x_i^-}{x_i^+ - x_i^-} \quad (8)$$

For the criteria belonging to a "cost" type (lower value of criteria is more desirable)

$$t_{ij} = \frac{x_{ij} - x_i^+}{x_i^- - x_i^+} \tag{9}$$

where x_{ij}, x^+ and x^- are representing elements of the starting matrix of making decision (X), where x_{ij}, x^+ and x- are defined as: x_j^+ =max ($x_1, x_2, .., x_n$) and representing maximal values of observed criteria by alternatives; x_j^- =min ($x_1, x_2, ..., x_m$) and representing minimal values of observed criteria by alternatives.

Step 3 Calculation of the element of weighted normalized matrix *(V)*

Elements of weighted normalized matrix (V) are being calculated on the base of expression (10):

$$v_{ij} = w_i \cdot t_{ij} + w_i \tag{10}$$

where Tij are representing the elements of normalized matrix N, *wi* represents weighting coefficients of criteria.

Step 4 Determining the matrix of bordering approximative fields (G)

Bordering approximative field (GAO) is determined by expression (11):

$$g_i = \left(\prod_{j=1}^{m} v_{ij} \right)^{1/m} \tag{11}$$

with v_{ij} representing the elements of weighted matrix V, *m* represents the total number of alternatives. Matrix of bordering approximative fields is being formed according to criteria G (12) in format *n* x 1.

$$\begin{matrix} & C_1 & C_2 & \cdots & C_n \\ G = & [g_1 & g_2 & \cdots & g_n] \end{matrix} \tag{12}$$

Step 5 The calculation of the distance matrix element is an alternative to boundary approximative area *(Q):*

$$Q = \begin{bmatrix} q_{11} & q_{12} & \cdots & q_{1n} \\ q_{21} & q_{22} & & q_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ q_{m1} & q_{m2} & \cdots & q_{mn} \end{bmatrix} \tag{13}$$

Distance of alternatives from boundary approximative area (q_{uid}) is determined as a difference of elements of heavier matrix (V) and values of bordering approximative areas (G).

$$Q = V - G = \begin{bmatrix} v_{11} & v_{12} & \cdots & v_{1n} \\ v_{21} & v_{22} & & v_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ v_{m1} & v_{m2} & \cdots & v_{mn} \end{bmatrix} - \begin{bmatrix} g_1 & g_2 & \cdots & g_n \end{bmatrix} \tag{14}$$

where q_{ij} represents the bordering approximative areas for criterion Ci, *vij* represents elements of weighted matrix (V), *n* represents number of criteria, *m* represents number of alternatives. Alternative Ai may belong to bordering approximative area (G), upper bordering approximative area (G^+) or lower bordering approximative area (G^-). Upper approximative area (G^+) represents the area in which ideal alternative (A+) is located, while lower approximative area (G^-) represents the area in which anti-ideal alternative is located (A^-).

$$A_i \in \begin{cases} G^+ \ if \ q_{ij} > g_i \\ G \ \ if \ q_{ij} = g_i \\ G^- \ if \ q_{ij} < g_i \end{cases} \tag{15}$$

In order for an alternative *Ai* to be selected as the best from a given set, it is necessary for it to belong to the upper approximating field by as many criteria as possible (G^+). If, for example, an alternative *Ai* belongs to the upper approximative area by 5 criteria (out of 6 in total), and to the lower approximative area by one criterion, (G^-) that means that, by 5 criteria, this alternative is close to or equal with the ideal alternative, while by one criterion it is close to or equal to anti-ideal alternative. If value $q_{ij} > 0$, i.e. $q_{ij} \in G^+$, then alternative Ai is close or equal to the ideal alternative. Value $q_{ij} > 0$, i.e. $q_{ij} \in G^-$, shows that alternative Ai is close or equal to the anti/ideal alternative.

Step 6 Alternatives ranking

Calculation of values of the criteria functions by alternatives is obtained as the sum of distance of the alternatives from bordering approximative fields (q_i). By summarizing the elements of Q matrix by rows, we obtain the final values of the criterion functions of alternatives (16) where *n* represents the number of criteria, and *m* represents the number of alternatives.

$$S_i = \sum_{j=1}^{n} q_{ij}, \ j = 1,2,...,n, \ i = 1,2,...,m \tag{16}$$

3 Evaluation of PVC carpentry manufacturer

On today's market, according to Stević et al. (2018), there is a large number of PVC carpentry manufacturers that bid a very diverse offer from their wide range of production. The research in this paper has led to the selection of five manufacturers, all located at the maximal distance of 70 km. The surface of apartment which requires the selection of the most suitable manufacturer of PVC carpentry is 64 m^2 and Fig. 1 shows dimensions of all the apartment surfaces in need of PVC carpentry. In addition, a selection of six-chamber PVC profiles with thermal insulation glasses of 24 mm was carried out in advance.

From Fig. 1 it can be seen that, according to the wishes of buyers who are also decision-makers, a montage of carpentry together with window blinds and mosquito nets is needed. Only Position 5 is without mosquitoes nets, and it is necessary to install internal and external benches. Position 1 as a single-hung window with Position 2 (a double-hung window) makes a corner window in the living room. Also, Position 3 is a single-hung window belonging to the living room. Position 4 of the single-hung window belongs to the bedroom, while Position 5 of the single-hung window and Position 6 of the balcony door belong to the dining room.

The criteria formulated in this research representing the basis for decision-making of those who select the most favorable manufacturer are: product quality, product price, timeframe guarantee, manufacturer's reliability, delivery time, payment methods and the possibility of walls treatment after the montage of new carpentry, marked hereinafter as C_1–C_7, respectively. The second criterion is a cost criterion that needs to be minimized, while the rest belongs to benefit criteria that are of maximizing type.

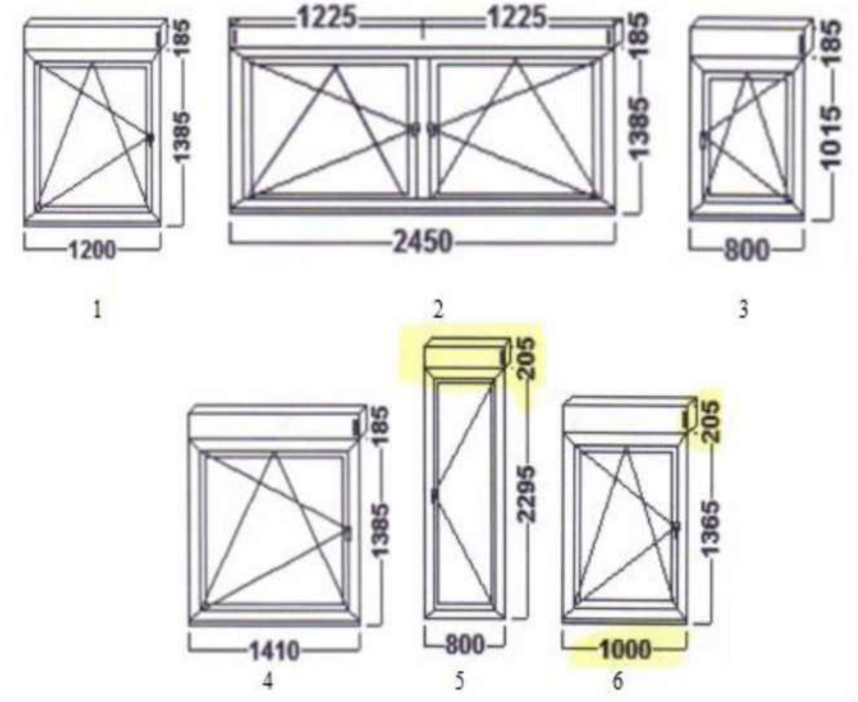

Fig. 1 Dimensions of elements needed for montage

Table 1 presents the criteria used to evaluate and select the manufacturer, while Table 2 shows the scale for assessing qualitative criteria. Some of these criteria can be successfully applied to evaluation of suppliers in the companies manufacturing PVC carpentry, which is confirmed by the research carried out in (Stojić et al. 2018).

Table 1 Criteria used in the research

Mark of criteria	Name of criteria
C_1	product quality
C_2	product price
C_3	timeframe guarantee
C_4	manufacturer's reliability
C_5	delivery time
C_6	payment methods
C_7	treatment of walls after the montage of new carpentry

Table 2 Linguistic scale for evaluating the benefit criteria (Stević et al. 2017)

Linguistic Scale	For Criteria Max Type (Benefit criteria)
Very Poor (VP)	1
Poor (P)	3
Medium (M)	5
Good (G)	7
Very Good (VG)	9

Table 2 shows only the benefit criteria scale since the only cost criterion is the product price that is quantitatively expressed. In addition to this criterion, the warranty period is also displayed through its real values. The criterion of delivery time could not be quantified because certain manufacturers display, as this criterion, time - by agreement. Therefore, this criterion is qualitative and benefit.

3.1 Determining criteria weight using the FUCOM method

Step 1 In the first step, the decision-makers perform the ranking of the criteria: C1> C2> C5> C3=C6>C4>C7.

Step 2 In the second step (Step 2b), the decision-maker perform pairwise comparison of the ranked criteria from Step 1. The comparison is made with respect to the first-ranked C2 criterion. The comparison is based on the scale $[1,9]$. Thus, the priorities of criteria ($\varpi_{C_{j(k)}}$) for all of the criteria ranked in Step 1 are obtained (Table 3).

Table 3 Priorities of criteria

Criteria	C_1	C_2	C_5	C_3	C_6	C_4	C_7
$\varpi_{C_{j(k)}}$	1	1.3	2	2.5	2.5	2.8	3.5

Based on the obtained priorities of the criteria, the comparative priorities of the criteria are calculated: $\varphi_{C_1/C_2} = 1.3/1 = 1.3$, $\varphi_{C_2/C_5} = 2/1.3 = 1.54$,

$\varphi_{C_5/C_3} = 2.5/2 = 1.25$, $\varphi_{C_3/C_6} = 2.5/2.5 = 1$, $\varphi_{C_6/C_4} = 2.8/2.5 = 1.12$ and $\varphi_{C_4/C_7} = 3.5/2.8 = 1.25$.

Step 3 The final values of the weight coefficients should meet the following two conditions:

a) The final values of the weight coefficients should meet the condition (3), i.e. that $\frac{w_1}{w_2} = 1.3$, $\frac{w_2}{w_5} = 1.54$, $\frac{w_5}{w_3} = 1.25$, $\frac{w_3}{w_6} = 1$, $\frac{w_6}{w_4} = 1.12$ and $\frac{w_4}{w_7} = 1.25$.

b) In addition to the condition (3), the final values of the weight coefficients should meet the condition of mathematical transitivity, i.e. that $\frac{w_1}{w_5} = 1.3 \times 1.54 = 2$, $\frac{w_2}{w_3} = 1.54 \times 1.25 = 1.82$, $\frac{w_5}{w_6} = 1.25 \times 1 = 1.25$, $\frac{w_3}{w_4} = 1 \times 1.12 = 1.12$ and $\frac{w_6}{w_7} = 1.12 \times 1.25 = 1.34$. By applying expression (5), the final model for determining the weight coefficients can be defined as:

$$\min \chi$$

$$s.t.\begin{cases} \left|\frac{w_1}{w_2} - 1.30\right| \le \chi,\ \left|\frac{w_2}{w_5} - 1.54\right| \le \chi,\ \left|\frac{w_5}{w_3} - 1.25\right| \le \chi,\ \left|\frac{w_3}{w_6} - 1.00\right| \le \chi,,\ \left|\frac{w_6}{w_4} - 1.12\right| \le \chi,\ \left|\frac{w_4}{w_7} - 1.25\right| \le \chi, \\ \left|\frac{w_1}{w_5} - 2.00\right| \le \chi,\ \left|\frac{w_2}{w_3} - 1.92\right| \le \chi,\ \left|\frac{w_5}{w_6} - 1.25\right| \le \chi,\ \left|\frac{w_3}{w_4} - 1.12\right| \le \chi,\ \left|\frac{w_6}{w_7} - 1.34\right| \le \chi, \\ \sum_{j=1}^{7} w_j = 1,\ w_j \ge 0, \forall j \end{cases}$$

By solving this model, the final values of the weight coefficients $(0.266, 0.207, 0.134, 0.108, 0.108, 0.098, 0.079)^T$ and DFC of the results $\chi = 0.018$ are obtained. The value of the criteria according to the marks given at the beginning is shown in Table 4. The model is solved using the Lingo17 software.

Table 4 Criteria weights

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7
ϖ_j	0.266	0.207	0.108	0.098	0.134	0.108	0.079

From Table 4 it can be concluded that the most important criterion for the selection of the PVC carpentry manufacturer is the first one, i.e. product quality, followed by product price and guarantee period, while the other criteria have somewhat less significance.

3.2 Evaluation of the manufacturer PVC carpentry using the MABAC method

The initial matrix presented in Table 5 consists of five alternatives that are presented in detail at the end of the previous subsection and seven criteria. Evaluation of the alternative is performed on the linguistic scale shown in Table 2.

Upon request for the production and montage of PVC carpentry, as noted earlier, five manufacturers have been selected and their locations are located at a distance of up to 70 km.

Table 5 Initial matrix

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
A_1	7	5776.000	5	5	5	3	5
A_2	7	8252.780	2	3	5	3	1
A_3	7	3490.030	5	5	5	3	7
A_4	3	4355.000	5	3	3	3	1
A_5	5	5795.000	0	3	1	1	1

Normalization is performed as follows:

For criteria C_1, C_3, C_4, C_5, C_6, and C_7 that belong to the benefit criteria, the normalization is carried out using equation (8)

$$t_{11} = \frac{7-3}{7-3} = 1.00$$

For criterion C_2, belonging to the cost criteria the normalization is carried out using equation (9)

$$t_{12} = \frac{5776 - 8252.780}{3490.030 - 8252.780} = 0.52$$

A complete normalized matrix is shown in Table 6.

Table 6 Normalized matrix

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
A_1	1	0.52	1	1	1	1	0.667
A_2	1	0	0.4	0	1	1	0
A_3	1	1	1	1	1	1	1
A_4	0	0.818	1	0	0.5	1	0
A_5	0.5	0.516	0	0	0	0	0

After normalization, the normalized matrix is weighted by applying equation (10):

$v_{ij} = w_i \cdot t_{ij} + w_i$ and the weighted normalized matrix is obtained and shown in Table 7.

Table 7 Weighted normalized matrix

V	C_1	C_2	C_3	C_4	C_5	C_6	C_7
A_1	0.532	0.315	0.216	0.196	0.268	0.216	0.132
A_2	0.532	0.207	0.151	0.098	0.268	0.216	0.079
A_3	0.532	0.414	0.216	0.196	0.268	0.216	0.158
A_4	0.266	0.376	0.216	0.098	0.201	0.216	0.079
A_5	0.399	0.314	0.108	0.098	0.134	0.108	0.079

The next step is to obtain a matrix of 1x7 boundary approximative values (Table 8) by applying the geometric mean or equation $GM = \left(\prod_{i=1}^{n} A_{ij}\right)^{1/n}$.

Table 8 Matrix of boundary approximative areas

G	0.437	0.317	0.175	0.129	0.220	0.188	0.101

The next step is to determine the Q matrix shown in Table 9 which represents the difference between the two previous matrices and is obtained by applying equation (14):

$$q_{11} = 0,532 - 0,437 = 0,095$$

Table 9 Matrix of bordering approximative field

Q=V-G	C_1	C_2	C_3	C_4	C_5	C_6	C_7
A_1	0.095	-0.002	0.041	0.067	0.048	0.028	0.031
A_2	0.095	-0.110	-0.024	-0.031	0.048	0.028	-0.022
A_3	0.095	0.097	0.041	0.067	0.048	0.028	0.057
A_4	-0.171	0.060	0.041	-0.031	-0.019	0.028	-0.022
A_5	-0.038	-0.003	-0.067	-0.031	-0.086	-0.080	-0.022

The results obtained using the FUCOM-MABAC model are shown in Table 10, where it can be noted that the alternative of the three is the best solution.

Table 10 Results of the FUCOM-MABAC model

A_1	0.307	**2**
A_2	-0.016	**3**
A_3	0.433	**1**
A_4	-0.115	**4**
A_5	-0.327	**5**

Characteristics of the selected manufacturer are as follows:

- PVC positions are made of the German six-chamber Inoutic PVC profile of Prestige system with three grey seals,
- depth of construction is 76 mm white colored with 1.5 mm reinforcement,
- dimensions of window frame are 76/85 mm and blinds of 84 mm in height,
- window blinds made of PVC system INOUTIC PROTEX with aluminum cover,
- box dimensions of 205x185 mm, except on the balcony door and the

corresponding window of dimensions 205x205 mm,
- all positions are with internal opening and integrated roller mosquitoes nets except Position 5 which is without mosquitoes net,
- Frame Roto NT, and
- glass: IZO Flot 24 mm thick (4+16+argon+4Low-e).

4 Sensitivity analysis

An important feature of the multi-criteria decision-making method is the sensitivity analysis of the applied model, and at the same time, the decision-maker enables testing of different sets of alternative solutions. The sensitivity analysis shows the relations of changing the priority of the alternative as a function of the significance of the attributes, that is, the criteria. In order to check the stability of the applied model, the sensitivity analysis is performed. It represents, beside the MABAC method, application of the following methods: ARAS (Zavadskas and Turskis, 2010) SAW (Maccrimmon, 1968), WASPAS (Zavadskas et al. 2012) and EDAS (Keshavarz Ghorabaee et al. 2015). The results of the applied FUCOM-MABAC model are shown in Table 11.

Table 11 Results of sensitivity analysis

	MABAC		SAW		WASPAS		ARAS		EDAS	
A_1	0.307	2	0.961	2	0.942	2	2.287	2	2.287	2
A_2	-0.016	3	0.748	3	0.699	3	1.519	3	1.519	3
A_3	0.433	1	1.065	1	1.058	1	2.410	1	2.410	1
A_4	-0.115	4	0.686	4	0.648	4	1.479	4	1.479	4
A_5	-0.327	5	0.487	5	0.243	5	1.270	5	1.270	5

On the basis of the results shown in Table 11 it can be concluded that the model is very stable and that the ranks obtained by the FUCOM-MABAC model are in complete correlation with those obtained by means of the other four methods.

5 Conclusions

This paper presents the results of the research which again demonstrates the applicability of multi-criteria decision-making methods in making everyday decisions. Making such decisions can be of significant importance to each individual. Solving the problem of the selection of the PVC carpentry manufacturer has included all the relevant criteria which are of influence upon the final decision. The objective was to obtain the most suitable offer, that is, the one which involves high quality, which means high quality, the lowest possible price, short times for delivery and montage, possibility of deferred payment, a longer warranty period with the manufacturer's reliability but it is not necessary to ignore other relevant facts that may have an impact on the formation of a final decision. Finally, when the final decision is made on the basis of the obtained results, it can be freely stated that the third manufacturer truly represents the most favorable solution since all the essential criteria that are mentioned above are satisfied to a great extent. Regarding the practical aspect, the contribution of this research is to the solving real-life problems by using the FUCOM-MABAC model. From the scientific aspect, the contribution of the applied model can be to the integration of the FUCOM and MABAC methods, which was first used in this paper in the literature. Future research is related to the application of the FUCOM method in combination with other methods and the taking of a larger set of relevant criteria for evaluation of a multi-criteria model.

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AN EXTENSION OF THE WASPAS METHOD FOR DECISION-MAKING PROBLEMS WITH INTUITIONISTIC FUZZY NUMBERS: A CASE OF WEBSITE EVALUATION

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Abstract: *The use of fuzzy sets in classical multiple criteria decision-making methods has led to forming fuzzy multiple criteria decision-making that has enabled solving of a significantly larger number of decision-making problems. However, the membership function introduced in the fuzzy set theory has some limitations. Unlike the fuzzy set theory, the intuitionistic fuzzy set theory introduces non-membership function. Therefore, the intuitionistic fuzzy set theory, as an extension of the fuzzy set theory, can provide for some advantages in solving complex decision-making problems. The WASPAS method is a newly-proposed, widely-used multiple criteria decision-making method for which numerous extensions have already been proposed. In order to enable the use of the WASPAS method for solving a significantly larger number of decision-making problems, a new extension based on the use of intuitionistic fuzzy numbers is proposed in this article. Compared to similar extensions, the proposed extension is based on the use of the Hamming distance for the purpose of ranking alternatives. Efficiency and usability of the proposed approach are considered on the example of website evaluation. Based on the successfully conducted numerical example of the website evaluation it can be concluded that the proposed extension of the WASPAS method based on the use of single-valued intuitionistic fuzzy sets and of the Hamming distance has proven to be very effective and applicable when it comes to website evaluation. Besides, usability of the proposed extension is demonstrated on the example of website evaluation. In doing so, the same order ranking order of the considered alternatives is obtained using the proposed ranking procedure and the procedure based on the score function, which confirms the correctness of the proposed procedure.*

Key Words: *WASPAS, Intuitionistic Fuzzy Set, Single-valued Intuitionistic Fuzzy Number, Hamming Distance, Website Evaluation*

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1. Introduction

In recent decades, the Multiple Criteria Decision Making (MCDM) has successfully been applied for the purpose of solving numerous decision-making problems. Significant progress in the MCDM was made after Zadeh (1965) had proposed his fuzzy sets theory on the basis of which Bellman and Zadeh (1970) also proposed the Fuzzy Multiple Criteria Decision Making, thus enabling the solving of many real-world problems in a much more adequate manner.

Evident progress was also made after Atanasov (1986) had proposed the Intuitionistic Fuzzy Sets (IFS) theory as an extension of the fuzzy sets theory, which additionally introduces not belonging to a given set. Up to now, the IFS has been successfully used to solve many decision-making problems such as: Szmidt and Kacprzyk (1996), Atanassov *et al.* (2002, 2017), Wei (2011), Xu (2011), Shen *et al.* (2015), Xu and Liao (2015), Oztaysi *et al.* (2017); besides, it has also got significant extensions.

Moreover, there is a number of MCDM methods adapted for the use of IFS such as TOPSIS (Tan, 2011), VIKOR (Devi, 2011).), PROMETHEE (Krishankumar *et al.* 2017), WASPAS (Zavadskas, 2014), and so on.

The weighted aggregated sum product assessment (WASPAS) method was proposed by Zavadskas *et al.* (2012) for solving different problems such as: contractor selection (Zavadskas *et al.* 2015), construction site selection (Stević *et al.* 2018; Turskis *et al.* 2015), supplier selection (Stojić *et al.* 2018; Keshavarz Ghorabaee *et al.* 2016), logistics (Sremac *et al.* 2018; Keshavarz Ghorabaee *et al.* 2017), garage location selection (Bausys, Juodagalviene, 2017), telecommunications (Mishra *et al.* 2018; Peng, Dai, 2017) manufacturing decision-making (Chakraborty, Zavadskas 2014; Jahan, 2018), personnel selection (Urosevic *et al.* 2017) and so on. Also, a systematic and comprehensive review of the application of the WASPAS method is given by Mardani *et al.* (2017).

A number of extensions of the WASPAS method have also been proposed. For example, Zavadskas *et al.* (2015a, 2015b) have proposed neutrosophic and grey extensions of the WASPAS method. Zavadskas *et al.* (2014) also proposed an extension that allows the use of interval-valued intuitionistic fuzzy numbers.

In order to enable the use of the WASPAS method for solving a significantly larger number of decision-making problems, an extension based on the use of intuitionistic fuzzy numbers is proposed in this article. Compared to similar extensions, the proposed extension is based on the use of the Hamming distance for the purpose of ranking alternatives. On the other hand, websites could have a very important role in modern companies; that is why their evaluation is chosen to demonstrate efficiency and usability of the proposed approach. Because of their growing importance, there has been an increasing attention paid to evaluation of their quality. One of the increasingly used methods for evaluating their quality is the approach based on the use of the MCDM method. Some of those approaches can be mentioned here, such as: Pamučar *et al.* (2018), Abdel-Basset *et al.* (2018), Chou *et al.* (2012), and Bilsel *et al.* (2016).

Therefore, this paper is organized as follows: In Section 2 some basic elements of the IFSs theory as well as some elements relevant to the proposed approach are discussed. In Section 3, the WASPAS method is presented and one extension adapted for use IFSs is proposed, and in Section 4, efficiency and usability of the proposed approach are considered on an example of a website evaluation problem. Finally, the conclusions are given.

2. Preliminaries

In this section some basic definitions and notations relevant for the proposed approach are discussed.

2.1 The basic concepts of intuitionistic fuzzy sets

Atanassov *Intuitionistic Fuzzy Sets*. An IFS $\tilde{A}$ in X can be defined as follows:

$$\tilde{A} = \left\{ \langle x, \mu_A(x), \nu_A(x) \rangle \middle| x \in X \right\} \tag{1}$$

where: $\mu_A(x)$ and $\nu_A(x)$ denote the degree of the membership and the degree of the non-membership of the element *x* to set *A*, respectively; $\mu_A : X \to [0,1]$ and $\nu_A : X \to [0,1]$, with the following condition

$$0 \le \mu_A(x) + \nu_A(x) \le 1. \tag{2}$$

2. 2 Intuitionistic Fuzzy Numbers

The IFSs theory proposes several shapes of Intuitionistic Fuzzy Numbers (IFNs). Triangular and trapezoidal shapes can be mentioned as significant ones.

In addition to the above mentioned shapes, the singleton (single-valued) shape can be pointed out as a characteristic one. A single-valued IFN $\tilde{A}$, $\tilde{A} = \langle a, a' \rangle$, shown in Fig. 1, is defined with membership $\mu_A(x)$ and non-membership $\nu_A(x)$ function, respectively, as follows:

$$\mu(x) = \begin{cases} 1 & x = a, \\ 0 & otherwise; \end{cases} \tag{2}$$

$$\nu(x) = \begin{cases} 1 & x = a' \\ 0 & otherwise; \end{cases} \tag{3}$$

where: parameter *a* indicates the most promising value that describes belonging to a set, parameter *a'* indicates the most promising value that describes not-belonging to a set

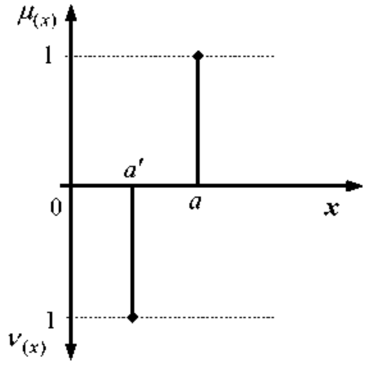

Fig. 1 A singleton IFN

Basic operations on IFNs. Let $\tilde{A} = \langle a, a' \rangle$ and $\tilde{B} = \langle b, b' \rangle$ be two IFNs. The operations of addition and multiplication on IFNs are as follows (Atanassov 1994):

$$\tilde{A} + \tilde{B} = \langle a + b - ab, a'b' \rangle \tag{4}$$

$$\tilde{A} \cdot \tilde{B} = \langle ab, a' + b' - a'b' \rangle \tag{5}$$

$$\lambda\tilde{A} = \left\langle 1 - (1-a)^{\lambda}, a'^{\lambda} \right\rangle \tag{6}$$

$$\tilde{A}^{\lambda} = \left\langle a^{\lambda}, 1 - (1-a')^{\lambda} \right\rangle \tag{7}$$

Score function of IFNs. Let be a single-valued IFN. Then, the score is as follows

$$S_{\tilde{A}} = a - a', \tag{8}$$

where $S_{\tilde{A}} \in [-1, 1]$.

The Hamming distance of IVIFNs. Let $\tilde{A} = \langle a, a' \rangle$ and $\tilde{B} = \langle b, b' \rangle$ be two IFNs. Then, the Hamming distance d_H is as follows

$$d_H(\tilde{A}, \tilde{B}) = \frac{1}{2}(|a - b| + |a' - b'|) \tag{9}$$

Intuitionistic Weighted Arithmetic Mean operator of single-valued IFNs. Let $\tilde{A}_j = \langle a_j, a'_j \rangle$ be a collection of *n* single valued IFNs. Then, the Intuitionistic Weighted Arithmetic Mean (IWAM) operator is as follows (Tikhonenko-Kędziak, Kurkowski, 2016):

$$IWAM = \left\langle 1 - \prod_{j=1}^{n}(1 - a_j)^{w_j}, \prod_{j=1}^{n}(a'_j)^{w_j} \right\rangle \tag{10}$$

where: w_j denote weight of *j*-th element of collection, $w_j \in [0,1]$ and $\sum_{j=1}^{n} w_j = 1$.

Intuitionistic Fuzzy Weighted Geometric operator of IFSs. Let $\widetilde{A}_j = \left\langle a_j, a'_j \right\rangle$ be a collection of *n* single-valued IFNs. Then, the Intuitionistic Fuzzy Weighted Geometric (IFWG) operator is as follows (Tikhonenko-Kędziak, Kurkowski, 2016):

$$IFWG = \left\langle \prod_{j=1}^{n} (a_j)^{w_j}, 1 - \prod_{j=1}^{n} (1 - a'_j)^{w_j} \right\rangle \tag{11}$$

where: w_j denote weight of *j*-th element of collection, $w_j \in [0,1]$ and $\sum_{j=1}^{n} w_j = 1$.

3. WASPAS method

The basic idea of the WASPAS method is that it integrates two well-known approaches: weighted sum (WS) and weighted product (WP). The computational procedure of the WASPAS method for a decision-making problem involving only the beneficial criteria can be presented as follows:

Step 1 Determine the optimal performance rating for each criterion as follows:

$$x_{0j} = \max_i x_{ij} \tag{12}$$

where x_{0j} denotes the optimal performance rating of *j*-th criterion, x_{ij} denotes the performance rating of *i*-th alternative in relation to the *j*-th criterion.

Step 2 Construct the normalized decision matrix, as follows:

$$r_{ij} = \frac{x_{ij}}{x_{0j}} \tag{13}$$

where r_{ij} denotes the normalized performance rating of *i*-th alternative in relation to the *j*-th criterion.

Step 3 Calculate the importance of each alternative based on WS method Q_i^{ws} as follows:

$$Q_i^{ws} = \sum_{j=1}^{n} w_j r_{ij} \tag{14}$$

Step 4 Calculate the importance of each alternative based on WP method Q_i^{wp} as follows:

$$Q_i^{wp} = \prod_{j=1}^{n} r_{ij}^{w_j} \tag{15}$$

Step 5 Calculate the overall importance of each alternative Q_i as follows:

$$Q_i = 0.5(Q_i^{ws} + Q_i^{wp}) \tag{16}$$

3.1 An extension of WASPAS method based on the application of IFN and group decision-making

One extension of the WASPAS method proposed with the aim to enable the use of IFN in a group environment is presented in this section.

At the very beginning, it can be said that normalization is not necessary in this approach. The normalization process, in MCDM methods, is used for the following reasons:

- to transform performance ratings in the interval (0,1], and
- to transform performance ratings of cost criteria into adequate beneficial criteria.

However, as has already been stated, the values of IFN already belong to [0, 1] interval, which makes no need for normalization in this extension of the WASPAS method. Therefore, the procedure of the proposed extension could be precisely presented by using the following steps:

Step 1 Form a group decision-making matrix based on individual decision-making matrices, which can be carried out using Eq. (10).

Step 2 Determine the group criteria weights. In the scientific literature, a number of methods for determining criteria weights are proposed, and each of them can be used in this approach.

Step 3 Calculate the importance based on the WS approach, for each alternative, by using Eq. (10).

Step 4 Calculate the importance based on the WP approach, for each alternative, by using Eq. (11).

Step 5 Calculate the overall importance of each alternative $\tilde{Q}_i$. In this step, $\tilde{Q}_i$ is calculated by using Eq (5). However, taking into account that the values of $\tilde{Q}_i^{ws}$ and $\tilde{Q}_i^{wp}$ are IFNs, the calculation must be carried out by using Eqs. (4) and (7).

Step 6 Rank the alternatives and select the most acceptable one. Ranking of IFNs can be done based on the value of their score functions, which is an often used approach. However, the use of the Hamming distance is recommended in this approach, where the distance of each alternate is determined in relation to the ideal point <1, 0>.

Finally, the alternative that has the least distance from the ideal point is the most acceptable one.

4. A Numerical Example

In order to provide for a detailed explanation of the proposed approach an example of websites evaluation, borrowed from Stanujkic et al. (2015), is considered. In this example, three websites are evaluated based on the following criteria:

- Environment (E),
- Content (C),
- Graphics (G), and
- Authority (A).

The ratings obtained from three respondents are shown in Tables 1, 2 and 3.

Table 1 Ratings obtained from the first of three respondents

Criteria Alternatives	En	Co	Gr	Au
A_1	<0.625,0.125>	<0.625,0.375>	<0.625,0.250>	<0.375,0.250>
A_2	<0.625,0.375>	<0.750,0.125>	<0.625,0.125>	<0.500,0.250>
A_3	<0.750,0.125>	<0.500,0.125>	<0.625,0.375>	<0.375,0.125>

Table 2 Ratings obtained from the second of three respondents

Criteria Alternatives	En	Co	Gr	Au
A_1	<0.875,0.125>	<0.625,0.375>	<0.625,0.250>	<0.375,0.250>
A_2	<0.750,0.250>	<0.750,0.250>	<0.625,0.125>	<0.500,0.250>
A_3	<0.750,0.125>	<0.500,0.125>	<0.500,0.250>	<0.375,0.125>

Table 3 Ratings obtained from the third of three respondents

Criteria Alternatives	En	Co	Gr	Au
A_1	<0.625,0.125>	<0.625,0.375>	<0.500,0.250>	<0.375,0.250>
A_2	<0.250,0.375>	<0.750,0.125>	<0.500,0.125>	<0.500,0.250>
A_3	<0.625,0.250>	<0.500,0.125>	<0.625,0.375>	<0.250,0.375>

The group ratings, determined by using Eq. (10), and criteria weights are shown in Table 4. In this calculation, the following weights were assigned to the respondents: 0.35, 0.34, 0.31. The importance of the considered alternatives based on the WS approach, calculated by using Eq. (10), are shown in Table 5. The importance of the considered alternatives based on the WP approach, calculated by using Eq. (11), are also shown in Table 5.

Table 4 Group ratings and criteria weights

Criteria	En	Co	Gr	Au
Weights Alternatives	0.28	0.25	0.24	0.23
A_1	<0.742,0.125>	<0.625,0.375>	<0.590,0.250>	<0.375,0.250>
A_2	<0.595,0.327>	<0.750,0.158>	<0.590,0.125>	<0.500,0.250>
A_3	<0.717,0.155>	<0.500,0.125>	<0.586,0.327>	<0.339,0.176>

Table 5 Overall ratings and ranking order of alternatives

	WS	WP	$\tilde{Q}_i$	H_d	Rank
A_1	<0.609,0.229>	<0.572,0.253>	<0.591,0.241>	0.325	3
A_2	<0.622,0.202>	<0.604,0.222>	<0.613,0.212>	0.300	1
A_3	<0.562,0.181>	<0.522,0.198>	<0.543,0.190>	0.323	2

The overall importance of the considered alternatives, calculated by using Eqs. (4) and (7), as well as ranking order of the considered alternatives, are also shown in Table 5.

As can be seen from Table 5, the most appropriate alternative is alternative denoted as A_2.

For the purpose of verifying the proposed approach, the result of ranking alternatives based on the use of score function is shown in Table 6.

Table 6 Values of the score function and the ranking order of alternatives

	S_i	Rank
A_1	0.190	3
A_2	0.210	1
A_3	0.190	2

As can be seen from Table 6, the results obtained by using the Hamming distance and the score function are identical, which confirms accuracy of the proposed approach.

5. Conclusions

In this article, an extension of the WASPAS method that allows the use of single-valued intuitionistic fuzzy numbers and the Hamming distance is proposed. Due to the use of intuitionistic numbers, the proposed extension allows the formation of multiple criteria decision-making models using a smaller number of criteria, which can be more appropriate in some cases.

In numerous extensions of many multiple criteria decision-making methods, the ranking of intuitionistic fuzzy numbers is mainly based on the use of the score function. Therefore, a ranking based on the Hamming distance is suggested in the proposed extension of the WASPAS method.

Usability of the proposed extension is demonstrated on an example of website evaluation. In doing so, the same order ranking order of the considered alternatives was obtained using the proposed ranking procedure and the procedure based on the score function, which confirms the correctness of the proposed procedure.

The proposed approach is based on the Intuitionistic Set theory, which is a generalization of the fuzzy logic. Therefore, there are currently no significant limitations in the application of the proposed approach. The only real limitation that is observed is the gathering of the interviewees' realistic attitudes, which can be overcome by preparing interviewees or by using interactive questionnaires. On the other hand, with the adjusted set of evaluation criteria, the proposed model can be applied to solving similar problems.

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APPLICATION OF THE ANFIS MODEL IN ROAD TRAFFIC AND TRANSPORTATION: A LITERATURE REVIEW FROM 1993 TO 2018

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Review paper

Abstract: *The paper's focus is on researching the application of the ANFIS (Adaptive Neuro Fuzzy Inference System) model in traffic and transport through a review of relevant papers. The ANFIS, as an element of artificial intelligence, is widely used in intelligent transport systems. All collected papers are divided into 7 sub-areas, namely: 1) vehicle routing, 2) traffic control at intersections with light signaling, 3) vehicle steering and control, 4) safety, 5) modeling of fuel consumption, engine performance and exhaust emissions, 6) traffic congestion prediction, and 7) other applications. For each sub-area, the analysis of the proposed models is performed with a tabular overview of respective input and output variables, while in the third section the discussion of the results is given. It is found that the steering and control of vehicles represent a sub-area with the highest percentage in the total number of examined papers, while the security applications take second place.*

Key Words: *ANFIS, Intelligent Transportation Systems, Light Signaling, Vehicle Routing, Prediction, Modeling*

1 Introduction

The development of science and technology has affected a wider study as well as application of the solutions based on artificial intelligence in various areas. Intelligent transportation systems represent a scientific and engineering discipline that implies integration of modern information and communication technologies into transport infrastructure and vehicles. Therefore, it is evident that smart solutions find their application in this field as well. Some of the most commonly used elements of artificial intelligence are fuzzy logic, artificial neural networks, and genetic algorithms. In addition, there are popular combinations of techniques such as: neuro-fuzzy systems, genetic fuzzy systems, and genetic programming neural networks (Kar et al., 2014).

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Often, though, a realistic system cannot be modeled precisely due to either insufficient or unclear information. When that happens, the solutions based on traditional computer methods do not yield satisfactory results. Therefore, an emphasis is placed on the neuro-fuzzy systems, which represent integration of fuzzy logic and artificial neural networks. Fuzzy logic is an extension of the classical logic so that the variables can have a certain degree of belonging to either true or false. The basic elements for the processing of ambiguities and uncertainty in the fuzzy logic are the fuzzy sets which are mathematically represented by the membership functions. The fuzzy technologies are human-oriented, which means they simulate the human way of thinking and conclusion-making based on the linguistic variables, which are represented by fuzzy sets that linguistic expressions are associated with. In addition to the advantages, some of which are already mentioned, the disadvantage of the fuzzy logic is the impossibility of its adaptation. This problem is solved by artificial neural networks representing models of the human brain with interconnected basic process elements - artificial neurons. The main features that distinguish them are the ability to learn from examples and adaptability, which is characteristic of man, as well as in the case of the fuzzy logic (Arora & Saini, 2014). Each neural network is defined with three properties: the type of artificial neurons, i.e. the type of their transfer function, the connection between the nodes and their structure, and the training algorithm. It can be said that the fuzzy logic and the artificial neural networks complement each other. One of the most commonly used neuro-fuzzy systems is an adaptive neuro-fuzzy inference system (ANFIS), first introduced by Jang 1993 (Jang, 1993). The problems that have led to the development of the ANFIS are the lack of a unique methodology that would transform human knowledge into the base of fuzzy rules, as well as the need for a method that will provide, for certain inputs, the minimum deviation of outputs from the expected values. The ANFIS model is trained by the input-output pairs (vectors), which adjusts the parameters of the membership functions of the input and output variables (Jang, 1996). The training algorithm is hybrid and combines the gradient descend method and the Last Square Estimation (LSE). The fuzzy inference is based on the Takagi-Sugeno system whose typical rule has the form: IF A THEN B, where A and B fuzzy sets are described by the membership functions. The ANFIS has a five-layer structure, and the network is a feed-forward type where neurons transmit their outputs to neuron inputs in the next layer and so on, without a cycle. The most important applications of the observed neuro-fuzzy model are the modeling of non-linear systems, chaotic time series prediction, and clustering.

The main objective of the survey is to review the ANFIS application in the field of road traffic and transportation, as components of the intelligent transportation systems. By searching the Web and the Google Scholar bibliographic database, the papers that deal with this topic since 1993 have been collected. All papers are divided into 7 sub-areas, namely: 1) vehicle routing, 2) traffic control at intersections with light signaling, 3) vehicle steering and control, 4) safety, 5) modeling of fuel consumption, engine performance and exhaust emissions, 6) traffic congestion, and 7) other applications.

Following the introduction, the paper is structured in three sections. The literature review deals with the analysis of papers in individual sub-areas with tabular representations of the variables of the proposed ANFIS models. The discussion is in the third section where the statistical review of the papers by the year of publication is given. On the basis of everything stated in the paper, the last section gives a conclusion.

2 Literature review

2.1 Vehicle routing

An increasing number of vehicles on roads, especially in cities, are causing great traffic jams as existing roads do not have the required capacity. In order to avoid or mitigate this problem, the choice of the optimal route of the vehicle is a very big challenge. Apart from avoiding traffic jams, the optimal route is selected on the basis of several criteria, some of which may be: travel time, distance, fuel consumption, road works, etc. It is evident that it is very difficult to find a route that meets all the requirements. Abbas et al. (2011) propose a model that represents integration of artificial neural networks, a neuro-fuzzy model, and an ant colony optimization algorithm to select the optimal route. All necessary input data are provided by the traffic control center. The proposed model is capable of dynamically adjusting the route change.

The choice of route for transport of dangerous goods in the city is a very complex task. In (Pamucar et al., 2016), a modified ANFIS model with the Dijskstra algorithm for determining the optimal route is proposed, i.e. ANFIS-D model. After training with the artificial bee colony algorithm, for the new input data, the model gives the value of the cost-risk ratio for each branch of the network individually. The role of the Dijkstra algorithm is to find a route in the network that minimizes the total value of the given ratio. The described model was tested in (Pamucar et al., 2016a) in the selection of optimal routes for the transport of oil and oil derivatives in Belgrade, Serbia.

Similarly to the described model, Pamučar & Ćirović (2018) represent the ANFIGS (*Adaptive Neuro Fuzzy Inference Guidance System*) model for choosing the route of vehicle movement under the conditions of uncertainty. In the neuro-fuzzy system the knowledge of the dispatcher is accumulated and seven criteria are defined that influence the selection of the route. The clustering technique is applied in the paper. One of the main advantages of this model is its ability to dynamically adapt to unpredictable events on the route.

In the conditions of natural disasters, it is very important to respond quickly and provide assistance to the affected areas as soon as possible. Under such conditions, the roads are often damaged but other factors that adversely affect the rapid route planning appear as well. Gharib et al. (2018) use the ANFIS in the first step of selecting a route for classification of critical areas into two clusters: 1) areas that can be assisted by road and 2) areas with an access only from the air. Table 1 shows the input and output variables for the listed ANFIS models.

Table 1 Input and output variables of the ANFIS models for vehicle routing

Author/year	Input variables	Output variables
Abbas et al. (2011)	Distance; traffic flow; environment monitoring; width; road condition; traffic lights	Pheromone level (ant colony)
Pamučar et al. (2016), Pamučar et al. (2016a)	Carrier's operating costs; emergency response; risk associated with the environment; risk of an accident; consequences of an accident; risk associated with infrastructure; risks of terror attack/hijack	Cost/risk value
Pamučar & Ćirović (2018)	Type of road surface; travel distance; travel time; route capacity; traffic capacity; road capacity; the existence of alternative roads along the length of the route	Preference of the dispatcher to select a particular route
Gharib et al. (2018)	Road slope; weather conditions; intensity of disaster; population density; road risk; distance of vehicle; distance from airport; road width	Cluster (1 or 2)

2.2 Traffic control at intersections with light signaling

The application of light signalization to control traffic at intersections is one of the most common and most effective methods. However, a great lack of this kind of regulation is that the intervals are fixed, which can often cause unnecessary delays and congestions. An intelligent solution consists in forming an adaptive model that adjusts intervals to the real state of traffic at the intersection. Such a model is presented in (Udofia et al., 2014). Its basis is the ANFIS model with two inputs. For training data, the urgency degree as an output variable is calculated analytically based on the input variables for each phase of the crossroads individually. The model uses real data collected by the sensor and gives a certain output based on them. The next green interval is assigned to the phase with the highest urgency degree. The model was tested at a real intersection and the results confirm its effectiveness. The described ANFIS model is also used in (George et al., 2015) within a system that receives incoming traffic data from the processing of video data. Lai et al. (2015) also use the same inputs, while the output variable is an extension time of the duration of the green light interval. The testing has found that the performance of the proposed model is better than that of the traditional and fuzzy controllers. The ANFIS traffic control model can also be tested using the graphical user interface in the MATLAB software package, which was done in (Abiodun et al., 2014). The model proposed in (Wannige & Sonnadara, 2008) has two inputs representing the number of vehicles entering the intersection in both directions. The model training was performed for the given input values and for calculating an optimal time of the green light interval based on them. According to Seesara & Gadit (2015), two input variables were selected based on the advice of competent institutions and traffic experts. In this paper, comparison of performance is performed between the ANFIS and the fuzzy controller with the ANFIS giving better results. Arraghi et al. (2014) observe four input variables for traffic control at the four-way intersection. In this case, the ANFIS justifies the application because it shows better testing results than fuzzy controllers and fixed-time models. Korkmaz & Akgüngör (2016) use the ANFIS to model vehicle delays at vehicle intersection, and, according to Gokdag et al. (2007), a model of the same purpose has a different set of input variables. Comparison of the prediction results with those of the usual methods, such as Webster, HCM, DDF and SSM, indicates that the ANFIS represents a very promising modeling method. Testing was carried out in the case of an intersection in Erzurum, Turkey. Similar research is also presented in (Hasiloglu et al., 2014), where comparison was done, instead of the DDF, with the Multiple Regression Analyzes method. The observed variables are the same for the two above mentioned models. Table 2 provides an overview of the input and output variables of the ANFIS models by authors.

Table 2 Input and output variables of the ANFIS model for traffic control at intersections with light signaling

Author/year	Input variables	Output variables
Udofia et al. (2014)	Waiting time; queue length	Urgency degree
George et al. (2015)	Waiting time; queue length	Urgency degree
Lai et al. (2015)	Waiting time; queue length	Extension time of the next phase
Abiodun et al. (2014)	Number of vehicles on the arrival side; number of vehicles on the queuing side	Extension time of green light
Wannige & Sonnadara (2008)	Vehicle inflow in two roads	Green light time of one lane
Seesara & Gadit (2015)	Arrival rate of the particular phase; last time vehicles that have not passed during last green phase	Green time extension
Arraghi et al. (2014)	Queue length of vehicles at each approaching link (for 4 links)	Green time for the current phase
Gokdag et al. (2007)	Time; number of approaching vehicles in the green duration; number of queuing vehicles in the red duration	Vehicle delay
Korkmaz & Akgüngör (2016)	Cycle time of signalization; green time; degree of saturation	Vehicle delay
Hasiloglu et al. (2014)	Time; number of approaching vehicles in the green duration; number of queuing vehicles in the red duration	Vehicle delay

2.3 Vehicle steering and control

A large number of controllers for control and stability in vehicles are based on neuro-fuzzy systems. Selma & Chouraqui (2012) propose ANFIS models to control vehicle paths based on previous training. Two models for positioning the X and Y axis have been developed. The model was tested by the simulation method and the results show its efficiency. According to Saifizul et al. (2006), the ANFIS model for steering has the task of keeping the lateral error and the yaw error at an acceptable level while driving. In this case, the input data are collected by means of camera on-board, which is a much simpler solution than the existing ones, which implies the installation of a magnet or wiring on the road. The ESC (Electronic Stability Control) is an unavoidable system in newer cars that significantly improves passenger safety. The ECS systems mainly use measured yaw velocity of the chassis and the sideslip angle (the angle between the directions of the vehicle's velocity and its chassis). The problem is the determination of the given angle because it is difficult to measure with the sensor. A Sideslip angle modeling involves the use of various methods, and Boada et al. (2015), propose ANFIS for this purpose. In (Boada et al., 2016), the same author uses the Kalman filter to evaluate the Sideslip angle, in combination with the ANFIS model. However, Hou et al. (2008) uses the Sideslip angle as one of the input variables in the integrated chassis control model. Model training and testing are carried out using the simulation method.

Automatic transmission control in modern vehicles is done with the computer that selects the optimal shift based on the input signals received by the sensors. However, in some driving conditions such a system is not efficient (low speed, vehicle load, etc.). A potential solution is presented in (Li et al., 2007) and is based on the ANFIS model. Perez et al. (2010) present an ANFIS model for controlling the braking and acceleration of autonomous vehicles that tend to expand in the future. The tests confirm the efficiency of the ANFIS model in determining the value of the output variables. Autonomous vehicles and the ANFIS model are also studied in (Al Mayyahi et al., 2014), where four such models are developed to avoid obstacles and reach the desired position.

When it comes to electric vehicles, using the observed neuro-fuzzy model in the regenerative braking system, it is possible to provide greater autonomy (Sindhuja et al., 2014). The system involves the use of an electric motor as a generator in braking, thus recycling the spent energy into a rechargeable battery. The ANFIS model is also applicable in the case of hybrid drives where it minimizes engine fuel consumption with internal combustion and maximizes torque (Mohebbi et al., 2005). Eski & Yıldırım (2017) describe the use of ANFIS model for the electronic regulation of throttle of heavy vehicles. Car parking is a demanding action, sometimes for experienced drivers, and if it is a truck with a trailer, the problem becomes very complex. Due to the non-linearity of the movement of such a vehicle, the observed neuro-fuzzy system was applied by Azadi et al. (2013). In the first stage of the proposed model, the vehicle in advance takes an adequate position in order to then position it back to the parking place. The use of sensors that provide environmental information is unavoidable in this case.

Several authors dealt with the use of an ANFIS suspension model to improve safety and travel comfort (Shuliakov et al., 2015; Nugroho et al., 2014;

Kothandaraman & Ponnusamy, 2012). Depending on the input data, the model is capable of adapting the characteristics of the shock absorbers and other elements that make up the mentioned system. An overview of the input and output variables of some ANFIS models with application in vehicle steering and control systems is shown in Table 3.

Table 3 Input and output variables of the ANFIS model in vehicle steering and vehicle control systems

Author/year	Input variables	Output variables
Selma & Chouraqui (2012)	X position, Y position	X position, Y position
Saifizul et al. (2006)	Lateral error; angle between longitudinal direction and local road tangent at look-ahead distance; yaw rate	Steering angle
Boada et al. (2015); Boada et al. (2016)	Lateral acceleration; yaw rate; steering angle; longitudinal velocity; yaw rate/longitudinal velocity	Sideslip angle
Hou et al. (2008)	Yaw velocity discrepancy; sideslip angle discrepancy	Brake/Throttle
Li et al. (2007)	Vehicle velocity; air damper angle	Shift point
Perez et al. (2010)	Speed error; acceleration	Brake/Throttle
Sindhuja et al. (2014)	Distribution of braking force; (front)battery's state of charge (SOC); speed of the motor	Braking force ratio
Al Mayyahi et al. (2014)	Angle difference (for the first and second controller); front, right and left distance (for for the third and fourth controller)	Right/left angular velocity
Mohebbi et al. (2005)	Desired torque; battery's state of charge (SOC)	Throttle angle of the internal combustion engine
Eski & Yıldırım, (2017)	Two different random inputs of the heavy duty vehicle speed	Servo motor speed
Azadi et al. (2013)	Tractor yaw angle; trailer yaw angle; horizontal distance from the wall	Steering angle
Shuliakov et al. (2015)	Turn rate; angular transducer output	Deviation angle of a stabilization object
Nugroho et al. (2014)	Velocity of sprung mass (car body); relative velocity between sprung mass and unsprung mass/velocity of unsprung mass (wheel); relative velocity between the sprung mass and unsprung mass	Fuzzy-skyhook force/fuzzy-ground force
Kothandaraman & Ponnusamy, (2012)	Suspension deflection; sprung mass velocity	Actuator force

2.4 Safety

Security has always been the highest priority in traffic, and today a large number of technologies (video surveillance, speed control, etc.) are present within intelligent transport systems, which have the task of raising safety to an even higher level (Rahimi, 2017). Every day, an increasing number of vehicles are in the streets and so are drivers who do not share the same experience and abilities. Statistics say that the driver's behavior is the main cause of traffic accidents. Bearing this in mind, a number of authors have paid attention to the development of various driver behavior prediction models, some of which are listed in (Kumar & Prasad, 2015).

The ANFIS application for the car following model is presented in (Poor et al., 2016; Khodayari et al., 2010). Similarly, Ghaffari et al. (2015) represent a new approach to modeling the car following when changing the lane of the leading vehicle. Such a maneuver can be viewed as a transient condition because the vehicle deviates from the conventional modeling for a certain time. The same author deals with the modeling of the overtaking path in (Ghaffari et al., 2011, 2011a), as one of the most demanding traffic operations.

Modern Collision Avoidance Systems involve the use of various sensors in order to collect the data necessary for determining the parameters. All this raises the price and complexity of such systems. Bearing this in mind, Saadeddin et al. (2013) develop a low-cost system based on a combination of the INS (*Inertial Navigation System*) data and a GPS (*Global Positioning System*) in their research. This integration is realized through the IDANFIS (Input-Delayed ANFIS). The data provided by satellite systems have been used as inputs in (Sun et al., 2017) in combination with a neuro-fuzzy model to develop a rear-end impact prevention system.

Dadula & Dadios (2016) represent an ANFIS which has the function of detecting critical events in public passenger transport based on characteristic sounds. The system can differentiate the normal circumstances from alarming (e.g. shooting) with a high percentage of accuracy.

Pedestrians are a very vulnerable group of participants in the traffic. For the sake of their protection, various mechanisms can be implemented in intelligent transport systems. One of them is modeling the pedestrian decision to cross the street with the help of artificial neural networks and the fuzzy logic, as presented in (Ottomanelli et al., 2010).

Determining critical points along the road can be of great use in preventing traffic accidents. In the case that statistical methods cannot provide reliable results, e.g. because of the lack of data, the authors use the observed neuro-fuzzy system that, based on the physical characteristics of the path and environmental factors, predicts the risk spots. Such studies are presented in (Hosseinlou & Sohrabi, 2009; Effati et al., 2014). Prediction of traffic accidents in real time using ANFIS is presented in (Liu & Chen, 2017). The authors analyze the traffic flow factors just before an accident occurs. By comparing the results with other models, it can be concluded that the ANFIS in this case also shows better performance.mTraffic sign detection is an important part of the Driver Assistance System because it allows automatic adjustment to the conditions prescribed for them. Billah et al. (2015) propose an ANFIS model for the recognition of circular signs based on the data obtained by image processing and video processing. The recognition accuracy is more than 98%, which sufficiently highlights the model's capabilities.

In order to improve the vehicle stability as well as its handling, it is important to adjust the speed to the road geometry. The model that performs this function is presented in (Wankhede et al., 2011). Its output represents a certain degree of acceleration or deceleration of the vehicle, depending on the current acceleration and winding of the road. Table 4 provides an overview of the security applications of the ANFIS model with input and output variables.

Table 4 Input and output variables of the ANFIS model in security applications

Author/year	Input variables	Output variables
Poor et al. (2016)	Distance difference (between cars); velocity difference; speed of the front car; driver reaction time	Acceleration of following vehicle
Khodayari et al. (2010)	Relative speed; relative distance; acceleration of leading vehicle	Acceleration of following vehicle
Ghaffari et al. (2015)	Distance between follower and front vehicle; relative acceleration of these two vehicles; velocity of follower; acceleration of follower	Acceleration of following vehicle
Ghaffari et al. (2011)	Lateral coordinate; longitudinal coordinate; velocity; acceleration; movement angle;	Lateral coordinate; longitudinal coordinate
Ghaffari et al. (2011a)	Velocity; acceleration; jerk; heading angle; heading angle race	Acceleration; heading angle
Saadeddin et al. (2013)	Position and velocity components (x, y, and z axis) from INS	Error in INS position and velocity
Sun et al. (2017)	Relative Distance; relative velocity; relative heading	Warning status
Dadula & Dadios (2016)	12 mel Frequency Cepstral Coefficients (MFCCs) for each audio frame	Crisis condition or normal condition
Ottomanelli et al. (2010)	Vehicle's speed; vehicle's distance; interval between vehicle arrival and pedestrian arrival at the crossing (or gap)	Decision (wait or cross)
Hosseinlou &	Topographical and geometrical	Accident frequency of the

Sohrabi (2009)	drawings of the road; amount of traffic volume per day; amount of hourly traffic volume in the day	road
Effati et al. (2014)	Roadway geometry; environmental factors	Danger value
Liu & Chen (2017)	Average speed; volume; occupancy in 30-second aggregation intervals (9 traffic flow variables)	Crash risk value
Billah et al. (2015)	Total black pixel; entropy; contrast; correlation; energy; homogeneity	Label which means a specific sign
Wankhede et al. (2011)	Angle curvature; acceleration	Acceleration

2.5 Modeling of fuel consumption, engine performance and exhaust emissions

Fuel consumption in the world is growing rapidly every day, while, at the same time, the world reserves are decreasing. In addition to the problem of energy shortages, the problem of increasing pollution is present, that is, the problem of harmful substances emissions into the atmosphere. Traffic and transport activities constitute a very large share of the total fuel consumption, and therefore, studies have focused on optimization. To do this, it is necessary to develop models for the consumption prediction. The model presented in (Massoud et al., 2014) takes into account the interaction of transport and land use in urban areas so that the planners can efficiently analyze and plan fuel consumption. When it comes to passenger cars, the ANFIS prediction model is proposed in (Syahputra, 2016; Atmaca et al., 2001). According to Abdallat et al. (2011), using the given model, it is possible to estimate the need for the amount of fuel for the transportation of the whole country. In the concrete case, the research was carried out for Jordan.

Diesel fuel is mostly used for trucks, and in order to reduce CO_2 emissions, the use of alternative fuels, such as biodiesel, is increasingly considered. Many studies deal with analyzing the effects of the addition of diesel fuel. The authors propose ANFIS models that have the task of predicting engine performance and concentration of harmful substances of exhaust gases when using such mixtures (Hosoz et al., 2013; Özkan et al., 2015; Ghanbari et al., 2015; Rai et al., 2015). Table 5 provides an overview of the ANFIS model with application in modeling fuel consumption, engine performance and exhaust emissions.

Table 5 Input and output ANFIS variables for modeling fuel consumption, engine performance and exhaust emissions

Author/year	Input variables	Output variables
Massoud et al. (2014)	Land use; transportation	Energy consumption
Syahputra (2016)	Car weight; year	Miles per gallon
Atmaca et al. (2001)	Car weight; year	Miles per gallon
Hosoz et al. (2013)	Biodiesel content in the fuel; engine speed; engine load	Brake power; brake specific fuel consumption; brake thermal efficiency; emissions of HC, CO, NO; exhaust gas temperature
Özkan et al. (2015)	Types of engine fuels; injection pressure; speed	Torque; specific fuel consumption; air consumption; efficiency; lambda values
Ghanbari et al. (2015)	Diesel–biodiesel and nano particles blends; speed	Engine power; torque; brake specific fuel consumption; emission components
Rai et al. (2015)	Percentage load; percentage liquefied petroleum gas; injection timing	Brake specific energy consumption; brake thermal efficiency; exhaust gas temperature; smoke
Abdallat et al. (2011)	Annual number of vehicles; vehicle owner level; income level; fuel prices	Energy consumption (in tons of oil)

2.6 Traffic congestion prediction

Traffic congestion is a part of everyday life in big cities, which has a negative impact on life quality because of considerable time spent. In addition to time expenditure, it is necessary to consider higher fuel consumption, which means more air pollution. Due to a number of problems caused by traffic jams, intelligent transportation systems should provide mechanisms to anticipate and avoid them (Joshi & Hadi, 2015). Zaki et al. (2016) present a framework for short-term prediction, where, apart from the ANFIS, a model based on the Hidden Markov Models is being developed. The same variables are taken into account by Shancar et al. (2012) in their model. Kukadapwar & Parbat (2015) represent an ANFIS model that uses real-time traffic data for the prediction of jams in Nagpur city, India. An overview of these models is given in Table 6.

Table 6 Input and output variables of the ANFIS model for predicting traffic congestion

Author/year	Input variables	Output variables
Zaki et al. (2016)	Speed; density	Level of congestion
Kukadapwar & Parbat (2015)	Speed reduction rate; proportion of time traveling at very low speed (below 5 kmph) compared with total travel time; traffic volume to roadway capacity ratio	Congestion index
Shankar et al. (2012)	Speed; density	Level of congestion

2.7 Other applications

For the purpose of surveillance, future planning and efficient management of the transportation system of a country, it is necessary to have accurate data on the classes and number of vehicles. Intelligent transportation systems include various technologies, and the observed neuro-fuzzy vehicle classification system is proposed in (Maurya & Patel, 2015). The authors take into account the physical dimensions of the vehicle, such as the wheelbase and the average distance of the wheels on the same track.

Vehicle activated signs to warn drivers of over speeds are a very useful mechanism for intelligent transportation systems. However, if the threshold of speed is adapted to the conditions and dynamics of traffic, the benefits become even greater (Jomaa et al., 2015).

The prediction of travel time can be realized mostly on the basis of statistics or artificial neural networks. Statistical solutions often do not yield satisfactory results due to the non-linear nature of the dependencies of the observed variables. Therefore, the application of neural networks, more precisely the ANFIS model is more appropriate in this case (Maghsoudi & Moshiri, 2017).

Thipparat & Thaseepetch (2012) propose an ANFIS model for predicting the possibility of sustainability of the highway construction. At the design and planning stage, expert knowledge is collected in order to evaluate some of the influential factors and, based on this, deduce the conclusion on sustainability.

The selection of an optimal vehicle for transportation in the Serbian army based on a given neuro-fuzzy model was presented in (Pamučar et al., 2013). The model is capable of simulating the decision-making process, as do logistics officers.

In (Ghaffari et al., 2012), the subject of research is a prediction of the future status of the vehicle with the Stop&Go system. The developed model can reduce the likelihood of impact on the rear of the vehicle, and in addition, improve the comfort experience during city driving.

Since traffic is an important source of noise, Sharma et al. (2014) present an ANFIS model for predicting the value of the mentioned variable. Vehicle speeds, traffic flows and the use of siren can be listed as the main influencing factors. Table 7 provides an overview of the ANFIS model with applications in intelligent transportation systems.

Table 7. Input and output variables of the ANFIS model for various applications in intelligent transportation systems

Author/year	Input variables	Output variables
Maurya & Patel (2015)	Wheelbase; average track	Light commercial vehicle/ car-jeep-van/two axle trucks-bus/three axle truck/ multi axle trucks
Jomaa et al. (2015)	Time of day; traffic flow; standard deviation of mean vehicle speeds	85^{th} percentile speed for each hour on the day
Maghsoudi & Moshiri (2017)	Vehicle speed; road occupation coefficient; traffic flow	Travel time
Thipparat & Thaseepetch (2012)	Geometrics and alignments; earthworks; pavement; drainage; retaining walls; slope protection; landscape and ecology… (14 groups, 60 variables)	Sustainability level of highway design
Pamučar et al. (2013)	Reliability of the means of transport; mobility of the means of transport in field conditions; exploitation of the cubage of transport; cost of tonal kilometer	Preferential dispatcher
Ghaffari et al. (2012)	Relative speed; relative distance; acceleration of follower vehicle; velocity of follower vehicle	Acceleration of follower vehicle in next steps
Sharma et al. (2014)	Road traffic flow; vehicle speed; honking	Traffic noise

3 Discussion

The adaptive neuro-fuzzy inference system provides wide application in road traffic and transportation. In this review, 62 papers were collected for a period of 25 years of its study. Fig. 1 shows the number of papers published per year. It can be concluded that the application of the ANFIS in the observed area was not the subject of research until 2001, followed by a break until 2005. Since then, the number of papers per year has grown exponentially in order to record the highest value in 2015. Nevertheless, in the last few years, there has been a clear decrease in interest in studying the given topic.

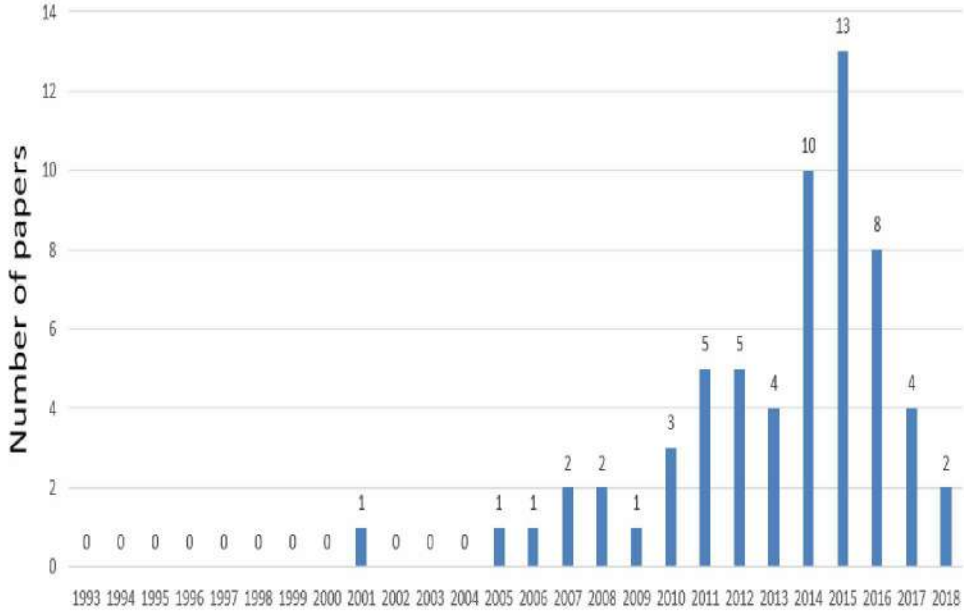

Fig. 1 Number of papers per years

The collected papers are divided into 7 sub-areas, as already discussed in Section 2. Fig. 2 shows percentage share of the papers from each sub-area in the total number. It is obvious that the vehicle steering and control make up the largest percentage, 24%, and the safety is immediately behind with 23%.

Ultimately, the ANFIS application in the area of vehicle steering and control, in addition to driving comfort, aims at increasing passenger safety. The smallest number of authors dealt with predicting traffic congestion with the help of the observed neuro-fuzzy model.

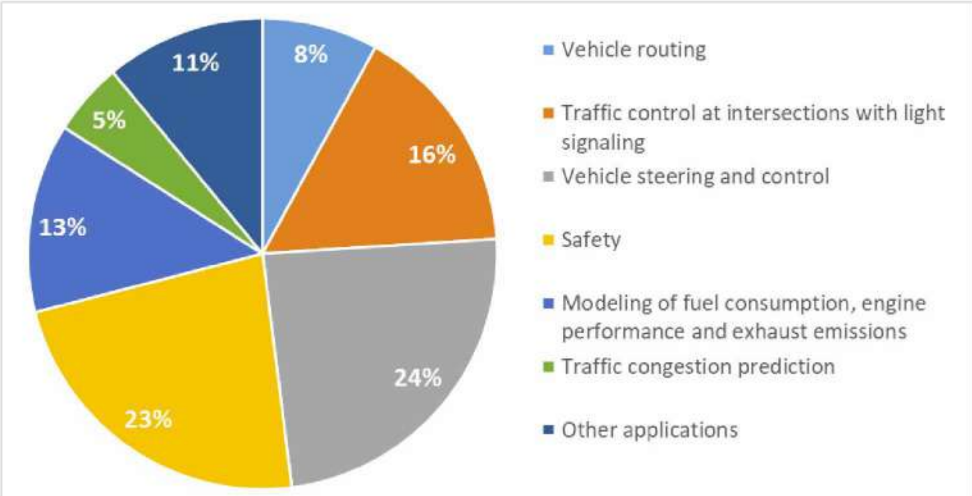

Fig. 2 Participation of individual sub-areas in the total number of collected papers

Table 8 gives an overview of the number of papers by individual areas and by year of publication, with the years with no posts left in Table. If observed in 2015, the greatest number of papers is published from the sub-area of traffic control at intersections with light signaling and modeling of fuel consumption, engine performance and exhaust emissions. The second year in terms of the number of published papers is 2014 where the largest number of papers is from the sub-area of traffic control at intersections with light signaling.

Table 8 *Number of papers by sub-areas and year of publication*

Year	VR	TC	SC	S	MF	CP	OA
2001					1		
2005			1				
2006			1				
2007		1	1				
2008		1	1				
2009				1			
2010			1	2			
2011	1			3	1		
2012			2			1	2
2013			1	1	1		1
2014		4	3	1	1		1
2015		3	2	2	3	1	2
2016	2	1	1	2	1	1	
2017			1	2			1
2018	2						

* VR – vehicle routing; TC – traffic control at intersections with light signaling; SC – vehicle steering and control; S – safety; MF – modeling of fuel consumption, engine performance and exhaust emissions; CP – traffic congestion prediction; OA – other applications

The total number of the sources dealing with the topic 60, comprising 41 journals and 19 conferences. When it comes to the number of papers published by a single source, only two magazines have two published papers, namely,

- Mechanical Systems and Signal Processing, and
- International Journal of Scientific and Engineering Research.

Depending on the purpose of the ANFIS model itself, authors use different input and output variables, but in a single sub-area, there are many cases in which they have opted for the same. The sets of values of the observed variables are obtained mainly in two ways, which are measurements and simulation methods in one of the softwares. Also, model testing and validation are in many cases performed in a simulation environment. For the functioning of ANFIS in real systems, such as road vehicles and generally intelligent transportation systems, sensors play a key role in providing input data. Model outputs are forwarded as information to the user or used as an input of an actuator or a separate system that needs to perform a particular action.

The basic limitation of this paper is the possibility of not including or failing to find all the referential papers from the observed area. In addition, papers in non-English languages are not taken into consideration.

Conclusions

The paper analyzes the application of the ANFIS model in the field of road traffic and transportation. It presents an overview of the papers, while the proposed models for specific purposes are theoretically analyzed with the results tabulated and graphically presented. It can be concluded that the use of ANFIS in traffic is largely due to its ability to model non-linear systems ans well as its ability of adaptability (learning from examples). A key step in developing the ANFIS model is the correct choice of input variables depending on the desired output. In addition, in order for the model to be trained, it is necessary to collect adequate data. The results of the testing of the observed model show its superiority in comparison to the classical, previously used models. Some authors combine the ANFIS with other techniques; hence, such modified models as ANFIS-D and ANFIGS. Given that the field of intelligent transport systems develops every day, new opportunities for potential applications of ANFIS are being created. Sensors for data acquisition have a very important role as the goal is to provide accurate inputs to the model. Future research could aim at analyzing the ANFIS model application to other modes of transport.

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A FUZZY MODEL FOR DETERMINING THE JUSTIFIABILITY OF INVESTING IN A ROAD FREIGHT VEHICLE FLEET

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Abstract: *A road freight vehicle fleet represents the basic means of work of a transport company which makes it the most important element of its business activities. Namely, it has a direct influence on the transport company's volume of income as well as costs of its business operations. The correct sizing and the management of the road freight vehicle fleet are both of essential significance for cost-effectiveness of the company and satisfaction of transporting demands. Both the defining of the road freight vehicle fleet and the selection of the vehicles that it will comprise are a complex problem, which should be approached from several aspects. In the paper, a fuzzy model for determining the justifiability of investing in the renewal of a truck road freight vehicle fleet is presented and so is assessment of the time period needed for the return on such investment. The forecasts of the expected volume of transport, i.e. income from transport, have been made on the routes with constant flows of freight for realistic, pessimistic and optimistic variants for the recommended period of the vehicle's exploitation.*

Key Words: *Fuzzy Logic, Road Freight Transport, Vehicle Fleet, Fleet Sizing, Investments*

1 Introduction

A successful transport company is recognized by constant monitoring, planning and management of its road freight vehicle fleet. The road freight vehicle fleet planning is a complex process, which directly influences efficiency and effectiveness of both freight transport, and, at the same time, its economy. On the one hand, an insufficient and inadequate road freight vehicle fleet may influence the choice of another form of traffic or, ultimately, inefficiency of the economy. On the other hand, an excessive and improperly structured road freight vehicle fleet has an influence on efficiency and effectiveness of the transport company (a loss of transport and income, costs of "tied up" capital, costs of maintenance, etc.).

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In other words, the sizing of the road freight vehicle fleet and the selection of the vehicles that it will comprise are a complex problem that should be approached from several aspects.

The road freight vehicle fleet of the road transport means consists of road and trailers, whose exploitation-technical characteristics are different and the technical conditions unequal. The exploitation-technical characteristics imply the overall dimensions of a vehicle – its length, width and height; the distance between the pivots (wheelbase), the distance between the wheels, the length of the front and rear overhangs, the semi-diameters of longitudinal and transverse maneuvering capability, the turning radius, the dynamic characteristics of a vehicle, the empty vehicle mass, the engine efficiency, a suitability for technical maintenance, the vehicle's capacity – the useful cargo load capacity, the specific area and volume capacity in t/m2, and so on.

If the road freight vehicle fleet consists of the vehicles of the same brand and type, then it is regarded as homogenous. Yet, the structure of the road freight vehicle fleet is, as a rule, rarely homogenous, which causes the need for its homogenization to the greatest possible extent. This step facilitates, to a great extent, the purchase of spare parts, while, at the same time, lowering the vehicles" maintenance costs.

The assets of the road freight vehicle fleet have a greater value and account for the biggest portion of the capital of a transport company. Accordingly, when the vehicles are not used, or when they are used in an inappropriate manner, they may be implicative of an unrealized profit and high opportunity costs.

In the case of investing in a road freight vehicle fleet, the purchase of newer vehicles, or brand new vehicles, which are going to replace the existing ones in the company, is what we primarily have in mind. The selection of the vehicles which are being invested in, as well as the type, or the price of new vehicles, directly dictate the amount of the investment, and pursuant to that – the repayment period, i.e. the period of return on investment.

In the literature, there are a significant number of the papers dealing with fleet sizing. One of the first papers concerning the sizing of the fleet but in the maritime sector is published by Dantzig & Fulkerson (1954). They presented the problem of determining the minimum number of tankers to carry out the timetable, while Kirby (1959) made one of the first attempts concerning optimization of the fleet of the railways. He dealt with the problem of increasing the degree of utilization of wagons owned by the small rail system and of reducing the level of rental cars by determining the relative cost of the system's own and leased cars per day.

Etezadi & Beasley (1983) studied the problem of determining the fleet's optimal structure and size. Assuming that the decisions made concerning the given task are long-term ones, they presented a model that is based on integer linear programming. In the same paper, the authors suggested that the problem may more accurately be solved by using simulation. Bojovic (2002) addressed the problem of optimizing the size of the fleet through meeting demand and minimizing the total cost. Lima et al. (2004) described a mathematical algorithm for problem-solving. This algorithm is a hybrid of genetic algorithm and local search based on GENIUS algorithm. Wu et al. (2005) addressed the problem of the dimensioning fleet in road traffic. Operational and tactical decisions for heterogeneous fleet were explicitly designed by the model of linear programming in order to determine the optimal size and mix of the fleet. Demand is assumed as known, while travel time is a stochastic parameter. Choi & Tcha (2007) presented an approach based on generating columns for problem resolution. The authors proposed an integer programming model whose LP relaxation is dealt with by the method of generating columns.

Models of optimization based on the behavior of swarms (colonies) "swarm intelligence" are partly inspired by the behavior of ants and bees in nature (Teodorovic, 2008). They solve the problems of combinatorial organization. It is a problem that occurs in the dimensioning of capacity of railway transport.

Bojovic et al. (2010) worked out the problem of determining the optimal composition of the freight wagon fleet. The problem is divided into two parts, namely, into determination of an optimal mix and that of an optimal size of the freight wagon fleet.

Sayarshad et al. (2010) proposed formulation and procedure for solving optimization size of the freight wagon fleet and allocation of wagons for the case of stochastic demand. The authors proposed a two-phase procedure based on the algorithm of simulated problem solving.

Loxston et al. (2012) considered the problem of forming a heterogeneous fleet with the presence of stochastic demand. The problem is based on determining the number of vehicles to be purchased for each type of vehicle specifically so that the total expected cost of the fleet would be set to minimum. These authors developed an algorithm that combines the dynamic programming method and the golden section to resolve the problem.

Milenković and Bojović (2013) proposed a fuzzy random model for the rail freight road freight vehicle fleet sizing problem. The problem is formulated as that of finding an optimal fuzzy regulator for a fuzzy linear system with a fuzzy quadratic performance index and fuzzy random initial conditions.

For a fleet size with environmental aspects, Sawik et al. (2017) used multi-criteria optimization.

Costa-Salas et al. (2017) presented the fleet size optimization in the discarded tire collection process.

In their study, Valmikia et al. (2018) presented a simulation model for the evaluation of an AGV fleet size in a flexible manufacturing system.

Telleza et al. (2018) introduced the fleet size and the mix dial-a-ride problem with multiple passenger types and a heterogeneous fleet of reconfigurable vehicles.

In the foregoing papers, different fleet-sizing aspects are observed. The basic goal of this paper is the development of the model that will give answers to the following questions:

1. When should vehicles be bought?
2. How many vehicles should be bought for the observed period?
3. What is the value of investment per single vehicle? and so on.

The model should be able to include more factors, commonly with different sizes and values. Avoiding mixing of different sizes and values or linguistic variables as the most appropriate method that can measure and compare differences represents the method of artificial intelligence - "Fuzzy logics" (fuzzy logic). This method allows measuring, comparing and synthesizing different variables that are hard to be quantified to carry more qualitative features, as well as simplifying the uncertainty regarding the input data and parameters regarding uncertainty, subjectivity, inaccuracy and ambiguity.

2 The Prognostic Model of the Volume of Business Operations

In this paper, our observation focuses on the “M” Company, which realizes its most significant transport services through five different activities with approximately constant cargo flows at the level of the whole of the fiscal year. In those activities, the three scenarios of business operations are forecast, namely pessimistic, optimistic and real scenarios. Each combination is attributed a certain financial value for each of the next 10 fiscal years, which is the length of the exploitation period.

The prognostic model provides input data for the development of the fuzzy model. The growth rate method is used for the prognostic model. In order to define the growth rate according to different forecast scenarios, eight experts did the surveying. By applying the Delphi method, the sublimation of their answers regarding the expected growth rate is performed (Table 1).

Table 1 The growth rates for different forecasts as per each year in the next 10 years of the exploitation period

Years of exploit. period	Growth rate prognosis					
	Pessimistic		Real		Optimistic	
	relative	cumulative	relative	cumulative	relative	cumulative
1	0%	0%	1%	1%	2%	2%
2	0%	0%	1%	2%	2%	4%
3	0%	0%	1%	3%	2%	6%
4	0%	0%	1%	4%	2%	8,2%
5	0%	0%	1%	5,1%	2%	10,4%
6	-1%	-1%	3%	8.2%	5%	15,9%
7	-2%	-3%-	3%	11,3%	6%	22.8%
8	-3%	-6%	3%	14,6	7%	31,4%
9	-4%	-10,3%	3%	18%	9%	43.2%
10	-5%	-15,8%	3%	21,5%	10%	57,5%

3 The Development of a Fuzzy Model for Determining the Justifiability of Investing in a Road Freight Vehicle Fleet

3.1 Fuzzy sets and fuzzy logic

Fuzzy sets are sets whose elements have degrees of membership. In the classical set theory, the membership of elements in a set is assessed in binary terms according to a bivalent condition - an element either belongs or does not belong to the set. By contrast, the fuzzy set theory permits the gradual assessment of the membership of elements in a set; this is described with the aid of a membership function valued in the real unit interval [0,1].

Fuzzy logic is the base of fuzzy system. It enables making decisions based on incomplete information, while the models based on fuzzy logic consist of the so-called "if-then" rules. "If-then" rules are interconnected with "else" or "and".

Fuzzy logic is defined using algorithms for approximate reasoning. When we assume that $x = [x_1, x_2, \ldots, x_n]$ is a vector of features describing any object or state and $y = [y_1, y_2, \ldots, y_m]$ is the vector of output values of a system, the rules are represented in the form, See Eq. (1).

$$\begin{aligned} &R^r : IF\ x_1\ is\ A_1^r\ AND\ x_2\ is\ A_2^r\ AND \ldots AND\ x_n\ is\ A_n^r \\ &THEN\ y_1\ is\ B_1^r, y_2\ is\ B_2^r, \ldots, y_m\ is\ B_m^r \end{aligned} \tag{1}$$

where $x \in X = X_1 \times X_2 \times \cdots \times X_n$, $y \in Y = Y_1 \times Y_2 \times \cdots \times Y_m$ and

$A^r = A_1^r \times A_2^r \times \cdots \times A_n^r \subseteq X$, $B^r = B_1^r \times B_2^r \times \cdots \times B_n^r \subseteq Y$ are the fuzzy sets.

The special significance of fuzzy logic is in the possibility of its application for modeling complex systems in which it is very difficult to determine the correlation of certain variables that exist in the model. Possible and logical rules are with weight 1, less possible 0.5.

The fuzzy rules are a manner of processing the numerical or information data obtained from the input interface. In the fuzzy model scheme, the rules are contained in the "processing" segment. Therefore, by means of the fuzzy rules, certain combinations of fuzzy numbers that will later be interpreted in the form of results, or fuzzy conclusions, are singled out.

There are several different forms of the fuzzy model use, whereas the model using numeric results, besides generating numeric results in the form of fuzzy sets, is the most important for this research study.

The characteristics of this type of the fuzzy model are as follows:

- the model reflects a broad modeling spectrum,
- numeric data are used and numeric results are generated, and,
- after its development, the model is applied for purely numeric purposes, while simultaneously accepting numbers and using them to obtain numbers in the form of a nonlinear input/output mirroring.

The scheme of this model is shown in Fig. 1 and consists of: the input interface, the processing module, and the output interface. The input interface stands for a fuzzy set, whereas the output interface is a set of outcomes, i.e. conclusions (Pedrycz & Gomide, 2007).

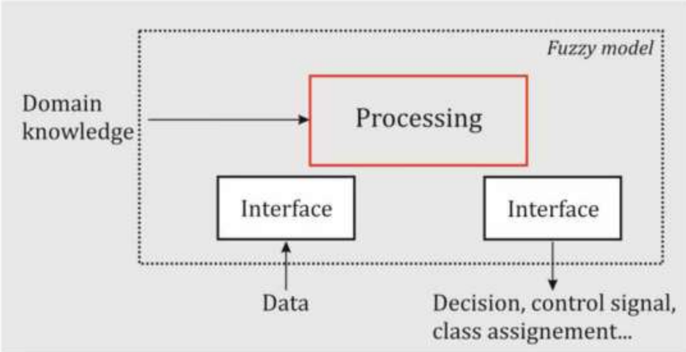

Fig. 1 General architecture of fuzzy model (Pedrycz & Gomide, 2007)

Fuzzy numbers, or the fuzzy sets consisting of such fuzzy numbers, represent the numeric data that create an input to the fuzzy model. So, the input interface uses fuzzy numbers or fuzzy sets, depending on how they are organized, and after processing data in the model, it comes to output data, i.e. conclusions.

3.2 The Idealized Fuzzy Tree Representing the Basis of the Fuzzy Investment Model

The fuzzy model type used in this paper is based on the fuzzy tree rule (Fig. 2).

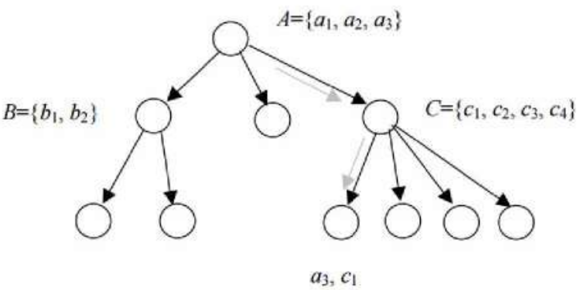

Fig. 2 Simple fuzzy tree (Pedrycz & Gomide, 2007)

This fuzzy tree contains three fuzzy sets: A, B, and C, which are differently organized and generate results, i.e. conclusions, by performing a defined algorithm. It is clear that B and C elements cannot intersect, and that only two elements from fuzzy sets, i.e. A and B elements, as well as A and C elements, can intersect.

3.3 The Input and Output Data of the Model

The input data in this model are financial parameters. They are presented in the form of the company's income from business operations.

Table 2 accounts for the income as per activities obtained with cargo permanent flows. They represent the input data for the development of the model. In the observed example of the "M" Company, as already mentioned, income with constant income is realized on five relations, i.e. five activities (Business).

Table 2 The total forecast (discounted) income of the company according to the pessimistic, real and optimistic forecasts for the period of 10 years

Business	Forecast income - P [10^3 €/10 god]		
	Pessimistic	Real	Optimistic
Business 1	1458.33	4416.67	5833.33
Business 2	437.50	1271.67	1675.00
Business 3	187.50	530.00	700.00
Business 4	46.67	141.67	186.67
Business 5	163.33	495.00	653.33
Total	2293.33	6855.00	9048.33

The input data are divided into fuzzy elements and fuzzy sets.

The fuzzy elements are grouped into fuzzy sets and are marked by colored circles, and represent the total financial income from one activity in a single year on the observed relation with constant income. It may have three forms, depending on the forecast: the red – pessimistic ($A_1, A_2,...,A_5$), the yellow – real ($B_1, B_2,...,B_5$), and the green – optimistic ($C_1, C_2,...,C_5$). By combining these elements, of which five combinations with different indices are chosen, a model for the assessment of the company's income is generated, while, at the same time, the model can be formed for each year, even on a quarterly basis, all depending on the needs of the company's management (Fig. 3).

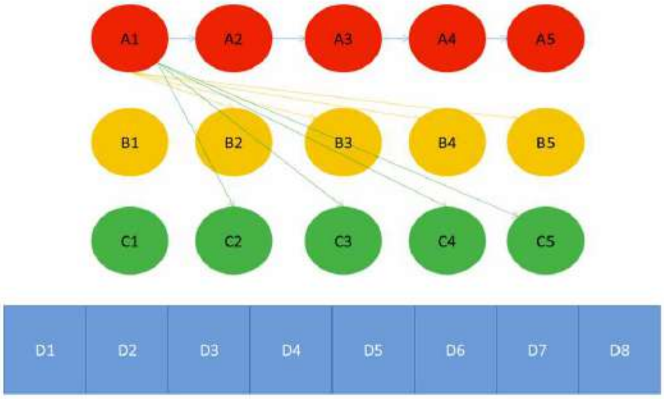

Fig. 3 Fuzzy tree used as the basis for model formation

Fig. 3 shows an idealized fuzzy tree generated based on the assumption that the maximum of eight vehicles are to be bought, according to the three possible prognostic scenarios for each activity with approximately constant commodity flows.

The output data are given in the D fuzzy set. The D fuzzy set will refer to the set of the conclusions, i.e. how many cargo vehicles, and of which type, to buy. In the model, eight groups are created: D_1, D_2,...,D_8. For example, the set marked as D_1 represents a decision to buy only one vehicle. This is important in the case the model is observed on a temporal basis, i.e. if we are interested in the number of the vehicles we will be able to pay off in a particular year. So, for example, at the end of the third year, it is necessary to determine the potentially available amount of income to be invested. Each of these groups will receive one combination generated from the three conditions, which means that the number of the vehicles to be bought annually will depend on the future business operations. In this manner, we are enabled to gradually observe investments in the model, from one year to another, depending on income.

Depending on the desired degree of the model's sophistication, every such tree can represent one business year, while the investment potential of each business year, i.e. the degree of return on investment, could simultaneously be determined.

The "M" Company's current road freight vehicle fleet consists of the vehicles older than 10 years; hence, all the vehicles should be replaced with newer ones (second-hand or new vehicles).

4 The Fuzzy Model Testing and the Results Analysis

While testing the fuzzy model, the fuzzy sets are formed with the forecast income, from which conclusions are derived. The fuzzy sets, i.e. the pessimistic, real and optimistic assessments of business operations will be the conditions, and investment in certain vehicles will be the conclusions. In other words, the three sets of conditions will be formed with one of them derived as the set of conclusions.

The basic assumption used in the paper is that the period of return on investment can be observed as the ratio between the *costs and income of the annual forecast in any observed year or period*. At the same time, taking into consideration the prescribed amortization rate for transport means in road traffic and the exploitation period, it is determined that 9.8% of income needs to be designated for the amortization of vehicles ($p_a=9.8\%$).

For the sake of the unification of the "M" Company's road freight vehicle fleet, experience, need and ecological parameters, the MAN TGX vehicle model is selected. In order to purchase one new vehicle, an investment of and exceeding EUR105000 needs to be earmarked, depending on the vehicle equipment.

As the forecast volumes of the scope of transport of the "M" Company required a larger number of vehicles in the road freight vehicle fleet, also taking into consideration the age of the existing vehicles, a possibility of purchasing second-hand vehicles of the MAN TGX brand, whose residual exploitation cycle can be fitted into the observed one, was the subject matter of consideration. The average purchase price of one such vehicle is EUR18480. The potential investment groups are formed in Table 4.

Table 4 Investment groups of the MAN TGX vehicle, depending on the number of the vehicles to be bought

	Investment group – Number of the vehicles to be purchased (10^3 €)							
	1	2	3	4	5	6	7	8
Value of investment (*I*)	**39.1**	**78.2**	**108.3**	**144.3**	**180.3**	**218.3**	**254.0**	**292.0**

There are several combinations related to the possible variants of business operations in the future, namely only for business operations on the five relations with constant flows. In the paper, only several such combinations are presented.

Based on the input parameters, the fuzzy model schematically shown in Fig. 4 is formed. As can be seen in Fig. 4, the fuzzy numbers are organized in the three fuzzy sets, whereas the fuzzy rules are organized within the processing segment. One of the rules reads as follows:

"If the sum of any five fuzzy numbers is equal to or greater than 254 $\cdot 10^3$ € , and less than 292 $\cdot 10^3$ €, i.e. if the forecasts indicate that the enterprise's income in the year to come will be within the alleged range, then the D_7 Option, namely the purchase of seven vehicles, will be opted for."

In this case, the income (P_i) according to the realistic scenario can be generated from Equation (2).

$$IF\ x_1\ is\ B_1\ AND\ x_2\ is\ B_2\ AND \ldots AND\ x_5\ is\ B_5,$$
$$THEN\left(\begin{array}{l} P_1^r = B_1 + B_2 + B_3 + B_4 + B_5 = 4416.67 + 1271.67 + \\ 530.00 + 141.67 + 495.00 = 6855.00 \cdot 10^3\ € \end{array}\right) \tag{2}$$

where x_i is the expected income according to the forecast B_i for $i=1, 2, 3, 4$ and 5 for the observed case of the realistic scenario (Table 2).

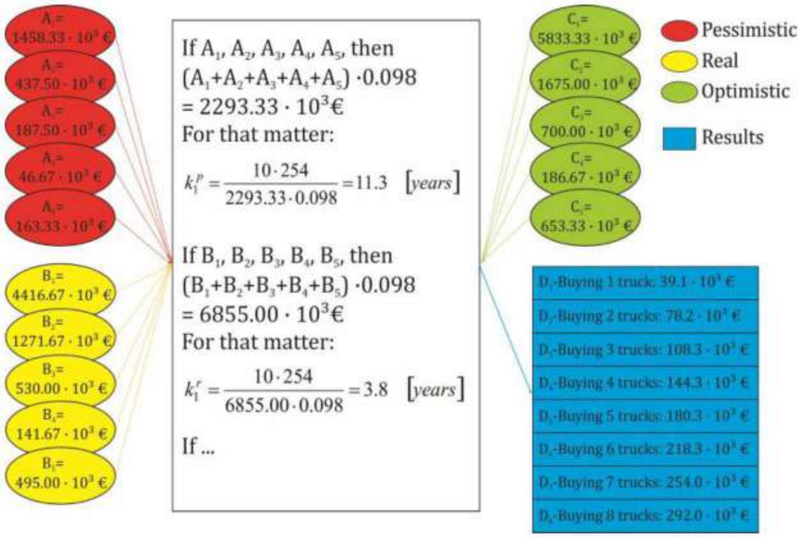

Fig. 4 Illustration of the investment fuzzy model

The total expected income from all business activities according to the realistic forecast amounts to 6855.00·10³ €. According to the assumption about the proportionality of income and the costs of investment that was mentioned earlier, the investment repayment period (k) for the observed exploitation period (n) in the case of the seven vehicles (D_1 variant) can be obtained by applying the following equation:

$$k_1^r = \frac{n \cdot I}{P_1^r \cdot p_a} = \frac{10 \cdot 39.1}{6855.00 \cdot 0.098} = 0.6 \qquad [years] \tag{3}$$

If all incomes of all businesses would be realized according to the real scenario, then the expected period for repayment of the investment for the D_8 variant is:

$$k_8^r = \frac{n \cdot I}{P_1^r \cdot p_a} = \frac{10 \cdot 292}{6855.00 \cdot 0.098} = 4.4 \qquad [years] \tag{4}$$

Analyzing all possible cases of realization of the relay scenario, it is possible to get periods of vehicle repayment for the cases of realization of variant D_i for *i = 1, 2, 3, ..., 7.* The test results are shown in Fig. 5.

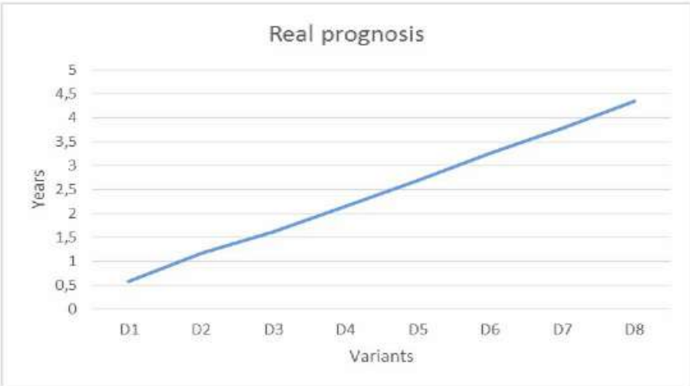

Fig. 5 *Investment repayment period according to the forecast realistic scenario*

As can be seen in Fig. 5, the model shows that the company "M" can obtain and replace all (eight) second-hand vehicles of the existing fleet in the first year of observation because the ratio of revenues and expenses is favorable and allows the return of invested funds within a reasonable period. This indicates that in the observation period, the company can once again renew the fleet with second-hand vehicles. Practical experience also points to such a conclusion. Depending on the condition of the used vehicle and the planned volume of exploitation, the remaining period of exploitation is usually up to 5 years. The model can also be tested for different exploitation periods, different allocations from company income for investment repayment (e.g. by reducing the other costs of business operations in favor of greater amounts for repayment), as well as for the cases of the purchase of only new vehicles (the values in Table 4 change).

When it comes to purchasing of new vehicles, whose value is estimated at 120·10³ €, for the period of observation (fifteen years), only three new vehicles can be purchased, if the procurement is carried out in the first year, see Eq. 5.

$$k_{new}^{r} = \frac{n \cdot I}{P_1^r \cdot p_a} = \frac{15 \cdot 3 \cdot 120}{6855.00 \cdot 0.098} = 8 \qquad [years] \tag{5}$$

If the expected period of exploitation will decrease to 10 years then only two new vehicles can be repaid, under condition to be purchased in the first year of observation.

4 Sensitivity Analysis

During the model's testing, the questions to arise are always the following: what happens with the results if the expected revenues will not be realized in the observed period, if operating costs will be higher than expected, if the market conditions will change... Therefore, the model is tested in the cases of realization of pessimistic and optimistic scenarios. According to the pessimistic scenario incomes (P_i) of all businesses can be obtained from the formula (6).

$$IF\ x_1\ is\ A_1\ AND\ x_2\ is\ A_2\ AND \ldots AND\ x_5\ is\ A_5,$$
$$THEN \begin{pmatrix} P_1^p = A_1 + A_2 + A_3 + A_4 + A_5 = 1458.33 + 437.50 + \\ 187.50 + 46.67 + 163.33 = 2293.33 \cdot 10^3\ € \end{pmatrix} \tag{6}$$

where x_i is the expected income according to the forecast A_i for $i=1, 2, 3, 4$ and 5 for the observed case of the pessimistic scenario (Table 2).

According to the optimistic scenario, incomes of all businesses can be obtained from the formula (7).

$$IF\ x_1\ is\ C_1\ AND\ x_2\ is\ C_2\ AND \ldots AND\ x_5\ is\ C_5,$$
$$THEN \begin{pmatrix} P_1^o = C_1 + C_2 + C_3 + C_4 + C_5 = 5833.33 + 1675.00 + \\ 700.00 + 186.67 + 653.33 = 9048.33 \cdot 10^3\ € \end{pmatrix} \tag{7}$$

Should all income according to all business activities be only realized according to the pessimistic, or only according to the optimistic scenario, the expected investment repayment period (k) according to different variants is shown in Fig. 6.

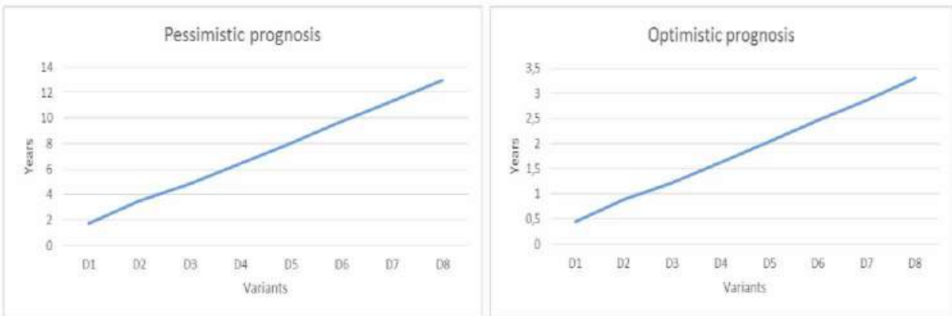

Fig. 6 Investment repayment period according to the different scenarios forecast

The model can also be tested for a combined forecasting revenue scenarios. So, for example, if we consider the combined revenue realization: real for business 1, 3 and 5, pessimistic for business 2 and optimistic for business 4, we get the expected revenue from $6065.83 \cdot 10^3$ €, see Eq. 8.

$$IF\ x_1\ is\ B_1\ AND\ x_2\ is\ A_2\ AND\ x_3\ is\ B_3\ AND\ x_4\ is\ C_4\ AND\ x_5\ is\ B_5,$$
$$THEN\begin{pmatrix} P_i^{com} = B_1 + A_2 + B_3 + C_4 + B_5 = 4416.67+ \\ +437.50+530+186.67+495=6065.83 \cdot 10^3\ € \end{pmatrix} \tag{8}$$

In this case, for example, for the purchase of eight vehicles, the repayment period of the investment is:

$$k_i^{com} = \frac{n \cdot I}{P_i^{com} \cdot p_a} = \frac{10 \cdot 292}{6065.83 \cdot 0.098} = 4.9 \qquad [years] \tag{9}$$

For this variant of revenue realization, eight vehicles can be purchased in the first year of observation and after five years, if the state of the vehicle requires, it is possible to purchase another eight used vehicles.

The sensitivity analysis of the model was also carried out for the cases of the purchase of new vehicles (Fig. 6).

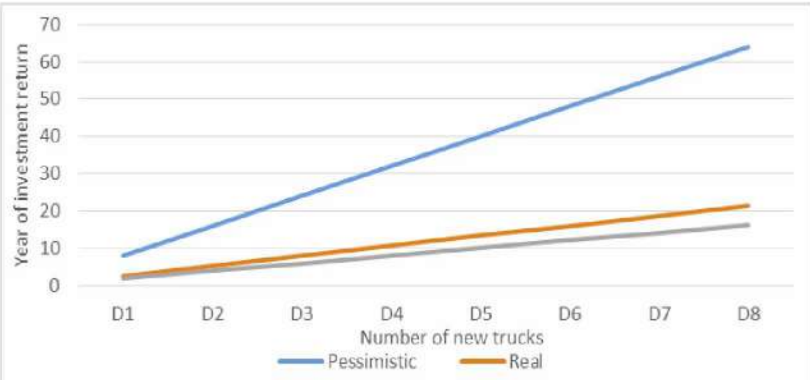

Fig. 6 Period of the repayment of investment in new trucks according to the different scenarios forecast

As can be seen from Fig. 6, the observed company "M" in the case of a pessimistic business scenario can return investments for only one truck in the observed period (15 years), in the case of the real scenario five, and in the case of the optimistic scenario, seven trucks.

Further testing of the model shows that the model is extremely sensitive to the height of the investments (type and number of vehicles) and the amount of realized revenues, primarily business 1, 2 and 3. The model is least sensitive to the realization of revenues of business 4.

5 Conclusions

In order for a transport company to successfully operate, it is extremely important that it should have an appropriate road freight vehicle fleet, with respect to both the quantity and the structure. Besides, the road freight vehicle fleet ages during the exploitation period, so it is extremely important to plan investments in its renewal. Investing in the renewal of the road freight vehicle fleet is a complex process, simultaneously taking different aspects into account. It is very important that vehicles should be chosen in accordance with future income. For that reason, it is very important to make a good forecast. In the paper, the pessimistic, real and optimistic forecasts are subjected to observation. The assessments of income, as well as the return-on-investment period, were performed for all of the three forecasts. In all of the three cases, the results were acceptable, and the conclusion is that the road freight vehicle fleet should be renewed irrespective of which forecast will come up to expectations, since it is very important that the emission standards should be followed due to the announcement of raising the minimum emission standard in the EU from EURO 3 to EURO 5 in the forthcoming period (3 years have been planned in that regard). That would mean that a large majority of transport means in Serbia do not meet the conditions and have to be replaced; in order to avoid problems related to that, the road freight vehicle fleet should be adapted as soon as possible to the conditions existent on the European transportation market, especially in the EU region. Although the economic business market, and simultaneously the market of transport companies as well, has its regularities, it also contains certain uncertainties, such as, for example, demand, competition development, the transport policy, the fuel price, etc. In the majority of cases, the known fleet management analytical models do not take into consideration that uncertainty. For that reason, this paper suggests the use of fuzzy logic for the development of the fleet management model that can provide answers to the following questions: should the road freight vehicle fleet be invested in? How many vehicles are cost-effective to buy? When to buy them? and how long is the return-on-investment period? Apart from that, the model can also be used for the variant of investing in the road freight vehicle fleet by purchasing new or second-hand vehicles. The deficiency of this model is its sensitivity to more significant changes in the volume of business operations (a decrease or increase in income). In that case, the reconfiguration of certain segments of the fuzzy model is required.

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IMPROVING ORGANIZATIONAL LEARNING BY SHARING INFORMATION THROUGH INNOVATIVE SUPPLY CHAIN IN AGRO-FOOD COMPANIES FROM BOSNIA AND HERZEGOVINA

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Abstract: *Innovation is essential for long-term success in business and companies need to develop an innovative supply chain to respond to environmental and market challenges. It is necessary to develop knowledge through organizational learning in order to strengthen the ability of companies to innovate. An innovative supply chain is the basis for developing innovation in companies. To improve its market position companies should continuously receive high quality information from participants in the supply chain by sharing information. The complexity of relationships within supply chain affecting organizational learning is the subject of this study. We conducted an empirical study focusing our attention on agro-food companies in Bosnia and Herzegovina. A questionnaire was used as a data collection tool applying random systematic sampling and a total of 159 companies took part in this study. The empirical findings showed that sharing of information has a significant linkage with an innovative supply chain, but only in establishing partnerships with customers. We confirmed that an innovative supply chain is essential for development of organizational learning and agile supply chain. The findings could assist the managers of agro-food companies in Bosnia and Herzegovina to improve their business. This study provides guidance for improving business using supply chains.*

Key words: *sharing information, innovative supply chain, organizational learning, buyer-supplier relationships, structural equation model.*

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1. Introduction

Innovation is a basis for creating an innovative supply chain and it is very important for success of small and large enterprises (Bag, 2018). In order to implement an innovative supply chain any company should be oriented to set up strategic directions that will promote innovation in their business. An innovative supply chain also requires proper communication with suppliers and buyers. Suppliers are an important element of an innovative supply chain because they are the source of innovative ideas and key technologies (Wang, et al, 2011). The key segments in every supply chain are customers. If customers are not satisfied with the products, they will not buy them. Customers are the driving force of innovative activities in the company. They are the reasons why companies innovates their business and products. It is necessary for customers to receive new enhanced products that are developed according to their requirements (Wagner and Bode, 2014). Innovation in today's dimensional business environment requires complex knowledge (Bag, 2018). And scholars emphasize the key role of innovation and organizational learning in improving the company's competitive advantage (Jiménez-Jiménez & Sanz-Valle, 2011).

Companies cooperate with suppliers in research and development, in production, and collect information from suppliers (Kawai, et al, 2013). In cooperation with suppliers, companies innovate products to meet the increasing demands of customers. In this process information sharing is a key activity. Through the establishment of a partnership relationship, companies receive information that helps them to reduce business uncertainty (Tai & Ho, 2010). The company receives from the customer the necessary information what they want and what are their needs. Thanks to this information, the company can adapt to these needs and offer new or customized products. In these processes the exchange of information with partners becomes a precondition for developing innovative business in the company. When exchanging information with key partners, not only information is exchanged but also data and knowledge (Kembro & Näslund, 2014). Through such information exchange, companies increase their organizational skills.

This study is focused on complex interactions within supply chain. We especially analysed the way in which information is exchanged through buyer-supplier relationships on an innovative supply chain, and how innovative supply chain acts on agility of the supply chain and organizational learning. This relationship was observed on the example of agro-food companies in Bosnia and Herzegovina. The importance of this paper can be found in the fact that it provides necessary information about how the buyer-supplier relationships are important for development of innovative supply chains and how influential on innovative supply chain are suppliers or customers through the exchange of timely information. We examined whether agro-food companies in Bosnia and Herzegovina how exchange information with customers and suppliers, and how they use this information when establishing an innovative supply chain in order to improve their organizational knowledge. Understanding the way in which information is exchanged by developing an innovative supply chain and influencing organizational learning is the main significance of this study. Based on the survey, we explored how companies use information sharing in business consolidation. The findings enable identification of major recommendations for companies in order to improve their competitiveness and market performance. The results obtained will assist managers of agro-food companies in Bosnia and Herzegovina to recognize the importance of sharing information in the operations of these companies. Furthermore, the role of suppliers and customers in the sharing of information will be considered. On the basis of this finding, managers can learn how to improve their cooperation with them in order to improve the quality of information and accordingly to make supply chain more innovative. Managers will also be given the answer whether an innovative supply chain is more agile and whether it increases the knowledge of the organization. Based on this, the following research objectives are set:

1. To explore the application of information sharing and partner relationships with the buyers and suppliers to establish an innovative supply chain;
2. To study the impact of an innovative supply chain on agility and organizational learning in agro-food companies in Bosnia and Herzegovina;
3. To test the proposed model and examine the direct and indirect effects used in the model.

2. Literature review

We booked this section to present our research model, hypotheses and theoretical framework of the study. Within the research model, several constructors were used: information sharing, buyer-supplier relationships, an innovative supply chain, an agile supply chain, and organizational learning. The mentioned constructors are explained in this part of the paper.

This study highlighted the importance of sharing information in establishing partnerships and observed how sharing information and relationships with customers and suppliers affect the functioning of an innovative supply chain. We examined whether the sharing of information influences an innovative supply chain, or only in the course of establishing partnership relationships, innovation of the supply chain is also established. The study examined the individual impact of partner relationships with buyers and suppliers on the establishment of an innovative supply chain. We considered direct and indirect impacts of information sharing on an innovative supply chain. The findings will enable to understand these relationships in agro-food companies in order to improve an innovative supply chain by sharing information.

The second part of the model explored the impact of an innovative supply chain on supply chain agility and organizational learning. This established relationship made it possible to understand whether an innovative supply chain contributes in improving speed of supply chain operations and whether it contributes to increasing company knowledge. This model will examine, in two different parts, the complex relations that prevail in agro-food companies in Bosnia and Herzegovina. The model represents a new perspective on the complexity of relationships within the supply chain.

In order to carry out this study, the following steps were set in this study:

1. Establishing the model based on the research constructors;

2. Investigating relevant literature and set up the questionnaire;
3. Passing the questionnaire and collecting data from agro-food companies in Bosnia and Herzegovina;
4. Processing data and testing the model and hypotheses of this study;
5. Presenting the findings;
6. Highlighting the most important results of this study and give recommendations for future research.

2.1. Sharing information

One of the most important segments of partnership is the exchange of information. The exchange of information is exchange of important information between partners in the supply chain (Lee & Ha, 2018). During establishment of collaboration within supply chain, sharing information is an important dimension and is in the focus of all partners within the supply chain (Chen, et al, 2011). During the exchange of information is necessary to implement two-way communication between partners. In doing so, not only information is exchanged, but also knowledge among partners. The exchange of information between the buyer and the supplier is of essential interest in building long-term trust based relationships (Eckerd & Hill, 2012). When exchanging information, it is crucial to determine the level of information sharing and the quality of information being exchanged. With true and precise information companies can respond to market changes. The efficiency of information sharing is not limited to the question "whether the information is shared or not," but also include the question "what kind of information is shared" and "when and how information is shared" (Li et al., 2014). When sharing information, partners in the supply chain develop mutual trust and belief that their partner will not break the deal by unethical behavior (Eckerd & Hill, 2012). With increasing trust among partners, reduction of transaction costs and a greater exchange of information between partners occur (Li, et al, 2017). Trust among partners grows with the development of partner relationships (Rogers & Fells, 2018). It is therefore important to develop a mutual relationship between partners based on trust. With the exchange of information in the supply chain, trust among partners is raised. Higher exchange reduces risk and uncertainty and increases the level of trust in relationships (Nyaga, et al, 2010). Based on all of the above, the following hypotheses of research are set:

H1: Sharing information has a significant positive impact on partner relationships with the suppliers

H2: Sharing information has a significant positive impact on partner relationships with customers

H3: Sharing information has a significant positive impact on innovativeness of supply chain.

2.2. Buyer-supplier relationship

Researchers noted that partnerships with suppliers and customers have a role in achieving business results (Faraz, et al, 2018). Zacharia et al. (2011) emphasized that managing relationships with customer and suppliers is essential for success of the supply chain. The effects gained partner relationship for suppliers and customers are two-folded: the affective basis where the supplier is devoted to the customer, and the cognitive basis where the supplier acquires enough knowledge through the exchange of information to improve performance (Shou, et al, 2013). It is therefore important that each company develops its buyer-supplier relationships. Companies are ready to establish strong partnerships with key customers and suppliers. Strong partnership is an opportunity to increase the success of partners rather than they work separately (Faraz, et al, 2018). In order to achieve desired benefits it is necessary to build a strong relationship with key partners in the supply chain. The most important key partners for the company's business are customers and suppliers. Chen & Wu (2010) showed that the transaction costs of the company can be reduced by strengthening cooperation with customers and suppliers. In order to reduce production costs companies transfer their business processes through outsourcing to suppliers, thus the ability to manage relationships with suppliers becomes very important (Faraz, et al, 2018). Furthermore, in order to improve product's quality and other business parameters such as costs and delivery times, it is necessary to have an efficient and capable supplier (Joshi, et al, 2016). During the establishment of relations communication, information sharing and joint activities facilitate knowledge transfer and assist suppliers to improve their innovation performance (Kim, et al, 2017). Having this in mind we set up the following hypotheses:

H4: Supplier relationship has a significant positive impact on innovativeness of supply chain.

H5: Customer relationship has a significant positive impact on innovativeness of supply chain.

2.3. Innovative supply chain

In order to offer new and more diversified products to customers, it is necessary to innovate in production and business processes (Joshi, et al, 2016). Innovation assists for companies to face with turbulent environment and it is a main driver of long-term success in the business (Jiménez-Jiménez & Sanz-Valle, 2011). Companies strive to adopt technological innovations that should deliver better business results. Without innovation, companies are not able to make adaptation to change. Innovations trigger changes in the environment. It is necessary to build an innovative supply chain in the company. The main elements of an innovative supply chain are: Supply Chain of Business Processes, Supply Chain Structure Network, and Supply Chain Technology (Arlbjorn, et al, 2011). Those companies oriented to build an innovative supply chain need to incorporate innovation in all processes of the company to meet the demands of the market. Furthermore, an innovative supply chain needs to be based on continuous improvements. For establishing innovative supply chain, it is necessary to include suppliers and customers. Suppliers are the source of innovative ideas and key technologies (Wang, et al, 2011), while customers are the drivers of innovative activities in the company. In order to respond to customer demands, it is necessary to provide new enhanced products that have been developed according to these requirements (Wagner & Bode, 2014). By developing innovative supply chain, companies have a more flexible and faster response to the demands placed on the market. Having this in mind, the following hypotheses are posed in this study:

H6: Innovative supply chain has a significant positive impact on agile supply chain.

H7: Innovative supply chain has a significant positive impact on organizational learning.

2.4. Agility

Agile supply chain is considered a key factor of success in the market. It allows companies to be more sensitive to signals on the market (Chan, et al, 2017). The concept of agility was introduced as a means by which the company adjusts to changes in the market (Gligor, et al, 2015). Agility should be applied when demand is unstable and customer demands are complex and varied. The concept of an agile supply chain has been introduced due to the complexity of the market. Agility is a mechanism that enables the company to establish a fast and flexible supply chain in terms of customizing customer requirements and market changes. An agile supply chain is defined as a strategic capability that enables the company to quickly feel and react to internal and external uncertainty through the effective integration of supply chain relationships (Fayezi, et al, 2015). In order to create an agile supply chain it is necessary to have developed internal and external integrations in the company. Internal and external integration affects the company's ability to introduce agility in the supply chain (Fayezi, et al, 2016). It is therefore necessary to achieve synergy of different forms of flexibility from all sides in the supply chain to empower the company to respond effectively to a highly volatile marketplace (Chan, et al, 2017). In order to improve the agility of the supply chain, it is necessary to apply company integrations that are accompanied by organizational learning (Braunscheidel & Suresh, 2009). Based on this, the following hypothesis is posed in this study:

H8: Agile supply chain has a significant positive impact on organizational learning.

2.5. Organizational learning

Organizational learning is a process that develops new knowledge through access to common experiences of people in the company and has the potential to influence the behavior of employees and improve the ability of companies (Jiménez-Jiménez & Sanz-Valle, 2011). For the company, it is very important to create new competencies to deal with changes in the market and to adapt to the requirements of customers. With new knowledge, the company builds a competitive advantage. Organizational learning can strengthen the company's ability to identify opportunities and seek new approaches to deal with changes in the environment. Based on this, organizational learning is seen as the basis for achieving sustainable competitive advantage and for improving the efficiency of the enterprise (Sanz-Valle, et al, 2011). The basic assumption is that organizational learning plays a key role and enables companies to achieve speed and flexibility in the innovation process. Organizational learning and innovation relate positively to each other (Jiménez-Jiménez & Sanz-Valle, 2011). Organizing learning contributes to improving company performance, competitiveness of the company, innovative activities, etc. (Braunscheidel & Suresh, 2009). Therefore, it was important to investigate whether innovation and agility influenced the improvement of organizational learning.

Based on the theoretical framework and set hypotheses, we introduced a research model (Figure 1). The applied research model has two segments. The first segment refers to the impact of sharing information on an innovative supply chain through partner relationships with suppliers and customers. The second segment refers to the examination of the impact of an innovative supply chain on an agile supply chain and on organizational learning. The proposed model has enabled the research whether an innovative supply chain had the role of a mediator in influencing the sharing of information on the agility of the supply chain and organizational learning.

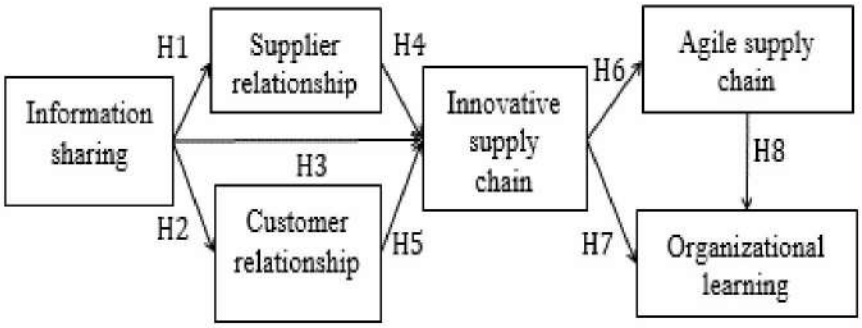

Figure 1. Research model

3. Methodology

In this section, we will present the basic set, sample survey and data collection procedures. We will show the results of non-response bias analysis of the collected data and will explain the operationalization of the research constructor.

Research for this study was carried out on the territory of Bosnia and Herzegovina. The research includes agro-food companies. According to the Statistical Business Register from June 30th of June 2016 there are 1745 such companies in Bosnia and Herzegovina. The basic sample included those companies that are primarily engaged in the production or processing of food and beverages were taken including registered farms and cooperatives. However, this sample is consisted mainly from companies located in urban areas. If it was not possible for a company to determine whether it is doing business or performing business activity, the first one below is taken into consideration. Data collection for this study was carried out from March to September 2016 and 149 companies took part in the survey. The basic characteristics of these companies are presented in Table 1.

Table 1. Basic data about companies involved in the study

	Companies' features	Frequency	%
Size	1. micro	24	16.1
	2. small	65	43.6
	3. middle	43	28.9
	4. big	17	11.4
Number of employees	1. 1-9	47	31.5
	2. 10-49	53	35.6
	3. 50-99	19	12.8
	4. 100-199	16	10.7
	5. 200+	14	9.4
Age	1. before 1970	15	10.1
	2. 1970-1989	16	10.7
	3. 1990-2010	96	64.4
	4. after 2010	22	14.8
Ownership	1. private	145	97.3
	2. state	0	0.0
	3. mixed	4	2.7
Possession of quality certificates	1. yes	99	66.4
	2. no	50	33.6
Primary activity	1. Food production	61	40.9
	2. Production of milk and beverages	25	16.8
	3. Agricultural production	44	29.5
	4. Other production	19	12.8

A survey questionnaire was used during the research. The questionnaire was created in the following way. First, relevant papers were collected that dealt with the subject of this study. Second, we identified the relevant papers which were used to create a questionnaire. Third, the questionnaire was forwarded to four experts who gave suggestions on the issue. Fourth, the survey questionnaire was corrected and sent to agro-food companies.

We analysed within non-response bias analysis those companies that did not want to take a part in the survey. The reasons for non-participation were the following: lack of time, lack of approval from the administration, nonperformin registered activities, etc. On the basis of these answers it can be established that there is no valid reason why they did not participate in the research. So the collected data from this research were confirmed. On the basis of these answers we understood that there is no valid reason why they did not participate in the study. Thus, the collected data from this study were confirmed.

We used the questionnaire consisting of two parts. The first part of the questionnaire examined the basic characteristics of agro-food companies: size, number of employees, company's age, ownership of the company, sales revenues in 2015 (BAM), possession of quality certificates and primary activity of the company. The second part of the questionnaire was measured research constructors: Information sharing, Supplier relationship, Customer relationship, Innovative supply chain, Agile supply chain and Organizational learning. These constructors were tested using the Likert scale with five levels of agreement with the offered claims that ranged from "completely disagree" to "completely agree".

For the measurement of research constructors, we used customized claims as follows:

- Information sharing - Chavez et al. (2015);
- Supplier relationship - Chavez, et al. (2015);
- Customer relationship - Baihaqi and Sohal, (2013) and Chavez, et al. (2015);
- Innovative supply chain - Mohezar & Nor (2014) and Lee, et al. (2014);
- Agile supply chain - Yang (2014) and Gligor, et al. (2015);
- Organizational learning - Braunscheidela and Suresh (2009).

4. Results

We used different statistical methods to examine established hypotheses and the model. Cronbach's Alpha (CA) was used to test the reliability of the measurement scale, Average Variance Extracted (AVE) was used to test discriminatory validity, Square Rot of AVE and Confirmatory Factor Analysis (CFA) was used to test the validity of the construction. The connectivity of the research constructors was tested using Pearson's correlation coefficient while the model was tested by using Structural Equation Model (SEM). We conducted these statistical analyzes with the assistance of statistical programs Lisrel 8.8 and SPSS 20.

4.1. Scale validity and reliability

Before we tested the model, we performed CFA analysis and tested the reliability of the scale, the discriminatory validity and the relationship between the constructors. Based on the CFA analysis performed (Table 2), the findings showed that all claims have a good factor load (Chi-square = 197.97; GFI = 0.88; AGFI = 0.84, NFI = 0.93; NNFI = 0.97; CFI = 0.98; RMSR = 0.043; p = 0.043), thus the model has acceptable unidimensionality and convergent validity (Prajogo, et al. 2012).

Our descriptive analysis (Table 2) showed that the companies most agree with the claims related to the Customer relationship constructor, while the least agree with the claims related to the Supplier relationship constructor which is showed by the value of arithmetic mean. This analysis has shown that there is the largest dispersion in the responses related to the Supplier relationship constructor, while the smallest dispersion has shown in the responses related to the Customer relationship constructors which is indicated by the values of standard deviation (SD). During testing the internal consistency of the measurement scale, the findings showed that all values are greater than the critical value of .70 and range from .77 to .86 which proves the existence of consistent measurement scales.

Table 2. Scale validity and descriptives

Scale	Item description	Loading	Mean	SD	CA
Information sharing	The information needed to improve cooperation are exchanged	.69	3.67	.82	.86
	Partners share key knowledge about developing business processes and products	.80	3.44	.88	
	Information are exchanged with partners to assist planning of future activities	.71	3.64	.86	
	Communication with partners is timely, accurate, complete, adequate and reliable	.62	3.75	.90	
Number of employees	Suppliers are involved to solve problems in the company	.87	3.17	1.13	.83
	It is being improved product quality with assistance of suppliers	.64	3.67	.96	
	Suppliers are involved in development of products and business processes	.85	3.44	1.13	
	It is being cooperated with suppliers to improve business	.83	3.21	1.05	
Customer relationship	By interaction with customers, reliability and accountability are improved	.47	4.28	.71	.77
	Ccustomer's satisfaction is measured often	.65	3.94	.91	
	It is trying to determine future customer expectations	.70	4.15	.86	
Innovative supply chain	We use modern technology for product development	.80	3.75	.99	.84
	We are technologically competitive	.77	3.62	.98	
	We use modern warehouses and means of transport	.74	3.85	.94	
Agile supply chain	We quickly respond to changes in the market	.69	3.77	.84	.86
	We adapt very quickly to customer demand	.77	3.90	.83	
	We can quickly offer new products	.70	3.66	.96	
Organizational learning	We invest in the employees' promotion and learning	.69	4.21	.79	.83
	All employees have an embedded vision of the organization	.76	4.00	.89	
	All employees are committed in achieving common goals of the organization.	.68	3.95	.92	

The results of CR constructors' reliability (Table 3) showed that the values are above the critical .50 and range from .81 to .89 which proves that all constructors are reliable. The value of the AVE indicator ranges from .59 to .74 which is above the critical value of .50, which confirms that the constructors have a good discriminatory value. The smallest value of square rot of AVE is .771 which is greater than the absolute value of the correlation analysis, which fulfills the requirement of discriminatory validity of the model construction. Correlation analysis showed that there is no significant connection in three cases. The least important is the relathionship between Information Sharing and Agile supply chain (r = .049) constructors, while the largest connection was found between Innovative supply chain and Agile supply chain (r = .534). Thus, it be concluded that the data collected are reliable and can be used to examine the research hypothesis and the research model.

Table 3. Composite reliability corelation and average variance extracted

Construct	CR	AVE	A	B	C	D	E	F
A. Information sharing	.87	.62	***.788***					
B. Supplier relationship	.81	.59	.292**	***.771***				
C. Customer relationship	.88	.65	.374**	.451**	***.805***			
D. Innovative supply chain	.89	.74	.107	.296**	.264**	***.857***		
E. Agile supply chain	.85	.66	.049	.310**	.243**	.534**	***.814***	
F. Organizational learning	.85	.66	.330**	.360**	.467**	.157	.160	***.810***

*Note: **Significance at 0.01 level, CR Composite reliability; AVE Average-variance-extracted; The square root of AVE is typed in bold italics along the diagonal*

4.1. Structural relationship

We used SEM analysis to examine the model. The findings showed that the model is reliable (Chi-square = 242.33; GFI = 0.86; AGFI = 0.82, NFI = 0.91; NNFI = 0.96; CFI = 0.96; RMSR = 0.058; p = 0.000). The results of model testing are presented in Table 4.

Table 4. Model results

Hypothesis	Path Estimates	t-value	p-value	Results
H1. Information sharing → Supplier relationship	.43	4.59	.000	Supported
H2. Information sharing → Customer relationship	.54	5.15	.000	Supported
H3. Information sharing → Innovative supply chain	.19	1.67	.097	Rejected
H4. Supplier relationship → Innovative supply chain	.18	1.86	.065	Rejected
H5. Customer relationship → Innovative supply chain	.34	2.85	.005	Supported
H6. Innovative supply chain → Agile supply chain	.41	4.42	.000	Supported
H7. Innovative supply chain → Organizational learning	.43	3.81	.000	Supported
H8. Agile supply chain → Organizational learning	-.03	-.28	.780	Rejected

The results obtained by examining the research hypotheses and the survey model showed that of eight total hypotheses, five hypotheses were accepted, while 3 hypotheses were discarded. The hypotheses H1 and H2 are accepted, confirming that there is a significant connection between information sharing with supplier relationship (path = .43; t-value = 4.59; p-value = .000) and customer relationship (path = .54; t-value = 5.15; p-value = .000). Hypothesis H3 has been rejected, which shows that there is no significant link between the sharing of information with an innovative supply chain (path = .19; t-value = 1.67; p-value = .097). There is no significant connection between the supplier relationship and the Innovative supply chain (path = .18; t-value = 1.86; p-value = .065), which eliminates H4, while there is a significant relationship between Customer relationship and Innovative supply chain (path =. 34; t-value = 2.85; p-value = .005) supporting hypothesis H5. Relation between Innovative supply chain with constructors Agile supply chain (path = .41; t-value = 4.42; p-value = .000) and Organizational learning (path = .43; t-value = 3.81; p-value = .000) show that there is a significant link between them, which confirms hypotheses H6 and H7. Hypothesis H8 was discarded, which explained that there is no significant link between Agile supply chain and Organizational learning (path = -.03; t-value = -.28; p-value = .780)

5. Discussion

This study focused on the role of sharing information in strengthening organizational learning. We did not study direct impact; rather we examined this issue through an innovative supply chain through the role of a mediator. The findings showed that sharing of information is not directly linked to innovative supply chain but rather through partner relations with the customer, wherein appeared another mediator. Sharing information is crucial for establishing partnerships with customers and suppliers (Lee & Ha, 2018). Partners will strengthen relationships if they develop trust among themselves through sharing of information. Sharing information is a tool for sharing the necessary information that needs to be quality in order to improve operations of all partners in the supply chain. Therefore, the impact of sharing information on partner relationships is explored. The findings showed that there is a significant correlation between sharing information and partner relationships with suppliers and customers. It is crucial for agro-food companies to have satisfied customer who will continue to buy their products. The company must find out what the customer wants and what his needs are. In order to reach information, the company must share information with key stakeholders. Customer information helps the company to get to know their desires and needs, and information provided by suppliers helps the company to innovate the supply chain in order to meet these wishes and needs of customers. In order to offer new and varied products that are tailored to their customers' wishes and needs, companies must develop innovative production and business processes (Joshi, et al, 2016). Thus, we put the innovative supply chain in the focus of this study. The findings showed that the sharing of information does not have a direct connection with an innovative supply chain. However, when considering an indirect relationship through partner relationships with suppliers and customers, it has been proven that customers play an important role as a mediator between sharing information and an innovative supply chain (path = .184; p = .012), while suppliers do not have the role of a mediator (path = .077; p = .084). These findings suggest us that partner relationships with customers are crucial for establishing of innovative supply chain. After we examined the connection between sharing information and innovative supply chain, we also tasted the relationship between innovative supply chain and agile supply chain and organizational learning. The findings have shown that innovative supply chain is essential for supply chain to be agile-related and with organizational learning. Based on these findings it can be concluded that agro-food companies in Bosnia and Herzegovina need an innovative supply chain to develop an agile supply chain. The results have shown that agro-food companies in Bosnia and Herzegovina need to develop an innovative supply chain to improve organizational learning in these companies. However, it is not necessary to have an agile supply chain to improve organizational learning. The obtained results of this study will assist agro-food companies in Bosnia and Herzegovina to improve organizational learning that is key issue for development of each company, because knowledge is the most important resource of the company. In order to enhance organizational learning of agro-food companies, they must first share information and develop partner relationships with customers enabling supply chain to be innovative. The study showed that an innovative supply chain is essential to improving organizational learning.

6. Conclusion

The study has shown that an innovative supply chain is necessary for development of organizational learning in the company. Furthermore, this study has also shown that sharing information through partner relationships with customers is crucial in improving an innovative supply chain. The obtained results of this study will assist agro-food companies to improve their business and provide theoretical basis for understanding the relationships established in this research. In future studies it is possible to improve the model by including more constructors that are not involved and which could influence the improvement of organizational learning. Moreover, the model enables research in other branches of industry in order to find out whether the same relations in these branches are matched. For future research, it is imperative to investigate which constructors are better linked to organizational learning. After that it is preferably to include those constructors in the model to give guidance on improving organizational learning. The study provided practical and theoretical basis for improving the knowledge on information sharing and an innovative supply chain for improvement of organizational learning. The used model will help agro-food companies in Bosnia and Herzegovina to organize their business in order to be more competitive on the market.

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OPERATIONS AND INSPECTION COST MINIMIZATION FOR A REVERSE SUPPLY CHAIN

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Abstract: *Reverse supply chain is a process dealing with the backward flows of used/damaged products or materials. Reverse supply chain includes activities such as collection, inspection, reprocess, disposal and redistribution. A well-organized reverse supply chain can provide important advantages such as economic and environmental ones. In this study, we propose a configuration in which quality assurance is a substantial operation to be fulfilled in the reverse chain so that to minimize the total costs of the reverse supply chain. A mathematical model is formulated for product return in reverse supply chain considering quality assurance. We consider a multilayer, multi-product for the model. Control charts with exponentially weighted moving average (EWMA) statistics (mean and variance) are used to jointly monitor the mean and variance of a process. An EWMA cost minimization model is presented to design the joint control scheme based on performance criteria. The main objective of the paper is minimizing the total costs of reverse supply chain with respect to inspection.*

Key words: *Reverse supply chain; Quality inspection; Mathematical Model.*

1. Introduction and related works

With the increase in environmental consciousness, reverse supply chain and reverse supply chain management have received significant attention from both business and academic research during the past few years. According to the American Reverse Logistics Executive Council, Reverse Logistics is defined as Rogers and Tibben-Lembke (1998): "The process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal." A reverse logistics system comprises a series of activities, which form a continuous process to treat return products until they are properly recovered or disposed of. These activities include collection, cleaning, disassembly, test and sorting, storage, transport, and recovery operations. The latter can also be represented as one or a combination of several

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main recovery options, like reuse, repair, refurbishing, remanufacturing, cannibalization and recycling (Dekker and Van Der Laan, 1999; Beaulieu et al., 1999; Thierry et al., 1993). Also, these options are to be reclassified into three broad categories such as reuse, recycling, and remanufacturing. In reuse, the returned product can be used more than once in the same form after cleaning or reprocessing. On the other hand, recycling denotes material recovery without conserving any product structure. Finally, remanufacturing is an industrial process in which worn-out products are restored to like-new condition.

The design/redesign of the supply chain with return flows has become a challenge for many companies. This is an important area of research as it helps lowering costs, while improving coordination and customer service (Guide et al., 2003). For instance, Nike, the shoe manufacturer encourages consumers to bring their used shoes to the store where they had purchased them. These shoes are then shipped back to Nike's plants and made in to basketball courts and running tracks. By donating the material to the basketball courts and donating funds for building and maintaining these courts, Nike has enhanced the value of its brand Rogers and Tibben-Lembke (1998).Furthermore, according to other advocators' opinions, effective reverse supply chain activities can enhance relationships with consumers and supply chain partners, can be a source of significant cost savings, and can even function as a profit center (Stock et al., 2003).

For the last decade, increasing concerns over environmental degradation and increased opportunities for cost savings or revenues from returned products prompted some researchers to formulate more effective reverse logistics strategies. These researchers including Salema et al. (2007) have proposed a MILP model to analyze the problem of closed loop supply chains. They consider multi-product returns with uncertain behavior but limit their consideration of demand for returned products to factories and not to secondary markets or spare markets. Thus a supplier network which may be required to remanufacture a new product to meet the market demand is not considered. Also, this model is not suitable for modular products.

Del Castillo and Cochran (1996) presented a pair of linear programs and a simulation model to optimally configure the reverse logistics network involving the return of reusable containers in such a way that the number of reusable containers was maximized. However, they did not take into account transportation issues related to reverse logistics. Patti et al. (2008) have formulated a mixed integer goal programming model for analyzing paper recycling network. The model assumes five echelons and studies the inter-relationship between cost reduction, product quality improvement through increased segregation at the source, and environmental benefits through waste paper recovery. The model also assists in determining the facility location, and route and flow of different varieties of recyclable wastes. Aras et al. (2008) developed a non-linear model and tabu search solution approach for determining the locations of collection centers and the optimal purchase price of used products in a simple profit maximizing reverse logistics network.

Initiating product recovery network design efforts, Thierry (1997) introduced a linear program to design product distribution and product recovery networks involving the collection of used copying machines. However, his model did not address the location issue of where the product recovery (resale of products after remanufacturing and refurbishment) process should be installed and at what capacity. Krikke (1998) proposed a network graph and a mixed integer program to optimize the degree of disassembly and evaluate product recovery options in collecting used copying machines and redistributing them after refurbishment, while determining the location and capacity of remanufacturing, central stocking, and disposal facilities. Similarly, Krikke et al. (1999) developed a mixed integer program to determine the locations of shredding and melting facilities for the recovery and disposal of used automobiles, while determining the amount of product flows in the reverse logistics network. Jayaraman et al. (1999) presented a mixed integer program to determine the optimal number and locations of remanufacturing facilities for electronic equipment. Jayaraman et al. (2003) extended their prior work to solve the two-level hierarchical location problem involving the reverse logistics operations of hazardous products. They also developed heuristic concentration procedures combined with heuristic expansion components to handle relatively large problems with up to 40 collection sites and 30 refurbishment sites. Despite their success in solving large-sized problems, their model and solution procedures are still confined to a single period problem and are not designed to deal with the possibility of making trade-offs between freight rate discounts and inventory cost savings resulting from consolidation of returned products. Lee and Dong (2008) developed an MILP model for integrated logistics network design for end-of-lease computer products. They consider a simple network with a single production center and a given number of hybrid distribution-collection facilities to be opened which they solve using tabu search. However, all of researches are found for some cost in reverse logistics that contain and define some centers (Govindan, and Nicoleta Popiuc, 2014; Cardoso et al., 2013; Chuang et al., 2014; Huang et al., 2013; Soleimani, and Govindan, 2014).

Reformulation of supply chain network from nonlinear to a similar piecewise linear programming model was investigated by Diabat and Theodorou (2015), Diabat (2016), and Al-Salem et al. (2016). Also, optimization approaches employed in the literature for closed loop or green supply chains included both certain and uncertain namely, stochastic programming, robust optimization, genetic algorithm, hybrid particle swarm-genetic algorithm and other metaheuristics (Diabat and Al-Salem, 2015; Diabat and Deskoores, 2016; Alshamsi and Diabat, 2017; Hiassat et al. 2017; Zohal and Soleimani, 2016; Wang et al. 2016).

Our study focuses on a general framework and propose total cost minimization model in reverse supply chain considering quality assurance. According to the importance of reverse supply chain for saving cost and improvement of customer loyalty and futures sales we design a framework and a mathematical model for costs in a multilayer multi-product in reverse supply chain system. The main contributions of the paper are, including EWMA control chart for inspection process of returned products, making use of process capability index for quality assurance purpose, and cost optimization for integrated operations and inspections model for a multi-layer and multi-product reverse supply chain. The main advantage of the proposed model is to include quality control in the cost minimization decision, i.e., a tradeoff between cost minimization and quality maximization. Thus, managers can keep cost and quality at the same time. This decision is challenging in real production system. Another advantage is the proposed reverse supply chain in which inspection of return products are fulfilled in a comprehensive control mechanism.

This paper is organized as follows. In the next section, quality inspection and the proposed EWMA control chart for inspection process are explained. In Section 3, a general framework and problem definition for reverse supply chain integrated with the inspection cost monitoring are proposed. Section 4 proposes the mathematical model of the reverse supply chain. Section 5 gives the numerical results and the required analysis. Finally conclusions are addressed in the last section.

2. Quality inspection

Statistical process control (SPC) is an effective method of monitoring a process through the use of control charts. Control charts enable the use of objective criteria for distinguishing background variation from events of significance based on statistical techniques. Much of its power lies in the ability to monitor both process center and its variation about that center. By collecting data from samples at various points within the process, variations in the process that may affect the quality of the end product or service can be detected and corrected, thus reducing waste as well as the likelihood that problems will be passed on to the customer. With its emphasis on early detection and prevention of problems, SPC has a distinct advantage over quality methods, such as inspection, that apply resources to detecting and correcting problems in the end product or service.

2.1. EWMA control charts

We assume that the observations for the process variable X are independent and normally distributed. When the process is in control, the mean and variance of X is μ_0 and σ_0^2, respectively. At any sampling instant t, the sample mean and variance are computed from

$$\overline{x}_t = \sum_{i=1}^{n} x_{it} / n \tag{1}$$

and

$$s_t^2 = \sum_{i=1}^{n} (x_{it} - \overline{x}_t)^2 / (n-1) \tag{2}$$

where $\overline{x}_t$ and s_t^2 are the sample mean and variance at time t, and n is the fixed sample size, $n \geq 2$. Using $\overline{x}_t$ and s_t^2, the chart statistics are calculated as

$$z_t = \lambda_m \overline{x}_t + (1-\lambda_m) z_{t-1} \tag{3}$$

$$Y_t = \max\left\{\ln(\sigma_0^2), \lambda_v \ln(S_t^2) + (1-\lambda_v) Y_{t-1}\right\} \tag{4}$$

$$0 \leq \lambda_m, \lambda_v \leq 1 \tag{5}$$

$$Z_0 = \mu_0 \tag{6}$$

$$Y_0 = \ln(\sigma_0^2) \tag{7}$$

where λ_m and λ_v are the smoothing constants associated with the EWMA chart for mean (EWMA-m) and variance (EWMA-v), respectively. The statistic z_t is used in the EWMA-m chart, and Y_t is associated with the EWMA-v chart.

2.2. Process monitoring by EWMA

When EWMA schemes are used for process monitoring, not only the current observations of X but also the observations from previous samples are taken into account. In the computation of the test statistic, more recent samples are given a larger weight than the ones taken earlier. The user can increase the weight given to the last sample by increasing the value of the smoothing constant.

Lucas and Saccucci (1990) described the properties of the EWMA-m chart in detail. We use the lower and upper control limits (LCL_m and UCL_m) computed based on the asymptotic in-control standard deviation of the EWMA chart statistic Z such that

$$LCL_m = \mu 0 - L_m \sigma_z \tag{8}$$

$$UCL_m = \mu 0 + L_m \sigma_z \tag{9}$$

whereis the control limit parameter. Thus, L_m , and $\sigma_z = \sigma_0(\lambda_m / (2-\lambda_m)n)^{0.5}$ whenever Z_t is outside the interval (LCL_m and UCL_m), the process is considered to be out of control and a search for assignable cause is conducted. Due to the natural variation of the process, out-of-control signals may also occur while the process is in control. However, when there is a shift in process mean and/or variance, the chart will generate an out-of-control signal much more quickly.

To monitor the process dispersion, a number of authors have previously studied the control charts based on EWMA of lnS^2 (Crowder and Hamilton, 1992; Gan, 1995; Acosta-Mejia et al., 1999). The particular dispersion chart we adopt in this study is referred to as EWMA-v which has the lower and upper control limits as follows:

$$LCL_v = \ln(\sigma_0^2)$$
$$UCL_v = \ln(\sigma_0^2) + L_v \sigma_y \tag{10}$$

where $\sigma_y^2 = \lambda_v \psi' \left[(n-1)/2\right] / (2-\lambda_v)$, ψ' (0) is the trigamma function, and L_v is the control limit parameter. The trigamma function is the second logarithmic derivative of the gamma function $\Gamma(0)$, i.e., $\psi'(u) = d^2 \ln\left[\Gamma(u)\right]/du^2$, u>0 . We consider an upper one-sided EWMA-v chart which is well-suited for detecting the increases in the process standard deviation. An increase in the process standard deviation would either reflect an undesirable special cause or the impact of an undesirable process change (either purposeful or unpurposeful); a decrease in process variation would indicate the effect of a process improvement. EWMA-v chart yields an out-of-control signal when Y_t exceeds *UCLv*. The statistical properties of the combined EWMA-m/EWMA-v control scheme have been explored in Morais and Pacheco (2000).

To illustrate the smoothing effect of exponential weighting, we plot the values of $\bar{X}_t$ and Z_t for 40 samples generated via simulation in Figure 1. The observations constituting the first 20 samples are generated from the in-control process distribution with mean=0, variance=1. The samples 21 through 40 are based on the out-of-control process distribution with mean=0.5, variance=1.5; we also set n=4, $\lambda_m = 0.2$ in this simulation experiment. The values of $\ln\left(S_t^2\right)$ and Y_t (with $\lambda_v = 0.2$) obtained from the same simulation run are displayed in Figure 2. The lower and upper control limits shown in these charts are based on $L_m = L_v = 2.5$. Figures 1 and 2 show that the time series of exponentially weighted sample statistics (Z_t and Y_t) exhibit less variability than the original series ($\bar{X}_t$ and $\ln\left(S_t^2\right)$) from which they are derived.

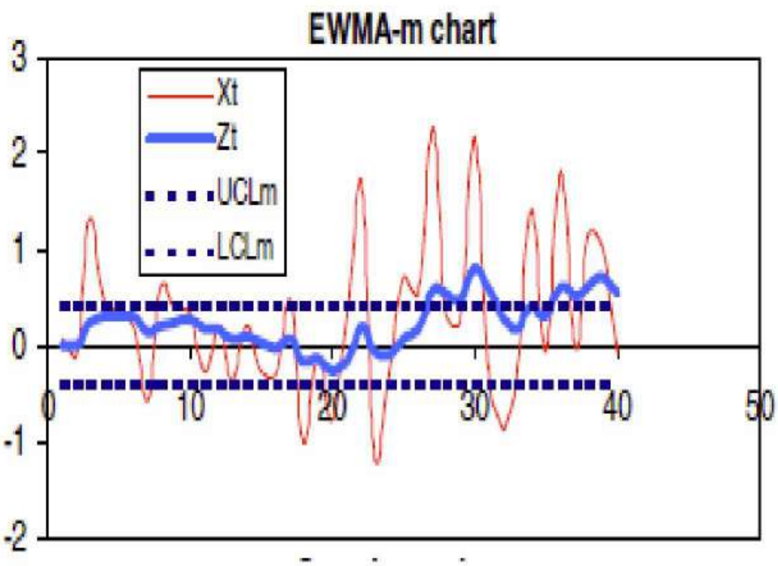

Figure 1. EWMA control chart for mean – Plot of $\bar{X}_t$ and test statistic Z_t

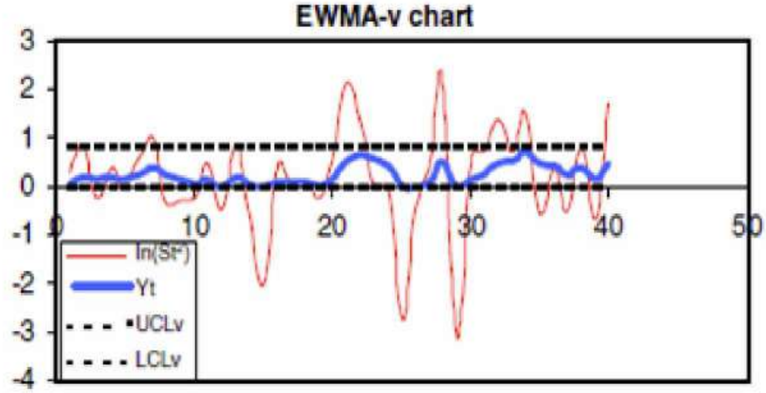

Figure 2. EWMA control chart for variance – Plot of $\ln\left(S_t^2\right)$ *and test statistic Yt*

3. Problem definition

The reverse supply chain under study is multi-layer and multi-product. In the designed model, the returned products after collecting and inspecting are divided into two groups of disassembling and not disassembling products. Some of the products that don't need to be disassembled will be transmitted to the inspecting center right after collecting centers. Then, considering to the variety of products and the request of manufacturing centers they will be sent directly to be remanufactured. In the remanufacturing process, according to the production center's demand, the parts which can be used again, after inspecting center will be sent to the remanufacturing center and after compounding with the other parts will be changed into new products and can return to the distribution chain to assure the quality of the product.. The quality assurance is based on the EWMA control chart for the product in inspection centers. The configuration of the problem is shown in Figure 3.

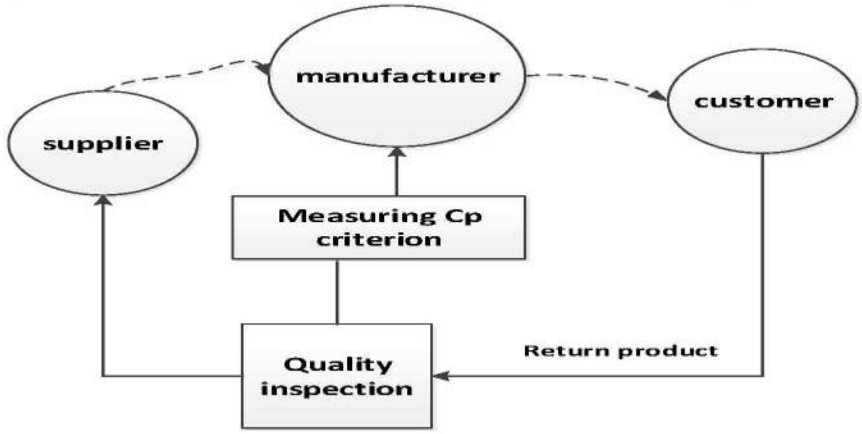

Figure 3. Framework for reverse supply chain

In this paper the reverse supply chain model has been considered for returned products with the purpose of minimizing the reverse supply chain costs considering the quality inspection process. The main assumptions included in the study are:

- ✓ The quantity of inspection and manufacturing are determined.
- ✓ Some products will transport straightly from customers to the inspection centers.

And the required indices are as follows:

k index of inspection centers
f index of manufacturing centers
m index of products

For the EWMA based inspection process, a comprehensive cost function is developed.

3.1. Cost of monitoring in EWMA

We denote the time between two consecutive samples (sampling interval) by h_{fm}. It is assumed that the in-control time for the process is distributed exponentially with mean $\frac{1}{\theta}$. We allow the possibility that both the process mean and variance may change when an assignable cause occurs. When the process is out of control, the mean of X becomes $\mu_1 = \mu_0 + \delta\sigma_0$ and the standard deviation of X shifts to σ_1. Using the Lorenzen and Vance (1986) framework, the expected cost per unit time (hour), C, associated with the control scheme consisting of EWMA-m and EWMA-v charts is in Lorenzen and Vance):

$$\begin{aligned} C = &\Big\{C_{0m}/\theta_{km} + C_{1m}\left(-\tau_m + n_m E_m + h_{fm}(ARL_{1m}) + \gamma_{1mf}T_{1m} + \gamma_{2mf}T_{2m}\right) \\ &+ S_m F_m / ARL_{0m} + RMC_{mf}\Big\} \\ &/\Big\{1/\theta_{km} + (1-\gamma_{1mf})S_m / ARL_{0m} - \tau_m + n_m E_m + h_{fm}(ARL_{1m}) + T_{1mf} + T_{2mf}\Big\} \\ &+ \Big\{\Big[(a_m + b_m n_m)/h_{mf}\Big]\Big[1/\theta_{km} - \tau_m + n_m E_m + h_{fm}(ARL_{1m}) + \gamma_{1mf}T_{1m} + \gamma_{2mf}T_{2m}\Big]\Big\} \\ &/\Big\{1/\theta_{km} + (1-\gamma_{1mf})S_m / ARL_{0m} - \tau_m + n_m E_m + h_{fm}(ARL_{1m}) + T_{1mf} + T_{2mf}\Big\} \end{aligned} \quad (11)$$

The effective parameters in the proposed inspection cost function are listed below:

C_0 cost per hour due to nonconformities produced while the process is in control
C_1 cost per hour due to nonconformities produced while the process is out of control
τ expected time between the occurrence of the assignable cause and the time of the last sample taken before the assignable cause $= [1-(1+\theta h)\exp(-\theta h)]/[\theta(1-\exp(-\theta h))]$
E time to sample and chart one item
ARL_0 average run length while in control
ARL_1 average run length while out of control
T_1 expected time to discover the assignable cause

T_2 expected time to repair the process

γ_1 =1 if production continues during inspection,

=0 if production ceases during inspection

γ_2 =1 if production continues during repair,

=0 if production ceases during repair

s expected number of samples taken while in control = $\exp(-\theta h)]/[1-\exp(-\theta h)]$

The traditional approach to the economic design of control charts involves calculation of the expected cost per hour by dividing the expected cost per cycle by the expected cycle length. Each cycle is made up of two parts: (a) an in-control interval, and (b) an out-of control interval following that. The cost function is derived by dividing the sum of costs incurred during the in-control and out-of-control segments by the expected cycle length. The expected lengths of the in-control and out-of-control intervals, $E(I_{in})$ and $E(I_{out})$, are

$$E(I_{in}) = (1/\theta) + (1-\gamma_1)sT_0 / ARL_0 \quad (12)$$

$$E(I_{out}) = -\tau + nE + h(ARL_1) + T_1 + T_2 \quad (13)$$

The in-control interval is composed of the expected time until failure and the expected time spent for investigating false alarms. The expected length of the in-control interval depends on whether the production continues during inspection or not.

The out-of-control interval includes the time from the occurrence of the assignable cause to the next sampling instant $(h_{fm} - \tau_m)$, the time until an out-of-control signal $h_{fm}(ARL_1 - 1)$, the time to collect and chart a sample (nE), the time to discover the assignable cause (T_1), and the time to repair the process (T_2). After an assignable cause is found and corrective action is taken, the process mean and variance are restored to their in-control values μ_0 and σ_0^2, and the cycle restarts.

The decision variables are $n, h_{fm}, L_m, L_v, \lambda_m, \lambda_v$. As defined previously, average run length is the expected number of samples taken before an out of control signal is observed. To minimize false alarms and react swiftly to out-of-control conditions, large values for ARL_0 and small values for ARL_1 are desirable. ARL_0 and ARL_1 depend on all decision variables except h.

4. Mathematical formulation

We want to demonstrate a model in reverse supply chain so that to minimize the chain costs. We aim to minimize total operations and inspection costs for the proposed reverse supply chain. The required parameters are reviewed as shown in Table 1:

Table 1. The parameters of the mathematical model

u_{km}	capacity of inspection center *k* for product *m*
h'_{fm}	capacity of manufacturing center *f* for product *m*
DM_{fm}	manufacturing center's demand *f* for product *m*
$CSPM_{kfm}$	unit cost of transportation from inspection center *k* into the manufacturing center *f* for product *m*
$FOCP_{km}$	fixed opening cost for inspection centers *k* and product *m*
RMC_{fm}	unit cost of remanufacturing in manufacturing center *f* for product *m*
C_{0m}	cost per hour due to nonconformities produced while the process is in control for product *m*
C_{1m}	cost per hour due to nonconformities produced while the process is out of control for product *m*
F_{mk}	cost per false alarm for inspection centers *k* and product *m*
a_{mk}	fixed cost per sample for inspection centers *k* and product *m*
b_{mk}	cost per unit sampled for inspection centers *k* and product *m*
S_{m}	expected number of samples taken while in control for product *m*
τ_m	expected time between the occurrence of the assignable cause and the time of the last sample taken before the assignable cause for product *m*
n_m	Number of sample for product *m*
E_m	time to sample and chart one item for product *m*
ARL_{0m}	average run length while in control for product *m*
ARL_{1m}	average run length while out of control for product *m*
T_{1mf}	expected time to discover the assignable cause for manufacturing center *f* and product *m*
T_{2mf}	expected time to repair the process for manufacturing center *f* and product *m*
γ_{1mf}	1 if production continues during inspection, and 0 if production ceases during inspection for manufacturing center *f* and product *m*
γ_{2mf}	1 if production continues during repair, and 0 if production ceases during repair for manufacturing center *f* and product *m*
λ_{me}	smoothing constants associated with the EWMA chart for mean
λ_{v}	smoothing constants associated with the EWMA chart for variance

And finally the decision variables are listed below:

Q_{kfm} amount shipped from inspection center into the manufacturing center *f* for product *m*

β_{km} 1, if inspection center *k* is open for product *m* and 0, otherwise

μ_{fm} the product *m* flow amount in manufacturing center *f*
θ_{km} the product *m* flow amount in inspection center *k*
CP_{kp} process capability for product *m* in inspection center *k*

The formulation of the mathematical model is given below:

$$Min \quad Z=\sum_{k=1}^{K}\sum_{f=1}^{F}\sum_{m=1}^{M} CSRM_{kfm}Q_{kfm}+\sum_{k=1}^{K}\sum_{m=1}^{M} FOCP_{km}\beta_{km}+\sum_{f=1}^{F}\sum_{m=1}^{M} RMC_{fm}\mu_{fm}+C \tag{14}$$

By attention to the definition of indices, parameters and decision variables; the objective function is defined to be minimizing the costs of transportation and inspection of products, the fixed opening cost of centers and operations costs on products in reverse supply chain.

Constraints:

$$\sum_{f=1}^{F} Q_{kfm} \le u_{km}.\beta_{km}.CP_{km} \quad \forall k,m \tag{15}$$

This constraint is stating that the amount of shipping products from any inspection centers (if it is opened) into the manufacturing centers should be equal or smaller than the capacity of the same inspection centers for each product considering product process capability index.

$$\theta_{km} \le u_{km}.\beta_{km}.CP_{km} \quad \forall k,m \tag{16}$$

This constraint is stating that the amount of a product which is in the inspection center should be equal or smaller than the capacity of the same inspection center with respect to the quality assurance measure.

$$\mu_{fm} \le h'_{fm} \quad \forall f,m \tag{17}$$

This constraint states that the amount of product in each manufacturing center should be equal or smaller than the capacity of the same manufacturing center.

$$\sum_{k=1}^{K} Q_{kfm} \ge DM_{fm} \quad \forall f,m \tag{18}$$

$$\mu_{fm} \ge DM_{fm} \quad \forall f,m \tag{19}$$

These two constraints guarantee the demand fulfillment in manufacturing and inspection centers for products.

(7) and (8) are the quality assurance inequalities to confine the model to satisfy the products' quality.

(9) and (10) enforce the binary and non- negativity restrictions on the corresponding decision variables.

$$CP_{km}=\frac{E(I_{in})-E(I_{out})}{6\sigma_{km}} \quad \forall k,m \tag{20}$$

If the upper and lower specification limits of the process are USL and LSL, the estimated variability of the process (expressed as a standard deviation) is $\hat{\sigma}$, then commonly accepted process capability index for product m in inspection center k is CP_{km}. Estimates what the process is capable of producing if the process mean were to be centered between the specification limits. Assumes process output is approximately normally distributed.

$$\begin{aligned}C=&\Big\{C_{0m}/\theta_{km}+C_{1m}\left(-\tau_m+n_mE_m+h_{fm}(ARL_{1m})+\gamma_{1mf}T_{1m}+\gamma_{2mf}T_{2m}\right)\\&+S_mF_m/ARL_{0m}+RMC_{mf}\Big\}\\&/\Big\{1/\theta_{km}+(1-\gamma_{1mf})S_m/ARL_{0m}-\tau_m+n_mE_m+h_{fm}(ARL_{1m})+T_{1mf}+T_{2mf}\Big\}\\&+\Big\{\Big[(a_m+b_mn_m)/h_{mf}\Big]\Big[1/\theta_{km}-\tau_m+n_mE_m+h_{fm}(ARL_{1m})+\gamma_{1mf}T_{1m}+\gamma_{2mf}T_{2m}\Big]\Big\}\\&/\Big\{1/\theta_{km}+(1-\gamma_{1mf})S_m/ARL_{0m}-\tau_m+n_mE_m+h_{fm}(ARL_{1m})+T_{1mf}+T_{2mf}\Big\}\end{aligned} \tag{21}$$

This function computes the inspection cost.

$$Q_{kfm},\mu_{fm},\theta_{km},CP_{km}\geq 0 \quad \forall k,f,m \tag{22}$$

$$\beta_{km}\in\{0,1\} \quad \forall k,m \tag{23}$$

In these relations, the sign and type of decision variables are emphasized.

5. Numerical example

In this section, we solve an example to show the validity of the proposed mathematical model. The multi-layer and multi-product supply chain considered here has 3 inspection centers, 3 manufacturing centers, and 4 products. Here, the other inputs are:

$$U_{km}=\begin{bmatrix}299&211&111&485\\350&375&425&270\\460&289&360&115\end{bmatrix} H_{fm}=\begin{bmatrix}412&965&592&978\\520&666&632&711\\483&786&842&822\end{bmatrix}$$

$$DM_{fm}=\begin{bmatrix}125&235&482&116\\455&142&471&192\\260&368&269&453\end{bmatrix} CSPM_{kfm}=\begin{bmatrix}11&44&27\\18&38&25\\22&32&49\end{bmatrix} FOCP_{km}=\begin{bmatrix}45&85&44&96\\46&75&61&93\\58&89&69&81\end{bmatrix}$$

$$RMC_{fm}=\begin{bmatrix}12&44&28&42\\18&48&33&15\\29&50&39&27\end{bmatrix} OCP_{km}=\begin{bmatrix}12&18&24&14\\13&19&22&11\\15&20&23&25\end{bmatrix}$$

Implementing the model in Lingo optimization software package, the following outputs are obtained:

Q_{113}=592; Q_{223}=632; Q_{333}=842; Q_{234}=822
μ_{13}=592;632=$_{23}\mu$; μ_{33}=842; μ_{34}=822;

θ_{11}=299; θ_{13}=111;350=$_{21}\theta$; θ_{23}=425; θ_{31}=460;
β_{11}= β_{13}= β_{21}= β_{23}= β_{31}=1.

5.1. Analysis

In the following analysis we assume production continues during the search for an assignable cause, but it ceases during repair, $\gamma_1 = 1$, $\gamma_2 = 0$. We use the following values of parameters:

θ∈ (0.01□0.05)

Parameter	F	W	a	b	E	T_0	T_1	T_2	P	σ_0^2	$\mu_0 = T$
Value	500	250	5	1	0.5	0	20	0	200	1	0

Let ρ be the ratio of the out-of-control standard deviation to in-control standard deviation, i.e. $\rho = \dfrac{\sigma_1}{\sigma_0}$. The optimal values of design parameters for given different shift values δ and ρ are listed in Table 1 for the joint EWMA scheme with K = 0.1. Note that, cost values from the proposed cost function is also computed in Table 2.

Regarding the decision variables, especially for large shifts, sample size and sampling interval have been found to be relatively more robust than other variables to changes in initial values. One of the reasons behind the observed sensitivity of control limits and smoothing constants to starting values may be the additional flexibility provided by using two charts rather than a single chart. The change in one variable, say L_m, is compensated by a change in another variable, say L_v, and hence, different combinations of variables essentially lead to the same impact on the total cost. If only a single chart was used, due to a smaller set of decision variables, the number of alternative combinations of variables resulting in approximately same value of the total cost would probably be less, and therefore, the search would be more likely to converge to the same values of decision variables at termination regardless of the initial values.

Table 2. Optimal economic design for the reverse supply chain

θ	δ	ρ	C	h	n	λ_{me}	λ_v	L_m	L_v
0.01	0.5	1	24.51	20.00	7	0.29	0.11	2.45	2.67
		1.5	32.26	10.65	11	0.80	0.77	2.80	1.83
		2	39.10	6.14	6	0.99	0.86	3.13	1.69
	1	1	28.54	15.63	10	0.83	0.15	2.53	3.12
		1.5	34.98	8.10	7	0.76	0.99	2.67	1.88
		2	41.92	5.19	5	0.81	0.84	3.09	1.69
	1.5	1	33.64	9.40	6	0.88	0.05	2.73	2.80
		1.5	39.43	5.53	5	0.85	0.81	2.75	2.04
		2	46.45	4.14	4	0.84	0.86	3.02	1.63

	2	1	40.21	5.27	4	0.85	0.11	2.96	2.27
		1.5	45.70	4.41	4	0.82	0.41	3.00	3.98
		2	52.68	3.43	3	0.83	0.89	2.94	1.53
0.05	0.5	1	25.36	20.00	2	0.68	0.11	3.90	1.38
		1.5	45.60	15.57	9	0.85	0.98	2.28	1.37
		2	65.77	4.87	5	0.94	0.74	2.90	1.52
	1	1	38.38	19.98	8	0.73	0.09	2.20	3.88
		1.5	54.33	7.64	6	0.80	0.94	2.34	1.65
		2	73.92	3.89	4	0.83	0.92	2.74	1.44
	1.5	1	53.15	7.41	5	0.82	0.86	2.44	3.19
		1.5	67.90	4.26	4	0.87	0.93	2.56	1.80
		2	87.20	3.03	3	0.93	0.88	2.77	1.41
	2	1	72.10	4.51	3	0.86	0.96	2.65	2.24
		1.5	86.35	3.37	3	0.78	0.66	2.63	1.78
		2	105.52	2.63	3	0.77	0.99	2.86	1.45

5.2. Managerial Implications

As we know, defects of a product, causes extra charges of substituting with a perfect one and etc. According to the obtained results and model analysis, managers can make important decisions in order to advance the goals. Quicker planning on more efficient products for timely delivery and recycling is important. In terms of timely delivery, it is also possible to plan, considering the return rate of the product with the highest return rate, that too many material and product other are Eco-friendly for precautionary reasons. Investing more on high-performance return products is another aspect for managers to decide. From the point of view of investing in return product with more efficiency, return product with reliability greater than other materials can be mentioned.

6.Conclusions

This paper concerned with inclusion of quality inspection in the process of reverse supply chain items' collection and re-manufacturing. We configured a reverse supply chain and modeled a minimization formulation to handle several cost operations within the return flow of the products. The major contribution of the work was to consider inspection operation as a quality assurance focal element. The presented model was an integer linear programming model for multi-layer, multi-product reverse supply chain that minimizes the products operation costs and inspection costs among different centers in layers for variety of products. We have studied the joint economic design of EWMA control charts for monitoring the mean and variance of a process. In our numerical examples we have observed that, in general, both the optimal sample size and sampling interval decrease as the size of shifts in mean and/or variance increases. The outputs implied that the proposed model is helpful in industrial system as it encompasses both cost and quality. The quality was monitored in EWMA control chart and then formulated as a cost model to be integrated with the operations cost minimization of the reverse supply chain.

As for future research directions, one can study the bullwhip effect of supply chain in the reverse model and analyze it as a new quality factor; also, the sensitivity analysis of the control parameters of EWMA control chart can be performed to have a more flexible interval for parameters.

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MULTI-CRITERIA FUCOM-MAIRCA MODEL FOR THE EVALUATION OF LEVEL CROSSINGS: CASE STUDY IN THE REPUBLIC OF SERBIA

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Abstract: *A level crossing, as a point of the crossing of road and rail traffic in the same level, is a place of conflicts subject to traffic accidents. In Serbia, the selection of the level crossings to be secured is mostly done based on the media and society pressure, as a result of an increase of the number of accidents at level crossings. This paper presents the application of a group multi-criteria FUCOM-MAIRCA (Full Consistency Method – Multi Attributive Ideal-Real Comparative Analysis) model that supports the process of selecting a level crossing in terms of investing in its security equipment. The FUCOM-MAIRCA multi-criteria model is tested in a case study which included the evaluation of ten level crossings within the railway infrastructure in the Republic of Serbia. The evaluation of the crossings is carried out through the assessment according to seven criteria set out on the basis of representative literature and surveys of experts. Sensitivity test of the FUCOM-MAIRCA model is performed by changing the weight coefficients of criteria and statistically processing the results using Spearman's rank correlation coefficient.*

Key words: *railway level crossings, FUCOM, MAIRCA, multi-criteria decision making, railway accidents.*

1. Introduction

A level crossing, as a point of the crossing of road and rail traffic in the same level, is a place of conflicts subject to traffic accidents (Law on Road Traffic Safety, 2018), which can have the consequences in terms of material damage and/or perished persons (Pamučar et al., 2015). At the occurrence of traffic accident between the road and the rail vehicle, there is an exchange of collision forces that are extremely high due to large mass of the two vehicles. The contact during the accident is usually made between the front part of a train and the lateral part of a road vehicle,

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so that such traffic accidents often result in substantial material damage or severe injuries.

It is estimated that as an average 1.312 lives are lost per day in traffic accident in the world (Park, 2007). According to the report of the European Railway Agency, 27% of total number of deaths in the railroad accidents happens at level crossings (Ćirović & Pamučar, 2013). Traffic accidents at level crossings are mostly the result of misconduct and careless behavior of participants in road traffic. In the previous year (2017) in Serbia in 57 accidents, eight people are died that shows the significance of this problem. Such statistics are not only in Serbia, but the indicators are approximate in other countries, and this problem has been recognized by the International Rail Union.

According to the EU statistics (European Railway Agency, 2011), the volume of rail transport will be doubled over the following 30 years, which is a direct indication of the expected increase of extraordinary events at level crossings on all railroads, including those in Serbia. Increasing traffic volume will increase also the need for raising the level of crossing insurance at road crossings. In this context, the need for investing funds in terms of road crossings safety will also be defined. The provision of road crossings with modern safety equipment is costly investment, so when making an investment decision, the responsibility of the management is high, because the approved funds have to provide adequate effect.

In Serbia, 77% of level crossings are not secured according to the Law on Traffic Safety and applicable instructions of the Serbian Railways (Pamučar et al., 2015). On the Serbian railways network with a total length of 6,974 km there are 2354 level crossings, 108 of which are pedestrian crossings. Out of this number, 588 crossings are secured with automatic or mechanical devices. Securing level crossings represents significant material expenditure, so it is necessary to be grounded on reliable strategies for the selection of a level crossing that needs to be secured, as well as to be supported by the investments realization plan in terms of its security.

In this paper is proposed the FUCOM-MAIRCA multi-criteria model for the evaluation of level crossings and the creation of a strategy for the selection of priority level crossings that need to be secured. The criteria affecting the selection of the level crossing for the installation of necessary equipment to increase the security are defined. The survey of experts is conducted in the research in order to collect necessary data for determining relative weight criteria using the FUCOM model. The final evaluation and selection of priority crossings is carried out using the MAIRCA model.

Through the research and development of the model in this paper several goals are presented: (1) Review of the existing methodologies for the evaluation of level crossings; (2) Improving the methodology for crossings evaluation and selecting priority crossings for the installation of security equipment through the development of original multi-criteria FUCOM-MAIRCA model; (3) Proposal of new methodology for the identification of high-risk crossings; (4) Bridging the gap that currently exists in the methodology for evaluating and selecting priority crossings for the installation of safety equipment; and (5) Popularizing and affirming new models of multi-criteria decision making (FUCOM and MAIRCA models) through their application in making complex decisions.

The remaining sections of the paper are organized as follows. In the second part, a brief overview of the literature is presented and a review of similar research topics in which are applied the models for the selection and evaluation of crossings. In the third part, the models used are briefly presented and the FUCOM-MAIRCA algorithm is shown. The fourth part presents a case study in which is carried out the evaluation of ten railway crossings within the railway infrastructure in the Republic of Serbia. The fifth part includes the sensitivity analysis in terms of testing the stability of the results by changing the weight coefficients of criteria in the FUCOM-MAIRCA model. The sixth part presents key contributions of the developed model, as well as suggestions for future research.

2. Literature review

The first mathematical models for the evaluation and ranking of crossings were developed in the mid 20th century (Berg, 1966). Berg (1966) presented the model for the evaluation and ranking of level crossings on the basis of a statistical model for predicting the number of traffic accidents. Later Qureshi et al. (2003) improved the statistical model shown by Berg (1966) through the application of data mining. In addition to the above mentioned models, in many countries of the world the evaluation of crossings is performed using Quantified Risk Analysis (QRA). QRA provides a suitable basis for establishing level crossing improvement priorities. This it does by allowing a ranking of level crossings in terms of their accident risk probability. Those crossings with high accident probabilities would normally qualify for funding allocations, while those with low accident probabilities would be assigned a low priority for improvement funding. The Oregon State Highway Department completed a study concerned with measuring the relative hazards of railroad grade crossings located on state and federal-aid highway systems (Tey et al., 2009). The majority of the 400 grade crossings considered were located in incorporated areas. Application of QRA can be see in papers of many authors (Reiff et al., 2003; Tey et al., 2009; Anandarao & Martland, 1998; Woods et al., 2008).

The Armour Research Foundation has conducted two grade crossing accident studies for the Association of American Railroads results of an analysis of 2.291 grade crossings in the State of Iowa were reported in 1958 (Crecink, 1958). Regression analysis techniques were utilized to develop risk factors (the expected accident rates at grade crossings over a 16- year period) as a function of type of protection, highway traffic volume, number of tracks, and a measure of visibility. However, the regression model lacked consistency with accepted a priori assumptions concerning the relationships between the study variables. The second study performed by the Armour Research Foundation was an investigation of the relationships between accidents and nine grade crossing characteristics at 7.416 locations in the State of Ohio (Crecink, 1958). A regression analysis routine was used to develop models predicting a ten-year expected accident rate. Equations were developed for four separate types of protection: painted crossbucks, reflectorized crossbucks, flashers, and gates.

In addition to the above mentioned models, there are also numerous models used by different states in the USA to prioritize rail-highway level crossings (Elzohairy & Benekohal, 2000): (1) The Department of Transportation accident prediction formula (USDOT Accident Prediction Model), (2) California s Hazard Rating Formula, (3) Connecticut s Hazard Rating Formula, that is very similar to that of California, (4) Kansas's Design Hazard Rating Formula, (5) The Missouri crossing improvement program currently uses a calculated Exposure Index (Missouri s Exposure Index Formula) to prioritize crossings for possible improvements, (6) nois s modified expected accident frequency formula used to rank grade crossings (Elzohairy & Benekohal, 2000).

As compare to conventional cost-benefit approach, multicriteria analysis allows effective comparative evaluation among options and stakeholders over a common set of evaluation objectives. Furthermore, multi-criteria analysis could overcome the limitation of cost-benefit analysis whereby all the costs and benefits have to be expressed in monetary terms (Ćirović & Pamučar, 2013). Ford and Matthews (2002) and Roop et al. (2005) adoped multi-criteria analysis technique to assess the relative merits of the candidate protection systems and evoluation of railway level crossings. In addition to classic multi-criteria techniques, Ćirović & Pamučar (2013) presented the modeling of the neuro-fuzzy system for the prioritizing of crossings. The study showed successful use of adaptive artificial intelligence models for predicting risks at the crossings.

Therefore, the managers of railway companies and agencies involved in improving road safety should try to answer several questions, such as how to prioritize level crossings and how to build a strategy of investing in the improvement of their security. In such cases, multi-criteria decision making models offer practical solutions. However, the design of multi-criteria framework for the evaluation of level crossings is a complex process that is still being developed to improve the area under consideration in this paper (Roop et al., 2005). Accordingly, in order to face the above challenges, it is necessary to develop a model for the evaluation and ranking of crossings. It is precisely this purpose that the goal of this study results from, and that is to provide a comprehensive model for making sustainable investment strategy in improving the security of crossings using multi-criteria models. In order to achieve this goal, the main research question of this study is how to form a decision-making model in which key risk indicators on the crossings are implemented and which allows determining priority of crossings while creating sustainable strategy for investing in security equipment? In order to solve this problem, this study suggests the evaluation of crossings using the FUCOM and MAIRCA models. The implementation of multi-criteria approach in the models for evaluating crossings has been very limited so far. More precisely, there are no studies that consider the integration of the FUCOM and MAIRCA models, not only in the field of evaluation of crossings, but neither in literature in the field of multi-criteria decision making (MCDM). The FUCOM-MAIRCA model is new comprehensive multi-criteria model that can be very successfully applied in other studies that are not covered by this paper.

3. Methodological presentation of the FUCOM and MAIRCA models

The FUCOM-MAIRCA model is implemented through two phases. In the first phase, through the application of the FUCOM model the expert evaluation of criteria is carried out and determining of weight coefficients of criteria. The obtained values of the weight coefficients are further used in the second phase of the model for determining the values of theoretical assessments of the MAIRCA model. In the following sections (sections 3.1 and 3.2), the steps of the FUCOM and MAIRCA model are presented in detail.

3.1. Full Consistency Method (FUCOM)

The FUCOM (Pamučar et al, 2018a) belongs to new models for subjective determining of weights of criteria in multi-criteria decision making. The FUCOM is a tool that helps managers deal with their own subjectivity in prioritizing criteria through simple algorithm and using a scale acceptable for them. Some advantages that make the authors opt for the FUCOM are the following: (1) FUCOM allows obtaining optimal weight coefficients with the ability to validate them by consistency of the results; (2) Applying FUCOM, the optimal values of weight coefficients are obtained with simple mathematical apparatus that allows favoring certain criteria in evaluating phenomena in accordance with current requirements of decision-makers and minimizing the risks in decision-making; (3) FUCOM provides optimal values of weight coefficients with minimal subjective influence and minimal impact of inconsistencies of expert preferences on the final values of the weights of criteria; (4) Only the n-1 comparison of criteria is required; (5) The model is flexible and suitable for application to different measurement scales representing expert preferences.

In the next section is presented the FUCOM algorithm including the following steps:

Step 1. In the first step, the criteria from the predefined set of the evaluation criteria $C=\{C_1, C_2, ..., C_n\}$ are ranked. The ranking is performed according to the significance of the criteria, i.e. starting from the criterion which is expected to have the highest weight coefficient to the criterion of the least significance. Thus, the criteria ranked according to the expected values of the weight coefficients are obtained:

$$C_{j(1)} > C_{j(2)} > ... > C_{j(k)} \tag{1}$$

where *k* represents the rank of the observed criterion. If there is a judgment of the existence of two or more criteria with the same significance, the sign of equality is placed instead of ">" between these criteria in the expression (1)

Step 2. In the second step, a comparison of the ranked criteria is carried out and the *comparative priority* ($\varphi_{k/(k+1)}$, $k=1,2,...,n$, where *k* represents the rank of the criteria) of the evaluation criteria is determined. The comparative priority of the evaluation criteria ($\varphi_{k/(k+1)}$) is an advantage of the criterion of the $C_{j(k)}$ rank compared to the criterion of the $C_{j(k+1)}$ rank. Thus, the vectors of the comparative priorities of the evaluation criteria are obtained, as in the expression (2)

$$\Phi = \left(\varphi_{1/2}, \varphi_{2/3}, ..., \varphi_{k/(k+1)}\right) \tag{2}$$

where $\varphi_{k/(k+1)}$ represents the significance (priority) that the criterion of the $C_{j(k)}$ rank has compared to the criterion of the $C_{j(k+1)}$ rank.

The comparative priority of the criteria is defined in one of the two ways defined in the following part:

a) Pursuant to their preferences, decision-makers define the comparative priority $\varphi_{k/(k+1)}$ among the observed criteria. Thus, for example, if two stones A and B, which, respectively, have the weights of $w_A = 300$ grams and $w_B = 255$ grams are observed, the comparative priority ($\varphi_{A/B}$) of Stone A in relation to Stone B is $\varphi_{A/B} = 300/255 = 1.18$. Also, if the weights A and B cannot be determined precisely, but a predefined scale is used, e.g. from 1 to 9, then it can be said that stones A and B have weights $w_A = 8$ and $w_B = 7$. respectively. Then the comparative priority ($\varphi_{A/B}$) of Stone A in relation to Stone B can be determined as $\varphi_{A/B} = 8/7 = 1.14$. This means that stone A in relation to stone B has a greater priority (weight) by 1.18 (in the case of precise measurements), i.e. by 1.14 (in the case of application of measuring scale). In the same manner, decision-makers define the comparative priority among the observed criteria $\varphi_{k/(k+1)}$. When solving real problems, decision-makers compare the ranked criteria based on internal knowledge, so they determine the comparative priority $\varphi_{k/(k+1)}$ based on subjective preferences. If the decision-maker thinks that the criterion of the $C_{j(k)}$ rank has the same significance as the criterion of the $C_{j(k+1)}$ rank, then the comparative priority is $\varphi_{k/(k+1)} = 1$.

b) Based on a predefined scale for the comparison of criteria, decision-makers compare the criteria and thus determine the significance of each individual criterion in the expression (1). The comparison is made with respect to the first-ranked (the most significant) criterion. Thus, the significance of the criteria ($\varpi_{C_{j(k)}}$) for all of the criteria ranked in Step 1 is obtained. Since the first-ranked criterion is compared with itself (its significance is $\varpi_{C_{j(1)}} = 1$), a conclusion can be drawn that the *n-1* comparison of the criteria should be performed.

As we can see from the example shown in Step 2b, the FUCOM model allows the pairwise comparison of the criteria by means of using integer, decimal values or the values from the predefined scale for the pairwise comparison of the criteria.

Step 3. In the third step, the final values of the weight coefficients of the evaluation criteria $(w_1, w_2, ..., w_n)^T$ are calculated. The final values of the weight coefficients should satisfy the two conditions:

a) that the ratio of the weight coefficients is equal to the comparative priority among the observed criteria ($\varphi_{k/(k+1)}$) defined in *Step 2*, i.e. that the following condition is met:

$$\frac{w_k}{w_{k+1}} = \varphi_{k/(k+1)} \tag{3}$$

b) In addition to the condition (3), the final values of the weight 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 $\varphi_{(k+1)/(k+2)} = \frac{w_{k+1}}{w_{k+2}}$, that $\frac{w_k}{w_{k+1}} \otimes \frac{w_{k+1}}{w_{k+2}} = \frac{w_k}{w_{k+2}}$ is obtained. Thus, yet another condition that the final values of the weight coefficients of the evaluation criteria need to meet is obtained, namely:

$$\frac{w_k}{w_{k+2}} = \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} \tag{4}$$

Full consistency i.e. minimum DFC (χ) is satisfied only if transitivity is fully respected, i.e. when the conditions of $\frac{w_k}{w_{k+1}} = \varphi_{k/(k+1)}$ and $\frac{w_k}{w_{k+2}} = \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)}$ are met. In that way, the requirement for maximum consistency is fulfilled, i.e. DFC is $\chi = 0$ for the obtained values of the weight coefficients. In order for the conditions to be met, it is necessary that the values of the weight coefficients $(w_1, w_2, ..., w_n)^T$ meet the condition of $\left|\frac{w_k}{w_{k+1}} - \varphi_{k/(k+1)}\right| \le \chi$ and $\left|\frac{w_k}{w_{k+2}} - \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)}\right| \le \chi$, with the minimization of the value χ. In that manner the requirement for maximum consistency is satisfied.

Based on the defined settings, the final model for determining the final values of the weight coefficients of the evaluation criteria can be defined.

$$\begin{aligned}
&\min \chi \\
&\text{s.t.} \\
&\left|\frac{w_{j(k)}}{w_{j(k+1)}} - \varphi_{k/(k+1)}\right| \le \chi, \ \forall j \\
&\left|\frac{w_{j(k)}}{w_{j(k+2)}} - \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)}\right| \le \chi, \ \forall j \\
&\sum_{j=1}^{n} w_j = 1, \ \forall j \\
&w_j \ge 0, \ \forall j
\end{aligned} \tag{5}$$

By solving the model (5), the final values of the evaluation criteria $(w_1, w_2, ..., w_n)^T$ and the degree of DFC (χ) are generated. In order to achieve a better understanding of the presented model, two simple examples will demonstrate the process of determining weight coefficients by applying FUCOM. In the first example, the procedure for determining the *comparative priority* ($\varphi_{k/(k+1)}$) is shown by applying Step 2a, whereas in the second example, $\varphi_{k/(k+1)}$ is determined by applying Step 2b.

3.2. Multi-Attributive Ideal-Real Comparative Analysis (MAIRCA)

The basic MAIRCA set-up is to define the gap between ideal and empirical ratings (Gigović et al., 2016; Pamučar et al., 2017, 2018b; Chatterjee et al., 2018). Summing up the gap by each criterion generates the total gap for each alternative observed. Ranking the alternatives comes at the end of the process, where the best-ranked alternative is the one with the lowest gap value. The alternative with the lowest total gap value is the alternative, by most of the criteria, with the values closest to the ideal ratings (the ideal criteria values). The MAIRCA method is carried out in seven steps:

Step 1. Formulation of the initial decision-making matrix (X). The initial decision-making matrix (6) determines the criteria values (x_{ij}, $i=1,2,...n;\ j=1,2,...m$) for each alternative observed.

$$X = \begin{array}{c} \\ A_1 \\ A_2 \\ \dots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \dots & C_n \end{array} \\ \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & & x_{2n} \\ \dots & \dots & \dots & \dots \\ x_{m1} & x_{22} & \dots & x_{mn} \end{bmatrix} \end{array} \tag{6}$$

The criteria from the matrix (6) can be quantitative (measurable) and qualitative (descriptive). The quantitative criteria values in the matrix (6) are obtained by quantification of real indicators which present the criteria. The qualitative criteria values are determined by decision-maker's preferences or, in a case of a large number of experts, by aggregating the experts' opinions.

Step 2. Defining preferences for the choice of alternatives P_{A_i}. While selecting the alternatives, the decision maker (DM) is neutral, meaning there's no preference for any of the offered alternatives. The assumption is that the DM does not take into account the probability of choosing any particular alternative, and has no preference in the alternative selection process. The DM can then view the alternatives as if each can materialize with the same probability, and the preference for any of the m possible alternatives is

$$P_{A_i} = \frac{1}{m};\ \sum_{i=1}^{m} P_{A_i} = 1,\ i = 1,2,...,m \tag{7}$$

where m is the total number of the alternatives being selected.

In a decision-making analysis with a priori probabilities we proceed from the point that the DM is neutral to selection probability of each alternative. In that case, all preferences for the selection of individual alternatives are equal, i.e.

$$P_{A_1} = P_{A_2} = ... = P_{A_m} \tag{8}$$

where m is the total number of the alternatives being selected.

Step 3. Calculation of the elements of the theoretical ratings matrix (T_p).

The format of the matrix (T_p) is $n \times m$ (where n is the total number of criteria, m is the total number of alternatives). The elements of the theoretical ratings matrix (t_{pij}) are calculated as a product of preferences for the selection of alternatives P_{A_i} and criterion weights (w_i, $i = 1,2,...,n$)

$$T_p = \begin{array}{c} \\ P_{A_1} \\ P_{A_2} \\ ... \\ P_{A_m} \end{array} \begin{array}{c} \begin{array}{cccc} w_1 & w_2 & ... & w_n \end{array} \\ \begin{bmatrix} t_{p11} & t_{p12} & ... & t_{p1n} \\ t_{p21} & t_{p22} & & t_{p2n} \\ ... & ... & ... & ... \\ t_{pm1} & t_{pm2} & ... & t_{pmn} \end{bmatrix} \end{array} = \begin{array}{c} \\ P_{A_1} \\ P_{A_2} \\ ... \\ P_{A_m} \end{array} \begin{array}{c} \begin{array}{cccc} w_1 & w_2 & ... & w_n \end{array} \\ \begin{bmatrix} P_{A_1} \bullet w_1 & P_{A_1} \bullet w_2 & ... & P_{A_1} \bullet w_n \\ P_{A_2} \bullet w_1 & P_{A_2} \bullet w_2 & & P_{A_2} \bullet w_n \\ ... & ... & ... & ... \\ P_{A_m} \bullet w_1 & P_{A_m} \bullet w_2 & ... & P_{A_m} \bullet w_n \end{bmatrix} \end{array} \tag{9}$$

Since the DM is neutral towards the initial alternative selection, the preferences (P_{A_i}) are the same for all alternatives. As the preferences (P_{A_i}) are the same for all the alternatives, we can also present the matrix (9) in the format $n \times 1$ (where n is the total number of criteria).

$$T_p = P_{A_i} \begin{array}{c} \begin{array}{cccc} w_1 & w_2 & ... & w_n \end{array} \\ \begin{bmatrix} t_{p1} & t_{p2} & ... & t_{pn} \end{bmatrix} \end{array} = P_{A_i} \begin{array}{c} \begin{array}{cccc} w_1 & w_2 & ... & w_n \end{array} \\ \begin{bmatrix} P_{A_i} \bullet w_1 & P_{A_i} \bullet w_2 & ... & P_{A_i} \bullet w_n \end{bmatrix} \end{array} \tag{10}$$

where n is the total number of criteria, and t_{pi} theoretical rating.

Step 4. Definition of the elements of real ratings matrix (T_r).

$$T_r = \begin{array}{c} \\ A_1 \\ A_2 \\ ... \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & ... & C_n \end{array} \\ \begin{bmatrix} t_{r11} & t_{r12} & ... & t_{r1n} \\ t_{r21} & t_{r22} & & t_{r2n} \\ ... & ... & ... & ... \\ t_{rm1} & t_{rm2} & ... & t_{rmn} \end{bmatrix} \end{array} \tag{11}$$

where n represents the total number of criteria, and m the total number of alternatives.

In calculation of the elements of the real ratings matrix (T_r) the elements of the theoretical ratings matrix (T_p) are multiplied by the elements of the initial decision-making matrix (X) using the following formulas:

For the benefit type criteria (preferred higher criteria value)

$$t_{rij} = t_{pij} \bullet \left(\frac{x_{ij} - x_i^-}{x_i^+ - x_i^-} \right) \tag{12}$$

For the cost type criteria (preferred lower criteria value)

$$t_{rij} = t_{pij} \bullet \left(\frac{x_{ij} - x_i^+}{x_i^- - x_i^+} \right) \tag{13}$$

where x_{ij}, x_i^+ and x_i^- represent the elements of the initial decision-making matrix (X), and x_i^+ i x_i^- are defined as:

$x_i^+ = \max(x_1, x_2, ..., x_m)$, representing the maximum values of the observed criterion by alternatives.

$x_i^- = \min(x_1, x_2, ..., x_m)$, representing the minimum values of the observed criterion by alternatives.

Step 5. The calculation of the total gap matrix (G). The elements of the G matrix are obtained as a difference (gap) between the theoretical (t_{pij}) and real ratings (t_{rij}), i.e. , a difference between the theoretical ratings matrix (T_p) and the real ratings matrix (T_r)

$$G = T_p - T_r = \begin{bmatrix} g_{11} & g_{12} & \cdots & g_{1n} \\ g_{21} & g_{22} & \cdots & g_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ g_{m1} & g_{m2} & \cdots & g_{mn} \end{bmatrix} = \begin{bmatrix} t_{p11} - t_{r11} & t_{p12} - t_{r12} & \cdots & t_{p1n} - t_{r1n} \\ t_{p21} - t_{r21} & t_{p22} - t_{r22} & \cdots & t_{p2n} - t_{r2n} \\ \cdots & \cdots & \cdots & \cdots \\ t_{pm1} - t_{rm1} & t_{pm2} - t_{rm2} & \cdots & t_{pmn} - t_{rmn} \end{bmatrix} \tag{14}$$

where n represents the total number of criteria, m is the total number of the alternatives being selected.

The gap g_{ij} takes the values from the interval $g_{ij} \in [0, \infty)$, by the equation (15)

$$g_{ij} = t_{pij} - t_{rij} \tag{15}$$

The preferable option is that g_{ij} gravitates towards zero ($g_{ij} \to 0$), since we are choosing the alterative with the smallest difference between theoretical ratings (t_{pij}) and real ratings (t_{rij}). If for the criterion C_i the alternative A_i has the theoretical rating value equal to the real rating value ($t_{pij} = t_{rij}$), the gap for the alternative A_i, by the criterion C_i, is $g_{ij} = 0$. In other words, by the criterion C_i, the alternative A_i is the best (ideal) alternative (A_i^+).

If by the criterion C_i the alternative A_i has the value of theoretical ratings t_{pij}, and the value of real ratings $t_{rij} = 0$, the gap for the alternative A_i, by the criterion C_i, is $g_{ij} = t_{pij}$. In other words, the alternative A_i is the worst (anti-ideal) alternative (A_i^-) by the criterion C_i.

Step 6. The calculation of the final values of criteria functions (Q_i) by alternatives. The values of criteria functions are obtained by summing the gap (g_{ij}) by alternatives, that is, by summing the elements of matrix (G) by columns, Eqn. (16)

$$Q_i = \sum_{j=1}^{n} g_{ij},\ i = 1,2,...,m \tag{16}$$

Where n is the total number of criteria, and m is the total number of the alternatives being selected.

Step 7. Defining the dominance index $\left(A_{D,1-j}\right)$ *of the best-ranked alternative and final rank of alternatives.*

The dominance index of the best-ranked alternative defines its advantage in relation to the other alternatives, and determined here by applying Eqn. (17).

$$A_{D,1-j} = \left| \frac{|Q_j| - |Q_1|}{|Q_n|} \right|,\ j = 2,3,..,m \tag{17}$$

where Q_1 denotes the criterion function of the best-ranked alternative, Q_n denotes the criterion function of the last ranked alternative, Q_j denotes the criterion function of the alternative which is compared to the best-ranked alternative, and *m* denotes the number of alternatives.

Once the dominance index is determined, the dominance threshold I_D is determined by applying Eqn.(18)

$$I_D = \frac{m-1}{m^2} \tag{18}$$

where *m* denotes the number of alternatives.

Provided that the dominance index $A_{D,1-j}$ is greater or equal to dominance threshold I_D ($A_{D,1-j} \geq I_D$), the obtained rank will be retained. However, if the dominance index $A_{D,1-j}$ is smaller than the dominance threshold I_D ($A_{D,1-j} < I_D$), then it cannot be said with certainty that the first ranked alternatives have an advantage over the alternative being analyzed. The said restrictions can be shown by applying the following Eqn. (19)

$$R_{final,j} = \begin{cases} A_{D,1-j} \geq I_D & \Rightarrow \ R_{final,j} = R_{initial,j} \\ A_{D,1-j} < I_D & \Rightarrow \ R_{final,j} = R_{initial,1} \end{cases} \tag{19}$$

where $R_{initial,j}$ and $R_{final,j}$ denotes the initial and final rank of the alternative, respectively, that is compared with the best-ranked alternative, I_D denotes the dominance threshold, and $A_{D,1-j}$ denotes the dominance index of the best-ranked alternative in relation to the alternative.

Provided that criterion $A_{D,1-j} < I_D$ is satisfied, then the rank of the alternative that is compared to the best-ranked alternative will be corrected and then treated as the best-ranked alternative and assigned the value "1*". In this way it is emphasized that the best-ranked alternative is characterized by a smaller advantage than the one specified in Eqn. (18).

Assume, for example, that the best-ranked alternative is compared to the second-ranked alternative and that the criterion $A_{D,1-2} < I_D$ is satisfied. Then the second-ranked alternative will be assigned rank "1*". The comparison may proceed with the third-ranked alternative. If for the third-ranked alternative criterion $A_{D,1-3} < I_D$ is satisfied, then the third-ranked alternative will be assigned rank "1**" and so on, until reaching the last alternative.

Finally, correction of the initial ranks ($R_{initial}$) is carried out for all alternatives satisfying criterion $A_{D,1-j} < I_D$, while the ranks of alternatives satisfying the criterion $A_{D,1-j} \geq I_D$ remain unchanged. Therefore, the final rank of alternatives (R_{final}) which is presented simultaneously with the initial rank of alternatives ($R_{initial}$) is obtained.

4. Application of the FUCOM-MAIRCA model

The most important task of the safety management in road and rail traffic is to raise safety level of traffic at level crossings (Jankovic & Mladenovic, 2011). In order to identify the crossings which requires the intervention, either in terms of changes in safety method, or in terms of reconstruction and maintenance of road and railway infrastructure, it is necessary to dispose of various data which can be classified in three categories (Jankovic et al., 2014): (1) data on current condition of the level crossings: location of the crossing from the aspect of railway (station area or open rail) and from the aspect of road (main, regional or local), existing safety system on the level crossing, existing road and railway signalization condition in the level crossing area, type and condition of road surface at the crossing, barriers and drainage systems in the crossing area, geometric parameters of the crossing, sight triangle and distance visibility, (non) existence of opportunities for level separation, prescribed speed of trains and road vehicles in the crossings area; (2) Data on traffic accidents at crossings for a selected period: total number of accidents, structure of accidents by consequences, total number of minor, serious injuries and killed persons, total material damage and (3) Data on volume and structure of road and rail traffic at crossings.

On the basis of the recommendations from the literature (Jankovic & Mladenovic, 2011; Ćirović & Pamučar, 2013; Jankovic et al., 2014), as well as the empirical knowledge of four experts collected through the survey, the criteria for the evaluation of level crossings are defined and shown in the Table 1.

Table 1. Criteria for the evaluation of level crossings

Criterion	Brief description
Frequency of rail traffic at the observed level crossing (C1) - max	A parameter with a major impact on the probability of occurrence of extraordinary events at road crossings. Traffic volume and frequency are influenced by trains in internal traffic, as the needs of certain regional or other centers at the part of the railway. The number of truck/month
Road traffic frequency at the observed level crossing (C2) - max	This factor is particularly significant in urban areas where the railway line divides city zones, where road traffic is loaded with more vehicles and pedestrians and where, due to poor technical possibilities of railway traffic equipment, waiting time for passing of a train is larger than usual (even up to 10 minutes). In urban zones, there are crossings where the road crosses several tracks. This increases the likelihood of occurrence of extraordinary events at the crossings. The number of vehicles/h
Number of tracks at the observed level crossing (C3) - max	The number of tracks directly affects the time that road users spend on the railroad. With the increase of the number of tracks, the time from the moment of moving of the vehicle from the stop line from one side of the crossing to the pass of the rear part of the vehicle out of the rail profile at the given crossing also increases. The number of tracks at road crossings
Maximum permitted speed of trains at the level crossing chainage (C4) - max	A parameter that is particularly significant for crossings that are only secured by road signs. This parameter is indirectly related to the visibility of the crossing for road vehicle drivers or pedestrians. Maximum permitted speed of trains at road section
Angle of crossing of road and rail (C5) - max	The optimum angle of crossing of rail and road at the crossing is 90 degrees. However, the construction possibilities, the terrain configuration, the position of the existing roads and other circumstances make the road and rail crossing angle in practice range from 30 to 175 degrees. Angle of crossing of road and rail
Number of extraordinary events at the observed level crossing (C6) - max	Extraordinary events are followed by great material damage, killed and severely injured persons. Number of extraordinary events at level crossing
Sight of the observed crossing from the aspect of road traffic (C7) - min	Sight at a given road crossing is a parameter that has an impact on the decision of a road vehicle driver to start driving over the crossing in cases where the crossing is not secured by active protection devices (semi-barriers or barriers). Sight of the crossing means that when a driver stops his vehicle on the stop line, he can observe the traffic situation. The qualitative criterion that evaluating using linguistic scale 1 - 9

As defined in the previous section, the first phase of the model implies the application of the FUCOM to determine weight coefficients of criteria.

Step 1. In the first step, the criteria are ranged from the defined set of criteria, which is shown in the Table 1. Ranking of the criteria according to its significance is carried out by four experts.

Table 2. Rank of criteria

Expert	Rank
E1	C2>C5>C7>C1>C6>C3>C4
E2	C2>C5>C7>C1=C6>C3>C4
E3	C2>C5>C7>C1>C6>C4>C3
E4	C2>C7>C5>C1=C6>C3>C4

Step 2. In the second step, comparison of the ranked criteria is done and comparative significance of the evaluation criteria is determined. Comparative significance of the evaluation criteria is obtained by the survey of experts and it is shown in the Table 3.

Table 3. Comparative significance of criteria

Expert	Comparative Significance ($\varphi_{k/(k+1)}$)						
E1	C2	C5	C7	C1	C6	C3	C4
	1	1.28	1.10	1.18	1.05	1.10	1.38
E2	C2	C5	C7	C1	C6	C3	C4
	1	1.31	1.08	1.15	1.00	1.15	1.25
E3	C2	C5	C7	C1	C6	C4	C3
	1	1.22	1.13	1.20	1.03	1.15	1.20
E4	C2	C7	C5	C1	C6	C3	C4
	1	1.18	1.12	1.17	1.00	1.17	1.30

Step 3. In this step, the final values of the weight coefficients of the evaluation criteria are calculated $(w_1, w_2, ..., w_7)^T$ forming the model (5). By applying both the expressions (3) and (4) and the data from the Table 3, it is formed special model for determining the weight coefficients of the criteria for every expert:

$$\text{Expert } 1 - \min \chi$$
$$\text{s.t.}\begin{cases} \left|\frac{w_2}{w_5}-1.28\right|=\chi,\ \left|\frac{w_5}{w_7}-1.10\right|=\chi,\ \left|\frac{w_7}{w_1}-1.18\right|=\chi, \\ \left|\frac{w_1}{w_6}-1.05\right|=\chi,\ \left|\frac{w_6}{w_3}-1.10\right|=\chi,\ \left|\frac{w_3}{w_4}-1.38\right|=\chi, \\ \left|\frac{w_2}{w_7}-1.408\right|=\chi,\ \left|\frac{w_5}{w_1}-1.298\right|=\chi,\ \left|\frac{w_7}{w_6}-1.239\right|=\chi, \\ \left|\frac{w_1}{w_3}-1.155\right|=\chi, \left|\frac{w_6}{w_4}-1.518\right|=\chi, \\ \sum_{j=1}^{7} w_j=1,\ w_j\geq 0, \forall j \end{cases}$$

$$\vdots$$

$$\text{Expert } 4 - \min \chi$$
$$\text{s.t.}\begin{cases} \left|\frac{w_2}{w_7}-1.18\right|=\chi,\ \left|\frac{w_7}{w_5}-1.12\right|=\chi,\ \left|\frac{w_5}{w_1}-1.17\right|=\chi, \\ \left|\frac{w_1}{w_6}-1.00\right|=\chi,\ \left|\frac{w_6}{w_3}-1.17\right|=\chi,\ \left|\frac{w_3}{w_4}-1.30\right|=\chi, \\ \left|\frac{w_2}{w_5}-1.322\right|=\chi,\ \left|\frac{w_7}{w_1}-1.310\right|=\chi,\ \left|\frac{w_5}{w_6}-1.17\right|=\chi, \\ \left|\frac{w_1}{w_3}-1.17\right|=\chi, \left|\frac{w_6}{w_4}-1.521\right|=\chi, \\ \sum_{j=1}^{7} w_j=1,\ w_j\geq 0, \forall j \end{cases}$$

By solving the presented models in the Lingo 17.0 software, we obtain the weight coefficients of the criteria for every expert, as shown in Table 4.

Table 4. Weight coefficients of criteria

Expe-rt	w_1	w_2	w_3	w_4	w_5	w_6	w_7	DFC (χ)
E1	0.1318	0.2190	0.1141	0.0827	0.1711	0.1256	0.1556	0.0000
E2	0.1319	0.2145	0.1147	0.0917	0.1638	0.1319	0.1516	0.0000
E3	0.1294	0.2140	0.0910	0.1093	0.1754	0.1256	0.1553	0.0002
E4	0.1327	0.2051	0.1134	0.0872	0.1552	0.1326	0.1738	0.0002
Ave-rage	0.1314	0.2132	0.1083	0.0927	0.1664	0.1289	0.1591	-

From the Table 4, it can be observed that the FUCOM provides fully consistent values of weight coefficients, since for every of the four models DFC≈0. Final values of the weight coefficients are obtained by averaging the weights obtained from every of the four models shown.

After calculating the weight coefficients of the criteria (w_i), the evaluation of the crossings is carried out using the MAIRCA method. In the Table 5 are shown the characteristics of ten level crossings (alternatives). The evaluation of the qualitative criteria C7 is made based on the assessments of the observed level crossing changing through the nine-degree scale.

Table 5. Evaluation of level crossings

Alternative	C1	C2	C3	C4	C5	C6	C7
A1	61	226	3	65	70	7	2
A2	91	33	2	60	88	4	8
A3	36	235	3	55	68	5	3
A4	99	122	2	80	62	3	2
A5	74	181	2	55	45	2	9
A6	86	33	3	55	78	6	6
A7	55	155	3	80	63	7	9
A8	111	128	4	75	60	3	7
A9	52	76	4	85	45	5	5
A10	77	123	2	50	85	5	3

After forming the initial decision matrix, as in the Table 5, the preferences are made according to the selection of the alternatives P_{A_i}. Since during the evaluation of the level crossing, experts do not have clear preference for selecting certain alternatives, then P_{A_i} is determined by applying the expression (7)

$$P_{A_i} = \frac{1}{m} = \frac{1}{10} = 0.10$$

In this case, all preferences for the selection of certain alternatives are the same (8)

$$P_{A_1} = P_{A_2} = \dots = P_{A_{10}} = 0.10$$

The calculation of the elements of the matrix of theoretical assessments (T_p), from the Table 6, is performed using the expression (9), respectively (10). Matrix elements are calculated by multiplying the preferences of selected alternatives P_{A_i} and the weight coefficients of criteria (w_i).

Table 6. Matrix of theoretical weights T_p

Alternative	C1	C2	C3	C4	C5	C6	C7
A1	0.0131	0.0213	0.0108	0.0093	0.0166	0.0129	0.0159
A2	0.0131	0.0213	0.0108	0.0093	0.0166	0.0129	0.0159
A3	0.0131	0.0213	0.0108	0.0093	0.0166	0.0129	0.0159
A4	0.0131	0.0213	0.0108	0.0093	0.0166	0.0129	0.0159
A5	0.0131	0.0213	0.0108	0.0093	0.0166	0.0129	0.0159
A6	0.0131	0.0213	0.0108	0.0093	0.0166	0.0129	0.0159
A7	0.0131	0.0213	0.0108	0.0093	0.0166	0.0129	0.0159
A8	0.0131	0.0213	0.0108	0.0093	0.0166	0.0129	0.0159
A9	0.0131	0.0213	0.0108	0.0093	0.0166	0.0129	0.0159
A10	0.0131	0.0213	0.0108	0.0093	0.0166	0.0129	0.0159

After forming the matrix of theoretical assessments (T_p), it is calculated the matrix of real assessments (T_r). The calculation of the real assessment matrix elements (Table 7) is carried out by multiplying the elements of the matrix of theoretical assessment (T_p) and normalized elements of the initial decision making matrix. Normalization of elements of the initial decision making matrix is performed using the expressions (12) and (13).

Table 7. Matrix of real assessments

Alternative	C1	C2	C3	C4	C5	C6	C7
A1	0.0044	0.0204	0.0054	0.0041	0.0104	0.0129	0.0159
A2	0.0096	0.0000	0.0000	0.0022	0.0166	0.0052	0.0023
A3	0.0000	0.0213	0.0054	0.0011	0.0077	0.0077	0.0136
A4	0.0110	0.0094	0.0000	0.0082	0.0063	0.0026	0.0159
A5	0.0067	0.0156	0.0000	0.0014	0.0002	0.0000	0.0000
A6	0.0088	0.0000	0.0054	0.0008	0.0147	0.0103	0.0068
A7	0.0033	0.0129	0.0054	0.0079	0.0104	0.0129	0.0000
A8	0.0131	0.0100	0.0108	0.0065	0.0039	0.0026	0.0045
A9	0.0028	0.0045	0.0108	0.0093	0.0000	0.0077	0.0091
A10	0.0072	0.0095	0.0000	0.0000	0.0159	0.0077	0.0136

The elements of the total gap matrix (G) are obtained as the difference (gap) between theoretical (t_{pij}) and real assessments (t_{rij}), respectively, by subtracting the elements of the matrix of theoretical assessments (T_p) and the elements of the real assessment matrix (T_r). By applying the expression (14) we obtain final total gap matrix, as shown in the Table 8. It is desirable that the value g_{ij} tends to zero ($g_{ij} \rightarrow 0$), since we select the alternative with the slightest difference between theoretical (t_{pij}) and real assessments (t_{rij}).

Table 8. Total gap matrix

Alternative	C1	C2	C3	C4	C5	C6	C7
A1	0.0088	0.0009	0.0054	0.0052	0.0063	0.0000	0.0000
A2	0.0035	0.0213	0.0108	0.0071	0.0000	0.0077	0.0136
A3	0.0131	0.0000	0.0054	0.0082	0.0089	0.0052	0.0023
A4	0.0021	0.0119	0.0108	0.0011	0.0104	0.0103	0.0000
A5	0.0065	0.0057	0.0108	0.0079	0.0164	0.0129	0.0159
A6	0.0044	0.0213	0.0054	0.0085	0.0019	0.0026	0.0091
A7	0.0098	0.0084	0.0054	0.0014	0.0063	0.0000	0.0159
A8	0.0000	0.0113	0.0000	0.0027	0.0128	0.0103	0.0114
A9	0.0103	0.0168	0.0000	0.0000	0.0166	0.0052	0.0068
A10	0.0060	0.0118	0.0108	0.0093	0.0007	0.0052	0.0023

The values of the criteria functions (Q_i) by alternatives (Table 9) are obtained by summing the gap (g_{ij}) by alternatives, as in the expression (16).

Table 9. Ranking alternatives according to the MAIRCA method

Alternative	*Q*	$R_{initial}$	R_{final}
A1	0.0266	1	1
A2	0.0641	9	9
A3	0.0431	2	2
A4	0.0466	4	4
A5	0.0761	10	10
A6	0.0532	7	7
A7	0.0472	5	5
A8	0.0485	6	6
A9	0.0557	8	8
A10	0.0460	3	3

A1>A3>A10>A4>A7>A8>A6>A9>A2>A5

Based on the obtained values of the criteria functions (Q_i) is determined the initial rank of alternatives ($R_{initial}$). According to the initial ranking, the best-ranked alternative is the alternative A1. In order to conclude whether the A1 is also the best alternative, it is necessary to determine if it sufficiently dominates over the other alternatives. It is therefore necessary to determine the index of domination of the alternative A1 ($A_{D,A1-j}$) over the other alternatives, as in the expression (17). Before determining the index of domination $A_{D,A1-j}$, using the expression (16), the dominance threshold I_D is to be defined which must be met by the alternative A1 so as to be ranked as the first one in final ranking.

$$I_D = \frac{n-1}{n^2} = \frac{10-1}{10^2} = 0.090$$

Since the condition $A_{D,1-j} \geq I_D$ is fulfilled for all the alternatives, we can conclude that all initial ranks of the alternatives are retained, respectively, that $R_{initial} = R_{final}$, as shown in the Table 9. On the basis of the obtained results, we conclude that the A1 alternative is first-ranked, respectively, A1> A3> A10> A4> A7> A8> A6> A9> A2> A5.

5. Sensitivity analysis and validation of results

The results of the multi-criteria models can significantly be influenced by the values of weight coefficients of the evaluation criteria. That is why the analysis of the influence of altering weight coefficients on the results of the research is a logical step to test the robustness of the applied model and the obtained results. Therefore, in this part of the paper is carried out the sensitivity analysis of the ranks of alternatives to changes in weight coefficients of the criteria. The sensitivity analysis is performed through seven situations. In every situation, one criterion is favorized whose weight coefficient is increased by 50 %. In the same situation, the weight coefficients are reduced by 50 % in the remaining criteria. Changes in the ranks of alternatives in seven situations are shown in the Figure 1.

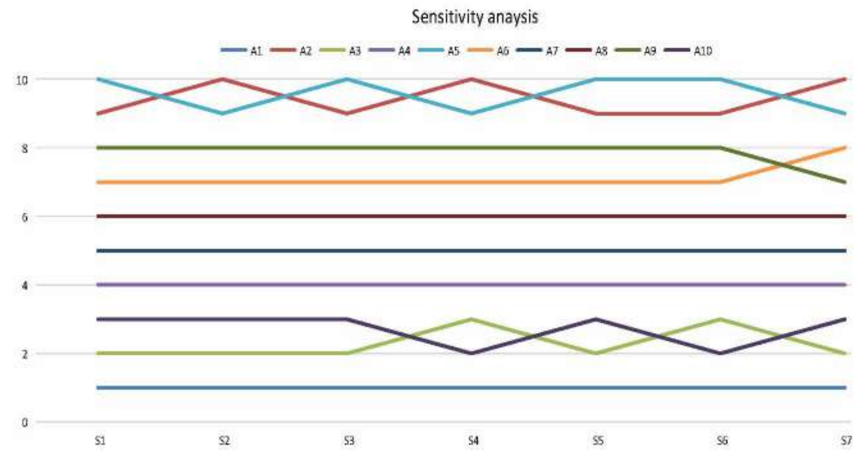

Figure 1. Sensitivity analysis of the ranks of alternatives through seven situations

The results (Figure 1) show that assigning different weights of criteria through situations leads to minor variations in the ranking of alternatives, which confirms that the model is sensitive to changes in weight coefficients. By comparing the first-ranked alternatives (A1 and A3), we note that the alternative A1 retains its rank in all situations (it remained the first-ranked), while the alternative A3 in five situations keeps its ranking, and in two situations it is third-ranked. During sensitivity analysis there was a change of ranks of the alternatives A2, A9 and A6. However, we can conclude that these changes were not drastic, as evidenced by high rank correlation through situations (Figure 2). The correlation was determined using Spearman's coefficient of correlation (Chatterjee et al, 2018).

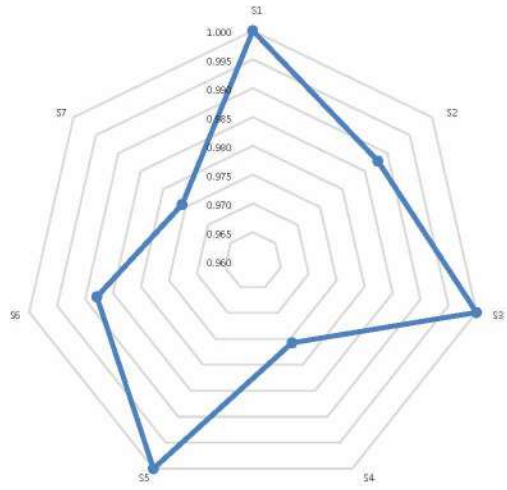

Figure 2. Correlation of ranks through seven situations of sensitivity analysis

The values of Spearman's coefficient of correlation were obtained by comparing the initial rank of the FUCOM- MAIRCA model (Table 9) with the ranks obtained through the situations (Figure 1). In the Figure 2, we note that there is extremely high correlation of ranks, since in all situations the value of the correlation coefficient is higher than 0.970. Mean value of the correlation coefficient through all the situations amounts to 0.990, which shows extremely high correlation. Since all values of the correlation coefficient are significantly greater than 0.90, we can conclude that there is a very high correlation (closeness) of ranks and that the proposed ranking is confirmed and credible.

6. Conclusion

In this research is presented the use of multi-criteria FUCOM-MAIRCA model for evaluating level crossings. The key contribution of this paper is new FUCOM-MAIRCA model for the evaluation of crossings. Presented model allows consideration of subjectivity in the process of group decision making through linguistic evaluation of the evaluation criteria. In addition, the model presented in this paper introduces new methodological principles for the evaluation of the crossings, which at the same time contributes to the improvement of theoretical basis of multi-criteria decision making in general. The developed approach allows bridging the gap that currently exists in the methodology for evaluating the crossings.

The FUCOM-MAIRCA model was applied in the evaluation of ten level crossings on the territory of the Republic of Serbia. The results obtained were verified through sensitivity analysis carried out based on seven situations. The stability of the model is verified through statistical correlation coefficient showing high correlation of ranks in all situations. Consideration of the results and sensitivity analysis of the FUCOM-MAIRCA model show significant stability of the results and promising applicability of the model shown. Securing level crossings represents significant material expenditure, so it is necessary to be grounded on reliable strategies for the selection of a level crossing that needs to be secured, as well as to be supported by the investments realization plan in terms of its security. Also, this integrated FUCOM-MAIRCA model can be applied for evaluation of reliable strategies for the selection of a level crossing that needs to be secured in the next phase.

Since these are new models of multi-criteria decision making, the directions of future research should focus on the application of uncertainty theories (fuzzy sets, rough numbers, gray numbers, neutrosophic sets *etc.*) in the FUCOM and MAIRCA models. The integration of the uncertainty theories in the FUCOM and MAIRCA models would allow significant exploitation of uncertainty and subjectivity existing in the decision-making process.

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