Economic Horizons, September - December 2017, Volume 19, Number 3, 193 - 209
UDC: 33 eISSN 2217-9232

Review paper
UDC: 005:519.8
doi:10.5937/ekonhor1703193T

MODEL FOR THE SUPPLY CHAIN MANAGEMENT BASED ON THE INTERVAL TYPE-2 FUZZY NUMBERS AND THE TOPSIS METHOD

Danijela Tadic* and Aleksandar Djordjevic

Faculty of Engineering, University of Kragujevac, Kragujevac, The Republic of Serbia

The Performance improvement that leads to an increase in business efficiency, both for the enterprises integrated in the supply chain and the entire supply chain, represents one of the basic strategic management problems. A solution to this problem, among other things, can be obtained by measuring and improving the performance of the supply chain, which simultaneously represents the basic purpose of this research study. The relative importance of performances and the values of their key performance indices are assessed by decision-makers. Their assessments are described by linguistic variables, which are modelled by interval fuzzy numbers type-2. The relative importance of performance is obtained by defining the fuzzy matrix of the relative importance of each pair of performances. The weight values of performances are calculated by means of the eigenvector method. Performance values are calculated by using the fuzzy middle-value operator. The rank of the enterprises, with respect to all of the considered performances as well as their weights, is determined by applying conventional TOPSIS. The ranking of the enterprises integrated in the supply chain can be marked as the main result of the research. On the basis of the obtained rank, appropriate measures can be taken to improve the performance of those enterprises that are rated the worst by respecting all the observed performances. The proposed model has been tested on the real life data from the automotive supply chain operating in Central Serbia.

Keywords: supply chain performance, interval type-2 fuzzy numbers, fuzzy AHP, TOPSIS, management measures

JEL Classification: C69, L62

INTRODUCTION

Supply chain (SC) management represents one of the most important issues, both in the practical and the theoretical domains. The considered issue is very complex and consists of a number of sub-problems. One of the sub-problems that has a critical impact on the effectiveness and competitive advantage of the SC is measuring and continuously improving the performance of the SC. This issue is especially important for the automotive industry SC that may

* *Correspondence to*: D. Tadic, Faculty of Engineering, University of Kragujevac, Sestre Janjic 6, 34000 Kragujevac, The Republic of Serbia; e-mail: galovic@kg.ac.rs

significantly contribute to the sustainable economic development of each country, especially in developing countries. The automotive industry can be seen as a potential stimulus for entrepreneurship by creating new markets and developing a number of the jobs that require higher skills and knowledge. In other words, the enhancement of the efficiency and effectiveness of the SC business in the automotive industry leads to the development of the region which the SC exists in, as well as the development of entire countries.

The subject matter of the research conducted in this paper is the evaluation and ranking of the enterprises involved in the LS, respecting the LS performance. The evaluation of the SC performances and their Key Performance Indicators (KPIs) can be obtained based on decision-makers' assessments. They base their assessments on their knowledge, experience, and evidence data. Decision-makers use linguistic statements to describe the values of the existent uncertainties. It is a well-known fact that it is far easier for decision-makers to express their knowledge and experience in a natural language than to map them into a scale of measures. The concept of the linguistic variable has been introduced by L. Zadeh (1975), and it was defined as the variable whose values are words, and not numbers. The modelling of linguistic variables can be carried out by applying various theories, such as the probability theory, the theory of fuzzy sets (Zimmerman, 2001), and the theory of rough sets (Pawlak, 1998). As is well known, the modelling of uncertain data by random variables requires a large number of relevant data from the records. Due to a rapid and continuous change in the environment, to provide enough accurate data can be said to be almost impossible. The rough set theory (Pawlak, 1998) can be efficiently used to analyze uncertain and incomplete information modelled by a closed interval. This can be identified as the main advantage of the rough sets theory in relation to the fuzzy sets theory (Zimmerman, 2001), in which uncertainties are described by the function of the distribution of possibilities, although, by comparing the rough sets theory and the fuzzy sets theory, the fuzzy sets theory can be said to have advantages in the modelling of inaccurate and vague data (Zhai, Khoo & Zhong, 2009). In this paper, all uncertainties are modelled by applying the interval type-2 fuzzy numbers that represent a special case of generalized type-2 fuzzy sets. It should be emphasized that generalized type-2 fuzzy sets require huge and complex mathematical, and therefore do not reflect bigger changes in describing and modelling the uncertainties that exist in real problems.

The main objectives of the research study presented in this paper are to rank companies within the supply chain, whereas the derived objectives of the research are to identify the performance of the SC and its KPIs, the modelling of uncertainties in the relative importance of performances and the values of their KPIs by means of interval type-2 triangular fuzzy numbers (Chen & Lee, 2010; Kahraman, Öztayşi, Sarı & Turanoğlu, 2014; Zhang & Zhang, 2017), determining the weights of performances by applying the relative importance of performances, determining the ranks of the enterprises that are integrated in the SC by using the TOPSIS method and undertaking appropriate management initiatives in order to improve the performances of the enterprise, which is further propagated so as to increase the effectiveness of the business SC and its competitive advantages.

The basic hypothesis set out in this paper may be expressed as follows: the priority of the measures that should lead to the improvement of the performances of the enterprises integrated in the SC can be based on the ranking of the considered enterprises.

In literature, a large number of developed methods can be found for measuring and improving the performances of the enterprises which different economic activities are carried out in. However, there are almost no papers that consider the problem of assessing the enterprises that are connected in the SC with the respectability of the SC performances.

Motivation for the research originates from the above-mentioned fact and the assumptions that the application of precise methods for the evaluation of the enterprises integrated in the SC can provide more accurate results, on the basis of which measures for improving the business operations of the SC are defined.

The paper is organized in the following manner: a brief review of the relevant literature is provided in Section 2. The representation of the SC performances and their KPIs is shown in Section 3. The modelling of the existing uncertainties and the proposed algorithm are accounted for in Section 4. The proposed procedure is illustrated by the data obtained in the automotive SC industry that operates in a real environment. The conclusions are presented in Section 5.

LITERATURE REVIEW

A brief review of the literature related to the discussed problem is given in this section. As is known, SC management is based on the determination, measurement, and the improvement of the performances of SCs and their KPIs. A. D. Neely, M. Gregory and K. Platts (1995) suggest that the continuous monitoring of performance values and taking measures based on the performance values can lead to the increased effectiveness and efficiency of SC management.

In the traditional SC management approach, management teams are commonly focused only on a single performance, most often on costs. By measuring and improving only one SC performance, it is not possible to achieve the improvement of all or at least the majority of the strategic goals defined at the SC level. In literature, there are numerous and diverse approaches proposed for solving the problem of determining the SC performances and its KPIs. Some authors believe that by determining the performance of any organizational system it is possible for the SC to be based on the results of the best practice (Coccoa & Alberti, 2010). J. Anitha (2014) believes that the identification of the performances should be based on the analysis of the data obtained by a survey. The validity of the results (in this case, it is a set of the SC performances) can be confirmed by applying a regression analysis. B. M. Beamon (1999) grouped all SC performances into the three groups: the performance resources, outputs and flexibility. Respecting the requirements of ISO 9001: 2008 and the results of good practice in (Nestic, Djordjevic, Puskaric, Zahar Djordjevic, Tadic, & Stefanovic, 2015; Tadić, Đorđević, Erić, Stefanović, & Nestić, 2017), the production SC performances are defined. In the paper (Ramesh & Kodali, 2012), the results obtained from the numerous literary sources were summarized, and a list of performances for the lean production SC was proposed. In this paper, the SC performance is determined according to the recommendations defined in the Supply-Chain Operations Reference (SCOR) (Bolstorff & Rosenbaum, 2003) model, and they are described in Section 3. It is a well-known fact that performance values can be obtained by measuring or that they may be based on the decision-maker's decision.

As is known, performance values can be obtained by measuring or they can be based on the decision-maker's assessment. Decision-makers can use pre-defined measuring scales to reflect their stands onto a set of real numbers. In literature, many measuring scales are used, such as the standard scale of measures in (Coccoa & Alberti, 2010). The mapping of assessment onto a set of linguistic statements instead of a set of precise numbers is far closer to the human way of thinking and, therefore, is more precise. Bearing this fact in mind, many authors suggest the use of linguistic expressions to describe performance values (Nestić *et al*, 2015). The modelling of linguistic expressions in the paper (Nestić *et al*, 2015; Tadić *et al*, 2017) is based on the theory of fuzzy sets (Zimmeramn, 2001; Dubois & Prade, 1980). In other words, these linguistic expressions are modelled by applying triangular fuzzy numbers. In (Nestić *et al*, 2015), the task of the assessment of the relative importance of each performance is set as a fuzzy group decision-making problem. The aggregated value of the decision-maker's assessments was obtained by using the fuzzy weighted aggregation operator (FOWA) that is widely used in literature (Merigó & Casanovas, 2008). The overall value of each performance is calculated as a product of relative importance and the estimated value, and is described by the triangular fuzzy number based on the fuzzy algebra rules (Dubois & Prade, 1980).

The numerous performance measurement methods developed in different mathematical and logical frameworks can be found in literature. These methods have been developed so as to measure the performances of the organizational systems that differ between themselves in their size, the economic branch which they belong to, the way of connection, and so on. Furthermore, a brief retrospective of some of the performance measurement methods is shown.

The most widely used method for measuring performances in the enterprises in which different economic activities are carried out is the Balanced Scorecard (BSC), developed by S. R. Kaplan and P. D. Norton (2008). By applying this approach, it is possible to determine performance values in different perspectives. In this way, a balance between long- and short-term goals, as well as that between financial and non-financial performances, is possible to establish. The BSC approach makes the transformation of strategic goals into a performance set possible. It is necessary to apply the BSC approach at each level of management in order to achieve better results of performance measuring (Behery, Jabeen, & Parakandi, 2014). In this manner, goal setting, setting priorities for the achievement of the goal and the allocation of the resources are significantly simpler compared to the other methods for performance measurement presented in literature. With the use of the BSC approach it is possible for managers to relatively easily maintain or improve the defined management strategy.

M. Hakimollahi, S. J. Naini, M. Bagherpour, S. Jafari and A. Shahmoradi (2012) have developed a method for measuring the performances based on the BSC approach with the fuzzy-interferential mechanism. The KPI performance values defined in each BSC perspective are determined by applying the fuzzy if-then rules. The assessment made by experts of the KPIs values was determined based on their knowledge and experience. In (Nestić *et al*, 2015) the rank of KPIs at the level of all of the considered processes, simultaneously respecting all the enterprises, was obtained by using the continuous fuzzy numbers comparison method (Baas & Kwakernaak, 1977; Dubosi & Prade, 1980).

Many authors suggest that the determination of performance values can be defined as the task of multi-criteria decision-making (Saranga & Moser, 2010; Feili *et al*, 2011). The estimates of the relative importance of KPIs at the level of each performance and their values were obtained by conducting a survey in (Feili *et al*, 2011), involving decision-makers from different enterprises belonging to the same industrial branch. The decision-makers responded to the questions defined in the survey by using the predefined linguistic expressions, modelled with triangular fuzzy numbers. The aggregated value of the decision–makers' assessments was calculated as the geometric mean of the assessments that were obtained from all of the experts participating in the survey. The weighted aggregate values of the KPIs within each performance were calculated as weight and assessment value products. The KPIs priority at the level of each performance was obtained by using the fuzzy Analytical Hierarchical Process (AHP), developed in (Chang, 1996). H. Saranga and R. Moser (2010) suggest the use of the Data Envelopment Analyses (DEA) method for determining performance values. In (Tadić *et al*, 2017), uncertainties in the relative importance of performances and their values are described by the linguistic expressions modelled with a triangular fuzzy numbers. The fuzzy pair-wise comparison matrix of the relative importance of performances was set. The processing of uncertainty was carried out by using the extended analysis method, developed in (Chang, 1996). The normalized performance values were obtained by applying the linear normalization procedure (Shih, Shyur & Lee, 2007). The elements of the weighted normalized fuzzy decision matrix were calculated as a calculated weight and an assessed performance product. The fuzzy positive ideal solution, the fuzzy negative ideal solution and the coefficient of approximation, on the basis of which the performance ranges were determined, were calculated as they were with the conventional Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), developed in (Yoon & Hwang, 1981).

According to the requirements of ISO 9001: 2015, it is necessary to perform the continuous improvement of business processes. This is achieved, among other things, by improving the performance of the processes themselves. In this way, the appointed business goals can be almost fully realized. Performance improvement is achieved by applying the appropriate management measures that are either defined in the standard by the quality system procedures implemented in enterprises or the same may be defined by decision–makers, on the basis of their own knowledge and experience. In the papers analyzed in this section, the priority of the measures corresponds to the priority of the enterprises integrated in the SC.

By comparing the proposed model with the models that have been developed and shown in this paper, the differences can be noted and they are further discussed. On the basis of the obtained results, it is possible to clearly see the advantage of the model developed in this paper, in relation to the papers published in literature.

Performance determination is a task of great importance because it affects the entire decision-making process. In this paper, SC performances are determined on the basis of literature (Bolstorff & Rosenbaum, 2003) and it can be assumed that the performance list is more consistently defined than in the other applied methods presented in (Coccoa & Alberti, 2010; Anitha, 2014; Nestić *et al*, 2015).

The relative importance of KPIs and their values are assessed by decision-makers by using the predefined linguistic expressions (Feili *et al*, 2011; Nestić *et al*, 2015). The use of linguistic variables can be said to allow decision-makers to better express their opinion, rather than use a scale of measures, as presumed in (Kaplan & Norton, 2008; Coccoa & Alberti, 2010). Uncertainties in the relative importance of performances or KPIs, as well as their values, are described by the interval type-2 fuzzy numbers (Chen & Lee, 2010; Kahraman *et al*, 2014; Zhang & Zhang, 2017). It is assumed that the interval type-2 fuzzy numbers can better describe uncertain and imprecise data (Chen & Lee, 2010) when it is impossible to determine the shape of the distribution of the possibilities function of the type-1 fuzzy number in the exact way (Castillo & Melin, 2012). Based on these assumptions, the modelling of uncertainty in this paper was performed in an improved way than it is the case in the papers found in literature (Feili *et al*, 2011; Nestić *et al*, 2015). It is closer to the human way of thinking to express the relative importance of performances by applying the fuzzy matrix of pairs, rather than by applying the direct estimation method (Nestić *et al*, 2015). In this paper, the pair-wise fuzzy matrix of the relative importance of the performances was set (Feili *et al*, 2011). Also, in the proposed method, the consistency of the decision-maker's judgment was carried out by the defuzzification of the interval type-2 phase numbers in the first step (Kahraman *et al*, 2014), and then in the second step, the method of the eigenvector was applied, as defined in the conventional AHP method (Saaty, 1990), so as to verify the consistency of the decision-makers' judgments. The developed procedure presents one of the differences between the proposed method for determining the weight of the performances and the methods presented in (Feili *et al*, 2011). The management measures to be taken in order to improve the performances of enterprises and the SC are based on the ranking of the enterprises. In this paper, as in all of the analyzed papers found in literature, management measures are considered to be defined by decision-makers based on their knowledge and experience. In the paper (Nestić *et al*, 2015), the application of the genetic algorithm determines the optimum value of improvement for the selected performance, which provides an opportunity for decision-makers to better select the management initiatives. The main disadvantage of the proposed method is the lack of a procedure for determining the optimum value of performance improvement.

SUPPLY CHAIN PERFORMANCE

In this paper, the problem of the ranking of the enterprises integrated in the SC with respect to their performances is considered. The SC is assumed to consist of one focal organization and a larger number of the enterprises that can be viewed as the focal organization providers. Such a structure is common for the automotive industry SC. Within this assumption, it can be said that almost all the products used in the assembly process within the focal organization are produced in providing enterprises. The effectiveness of each enterprise's processes affects the efficiency of the final assembly process, as well as the realization of both the operational and the strategic objectives of the automotive industry SC. Formally, the considered enterprises can be represented by a set of indices $E = \{1,\ldots,e,\ldots,E\}$. The total number of the companies considered is E, whereas each enterprise index is denoted as e, $e = 1, \ldots, E$.

The degree of the achievement of the SC business objectives can be determined based on the value of the performances of the enterprises integrated in the SC. The SC performances are defined in appropriate standards or models (Bolstorff & Rosenbaum, 2003). In this paper, the SC performances are defined by SCOR (Bolstorff & Rosenbaum, 2003), which is widely used in literature and in practice. In addition, the SC performances are briefly described, and they also represent the performances of the enterprises that are integrated in the considered SC.

Complexity

The concept of complexity has been studied in the framework of the graph theory (Bezuidenhout, Bodhanya, Sanjika, Sibomana & Boote, 2012), the SC theory (Pathak, Day, Nair, Sawaya & Kristal, 2007), and other theories. Hence, there is no unique definition of the complexity of the SC term. C. Y. Cheng, T. L. Chen and Y. Y. Chen (2014) implicated that the SC complexity was influenced by a number of factors, such as the size, the degree, and the intensity of the relationships between entities. Quite minor changes in complexity are known to lead to a reduction in the degree of the accomplishment of the placed business goals. The complexity value at the level of each SC entity can be determined based on the estimated values of the KPIs of the SC complexity.

In this paper, the KPIs are determined according to L. Xu, Y. Li, K. Govindan and X. Xu (2015), and they are as follows: (1) the complexity of the environment, (2) the complexity of the production process, (3) operational complexity, and (4) the complexity arising due to the integration of the entities. The value of the complexity of the environment can be assessed with respect to the data on the demand variability. Taking into consideration the information about the complexity of receiving and storing both raw materials and semi-finished products, the complexity of technological procedures and the methods of the quality control of the processes, semi-products and products, it is possible to estimate the value of the complexity of the production process. The value of operational complexity can be determined by respecting the data on complexity, regarding the processes of production planning and control, internal transport, quality control methods, necessary knowledge and skills, and others. The complexity that arises from the integration of the SC entities is influenced by the number of such entities, the number of the hierarchical levels of each entity, and the links that exist between the entities within the SC.

Uncertain Demand

In recent decades, in almost all SCs, it has been possible to see that the deviation between a planned quantity and real demand has been on an increase. These deviations have appeared due to the many changes that have been occurring: (a) in SCs, according to T. Maiti and B. C. Giri (2016), which occur due to the lack of relevant information about the changes related to production and demand costs over time; and (b) in the environment, e.g. the development and rapid application of new technologies, customer demand changes, and so forth. Uncertain demand leads to many difficulties in planning the production of the enterprises associated with the SC (Felfel, Ayadi & Masmoudi, 2016).

A number of KPIs have been considered in literature, on the basis of which the value of uncertain demand can be determined. In this paper, the KPIs of uncertain demand are determined according to C. Y. Wong and S. Boon-itt (2008), and they are as follows: (1) customer uncertainty, (2) technological uncertainty, (3) the economic situation, (4) market competitiveness, and (5) law regulation. The decision-makers have based their assessments regarding the first KPI values on the pieces of information related to the types and quantities of the products required by customers, changes in delivery times, and the delivery flexibility. Every complete SC can be said to be characterized by a lack of reliable information which decision-makers can assess the value of customers' uncertainty on. The uncertainty of demand can be significantly reduced if the SC is customer-, rather than product-oriented (Frohlich & Westbrook, 2002). Technological uncertainty is mostly affected by the technological level of a company. It is known that the higher the technological level, the lower a technological uncertainty. This also applies vice versa. The assessment of the economic situation (Bolstorff & Rosenbaum, 2003) is related to the market growth, the gross domestic product, the unemployment rate, the mortality rate, and so on. The value of the market competitiveness can be estimated by taking into consideration the price of a product by a competitive SC, the time of the delivery of the final products, and the degree of the innovation of competitive SCs (Pal & Kumar, 2008). The business of the enterprise in the SC must be in accordance with valid legal propositions.

Quality

Predicting demand and determining the product quality are based on the requirements that come from an environment that is rapidly and continuously changing. In order to meet all the requirements, it is necessary that the quality management system should be integrated in any enterprise that is part of the SC. In this way, it is possible to achieve an improvement in the production process in each company, and therefore in the SC as well.

In literature, different KPIs classifications of the considered performances can be found (Bolstorff & Rosenbaum, 2003; Sadikoglu & Zehir, 2010). In this paper, those KPIs that are defined in (Bolstorff & Rosenbaum, 2003) are adopted: (1) the capability, (2) the critical success factors, (3) the strategic components, and (4) the operational components. Many researchers suggest that capacity assessment depends not only on a product quality, but also on the reliability of the delivery, the trust that exists between the focal organization and the enterprise, etc. The value of the critical success factors is assessed according to the results of the integration related to external stakeholders (Kuei & Madu, 2001), as well as to the quality of leadership in the SC (Kupers, 2000). The values of a KPI, which is designated as a strategic component, are assessed with respect to organizational culture and technology management. The assessment of the value of the operational component is based on the information about the extent to which the demand of the focal organization and the volume of the production of the networked enterprises differ, which the company development policies are, and so on and so forth.

Added Value

Added value is defined as the difference between the price of the product and the cost of production. In recent years, the management of many SCs considers this to be one of the most important SC performances (Presutti, 2003). Based on the results from literature, it can be concluded that the added value of almost every product varies very much over time, and that these variations occur primarily due to changes in production costs.

The KPIs of this performance are defined according to the literature data: (1) the average value of the income of the stakeholder, (2) an increase in the profit, (3) the utilization of the property in possession, (4) communication within the SC and with customers, and (5) the SC's social responsibility.

MODELING OF UNCERTAINTIES

This section presents the method for the modeling of uncertain and imprecise data in the relative importance of the performances and their values at the level of the considered enterprises. The interval fuzzy set of the type-2 is represented by the function of the distribution of possibilities. The upper and lower functions of the interval type-2 fuzzy set are the functions of the distribution of the possibilities of the fuzzy set defined in (Dubois & Prade, 1980; Zimmeramann, 2001). The parameters of this function are the shape, granulation, and domains. The distribution of the functions of opportunities is determined on the basis of subjective assessments made by decision-makers, and the same should reflect the knowledge of such decision-makers of the uncertainties involved. In literature, trapezoidal and triangular interval type-2 fuzzy numbers for the description of numerous and varied uncertainties (Chen & Lee, 2010; Kahraman *et al*, 2014; Zhang & Zhang, 2017) are the most commonly used ones. Granulation is defined as the number of the fuzzy sets that are associated with each considered uncertainty. Some authors (Lootsma, 1997) believe that the decision-maker can use up to seven linguistic statements to describe uncertainty. In this paper, the relative importance of performances can be described by the five linguistic expressions and their values at the level of each enterprise by the application of the seven linguistic expressions modeled by the interval type-2 triangular fuzzy numbers. The domains of these fuzzy numbers are defined at a closed interval in a set of real numbers.

The Selection of Appropriate Linguistic Expressions to Assess the Relative Importance of Performances and the Values of Their KPIs

Respecting the type and the size of the problem, it was assumed that the real value of each pair of the SC performances can be adequately described by applying the five linguistic expressions modeled by the interval type-2 triangular fuzzy numbers in the following way:

very low importance - $\tilde{\tilde{W}}_1 = ((1,1,3.5;1),(1,1,2,5;0.75))$,

low importance - $\tilde{\tilde{W}}_2 = ((1,2,4;1),(1.5,2,3.5;0.75))$,

medium importance - $\tilde{\tilde{W}}_3 = ((1,3,5;1),(2,3,4;0.75))$,

high importance - $\tilde{\tilde{W}}_4 = ((2,4,5;1),(1.5,4,4.5;0.75))$ and

the highest importance - $\tilde{\tilde{W}}_5 = ((2.5,5,5;1),(3,5,4,5;0.75))$.

The domains of these interval type-2 triangular fuzzy numbers are defined on a set of real numbers within the interval [1-5]. Value 1, or Value 5, indicates that the performance p has the same relative importance, i.e. the highest importance, in relation to the performance *p′, p, p′ = 1,...,P*, respectively.

The overlapping of the defined interval type-2 triangular fuzzy numbers used for the modeling of the relative importance of the SC performances is higher because there is insufficient knowledge of their priority.

The KPI values for each of the considered performances are described by applying the seven linguistic expressions modeled by the interval type-2 triangular fuzzy numbers, as is shown below:

very small (VM) - $((1,1,2.5;1),(1,1,2;0.6))$,

small (M) - $((1.5,3,4.5;1),(2,3,4;0.6))$,

almost middle (GS) - $((2.5,4,5.5;1),(3,3.5,5;0.6))$,

middle (S) - $((3.5,5,6.5;1),(4,5,6;0.6))$,

gotovo visoka (GV) - $((4.5,6,7.5;1),(5,6,7;0.6))$,

high (V) - $((5.5,7,8.5;1),(6,7,8;0.6))$ and

very high (VV) - $((7.5,9,9;1),(8,9,9;0.6))$.

The domains of the interval type-2 triangular fuzzy numbers used for the modeling of the performance values at the level of each enterprise are defined by a respectable standard measuring scale (Saaty, 1990). The value 1, i.e. value 9, indicates that the performance *p, p = 1, .., P* has the smallest, i.e. the highest value, respectively.

Constructing the Fuzzy Pairing Matrix for the Comparison of Performances

In literature, a large number of papers can be found, in which the relative importance of the attributes in terms of which the alternatives are given by the fuzzy matrix of the relative importance of the attributes (Tadić *et al*, 2016). It is assumed that this way is closer to the human way of thinking than to a direct assessment. In this paper, the pair-wise fuzzy matrix of the relative importance of the performances is set, according to which the SC enterprises are evaluated. The relative importance of each pair of the criteria is assessed by the strategic management that makes a decision by consensus. The elements of this matrix are defined as the relative importance of the performance p, $p = 1,...,P$ compared to the performance p', $p' = 1,...,P$, $p \neq p'$. The values of these elements are described by the previously defined linguistic expressions modeled by the interval type-2 triangular fuzzy numbers (Chen & Lee, 2010):

$$\tilde{\tilde{W}}_{pp'} = \left(\left(\tilde{X}^{U}_{pp'}; \mu_1\left(X^{U}_{pp'}\right), \left(\tilde{X}^{L}_{pp'}; \mu_2\left(X^{L}_{pp'}\right)\right)\right)\right).$$

Type-1 triangular fuzzy numbers are marked as:

$$\tilde{X}^{U} = \left(a^{U}_{pp'}, b^{U}_{pp'}, c^{U}_{pp'}\right)$$ and

$$\tilde{X}^{L} = \left(a^{L}_{pp'}, b^{L}_{pp'}, c^{L}_{pp'}\right).$$

The reference points of the interval type-2 triangular fuzzy numbers are denoted as:

$$a^{U}_{pp'}, b^{U}_{pp'}, c^{U}_{pp'}\ a^{L}_{pp'}, b^{L}_{pp'}, c^{L}_{pp'}.$$

The distribution function of the higher or lower interval type-2 triangular fuzzy numbers is denoted as $\mu_1\left(\tilde{X}^{U}_{pp'}\right)$, i.e., $\mu_2\left(\tilde{X}^{L}_{pp'}\right)$, respectively.

If the relative importance of the performance p' is greater than the relative importance of the performance p, then the value of the element to the pair-wise fuzzy matrix of the relative importance of the performances can be described as:

$$\tilde{\tilde{W}}_{pp'} = \left(\tilde{\tilde{W}}_{p'p}\right) = \left(\left(\frac{1}{c^{U}_{p'p}}, \frac{1}{b^{U}_{p'p}}, \frac{1}{a^{U}_{p'p}}; \min\left(\mu_1\left(\tilde{X}^{U}\right)\right), 1\right), \left(\frac{1}{c^{L}_{p'p}}, \frac{1}{b^{L}_{p'p}}, \frac{1}{a^{L}_{p'p}}; \min\left(\mu_1\left(\tilde{X}^{L}\right)\right), 1\right)\right).$$

Based on the experience and results of good practice, it can be argued that decision-makers make mistakes in assessment. Therefore, it is, firstly, necessary to determine the consistency of the assessment made by strategic managers. In the first step, the pair-wise fuzzy matrix of the relative importance of the performances is mapped onto the pair-wise fuzzy matrix of the relative importance of the performances whose values are precise numbers. The representative scalars of the interval type-2 triangular fuzzy numbers were obtained using the defuzzification procedure (DTriT), developed by C. Kahraman *et al* (2014), so that

$$W_{pp'} = \frac{\frac{\left(c^{U}_{pp'} - a^{U}_{pp'}\right) + \left(b^{U}_{pp'} - a^{U}_{pp'}\right)}{3} + a^{U}_{pp'} + \alpha \cdot \left[\frac{\left(c^{L}_{pp'} - a^{L}_{pp'}\right) + \left(b^{L}_{pp'} - a^{L}_{pp'}\right)}{3} + a^{L}_{pp'}\right]}{2}$$

where α denotes the maximum value of the distribution function of the possibilities for the lower interval type-2 triangular fuzzy number.

In the second step, the consistency of the pair-wise fuzzy matrix of the relative importance of the performances is determined by applying the eigenvector method (Saaty, 1990). Decision–makers' assessments are assumed to be consistent if the coefficient of consistency (C.I.) is less than 0.1.

The Proposed Algorithm

Step 1. Construct the fuzzy comparison matrix of the pairs of the relative importance of the performances, $\left[\tilde{\tilde{W}}_{pp'}\right]_{PxP}$, and determine the weight of the performance p, $\tilde{\tilde{w}}_p$, $p = 1,\ldots,P$:

$$\tilde{\tilde{w}}_p = \frac{\tilde{\tilde{r}}_p}{\sum_{p=1}^{P} \tilde{\tilde{r}}_p} \tag{1}$$

where:

$$\tilde{\tilde{r}}_p = \left(\left(\sqrt[P]{\prod_{p=1}^{P} a^{U}_{pp'}}, \sqrt[P]{\prod_{p=1}^{P} b^{U}_{pp'}}, \sqrt[P]{\prod_{p=1}^{P} c^{U}_{pp'}}; \mu_1\left(b^{U}_{pp'}\right)\right), \left(\sqrt[P]{\prod_{p=1}^{P} a^{L}_{pp'}}, \sqrt[P]{\prod_{p=1}^{P} b^{L}_{pp'}}, \sqrt[P]{\prod_{p=1}^{P} c^{L}_{pp'}}; \mu_2\left(b^{L}_{pp'}\right)\right)\right) \tag{2}$$

The performance weight is described by the interval type-2 triangular fuzzy number.

Step 2. Assess the KPI values of each performance at the level of each enterprise,

$$\tilde{\tilde{V}}_{jep}, j = 1,..,J_p; e = 1,...,E; p = 1,...,P \tag{3}$$

Step 3. Determine the aggregated performance *p* value:

$$\overset{\approx}{z}_{ep} = \frac{\overset{\approx}{V}_{jep}}{J_p} e = 1, \ldots, E; p = 1, \ldots, P \tag{4}$$

Step 4. Construct the decision matrix, $\left[\overset{\approx}{d}_{ep}\right]_{ExP}$, so that:

$$\overset{\approx}{d}_{ep} = \overset{\approx}{w}_p \cdot \overset{\approx}{z}_{ep} \tag{5}$$

The decision matrix values are described by the interval type-2 triangular fuzzy number, based on the multiplication rule defined in (Mendel & Liu, 2017).

The representative scalar of the interval type-2 triangular fuzzy number, $\overset{\approx}{d}_{ep}$ is obtained by applying the defuzzification procedure (Kahraman *et al*, 2014), $d_{ep}, e = 1,..,E, p = 1,..,P$.

The decision matrix can be written as:

$$\left[d_{ep}\right]_{ExP} \tag{6}$$

Step 5. Determine the Positive Ideal Solution (PIS), $d_p^+,\ p = 1, \ldots, P$ and the Negative Ideal Solution (NIS), $d_p^-,\ p = 1, \ldots, P$ while respecting the type of the performance:

a) for the beneficial type:

$$d_p^+ = \max_{e=1,..,E} d_{ep},\quad d_p^- = \min_{e=1,..,E} d_{ep} \tag{7}$$

b) for the cost type:

$$d_p^+ = \min_{e=1,..,E} d_{ep},\quad d_p^- = \max_{e=1,..,E} d_{ep} \tag{8}$$

Step 6. Calculate the Euclidean distance from PIS, y_p^+ and NIS, y_p^- for each decision matrix element value:

$$y_p^+ = \sum_{p=1}^{P} \left(d_p^+ - d_{ep}\right)^2 \text{ i } y_p^- = \sum_{p=1}^{P} \left(d_p^- - d_{ep}\right)^2 \tag{9}$$

Step 7. Calculate the coefficients of the approximation that is associated with each enterprise, according to the procedure developed in the conventional TOPSIS method (Yoon & Hwang, 1981) k_e:

$$k_e = \frac{y_p^-}{y_p^- + y_p^+} \tag{10}$$

Step 8. Assort the coefficients of the approximation into a decreasing set. The rank of the enterprise is determined by the k_e. values. The enterprise with the highest associated value k_e is the considered to be the first-ranked.

An Illustrative Example

The automotive industry SC that has been the subject matter of discussion, which exists in Central Serbia, includes the focal enterprise (in which the process of the assembly of the final product is realized) and the nine big enterprises (in which the components are built, which are later installed in the final product). It should be emphasized that the revenue generated by the automotive industry SC has a major impact on the gross domestic product of each country, especially developing countries. SC performances are defined on the basis of literature recommendations (Bolstorff & Rosenbaum, 2003). To assess the relative importance of the performances, as well as their values, appropriate questionnaires were sent to the SC's strategic management, as well as the management teams (the production manager, the quality manager, the financial manager and the supply manager) involved in the SC, respectively. The decision-makers were asked through the questionnaire to select one of the predefined linguistic expressions in order to assess the relative importance of each pair of the performances, and the value of each performance. All decision-makers may be assumed to have made decisions by consensus.

The fuzzy matrix of the relative importance of the pairs of the performances at the SC level is defined as follows (Step 1 of the developed Algorithm):

$$\begin{bmatrix} ((1,1,1;1),(1,1,1;1)) & 1/\tilde{\tilde{W}}_1 & 1/\tilde{\tilde{W}}_3 & 1/\tilde{\tilde{W}}_4 \\ \tilde{\tilde{W}}_1 & ((1,1,1;1),(1,1,1;1)) & 1/\tilde{\tilde{W}}_2 & 1/\tilde{\tilde{W}}_3 \\ \tilde{\tilde{W}}_3 & \tilde{\tilde{W}}_2 & ((1,1,1;1),(1,1,1;1)) & 1/\tilde{\tilde{W}}_2 \\ \tilde{\tilde{W}}_4 & \tilde{\tilde{W}}_3 & \tilde{\tilde{W}}_2 & ((1,1,1;1),(1,1,1;1)) \end{bmatrix}_{4x4}$$

The mapping of the fuzzy pair-wise matrix of the comparison of the relative importance of the performances in the pair-wise matrix of the comparison of the relative importance of the performances is performed by applying the defuzzification process, DTriT (Kahraman *et al*, 2014), in order to determine the consistency of the assessment of the strategic managers:

$$\begin{bmatrix} 1 & 0.681 & 0.422 & 0.301 \\ 1.468 & 1 & 0.473 & 0.422 \\ 2.369 & 2.114 & 1 & 0.473 \\ 3.322 & 2.369 & 2.114 & 1 \end{bmatrix}, \quad C.I. = 0.258$$

Using the expressions (1) and (2), the weights of the considered performances are calculated. The procedure shown in Step 1 of the Developed Algorithm is illustrated in the case of calculating the weight of the performance, which is denoted as complexity (*p = 1*).

$$\tilde{\tilde{r}}_1 = \left(\left(0.327, 0.536, 0.841; 1\right), \left(0.386, 0.536, 0.759; 0.75\right)\right)$$

$$\sum_{p=1}^{4} \tilde{\tilde{r}}_p = \left(\left(0.327, 0.536, 0.841; 1\right), \left(0.386, 0.536, 0.759; 0.75\right)\right) +$$
$$+\left(\left(0.473, 0.639, 1.268; 1\right), \left(0.518, 0.639, 0.955'0.75\right)\right) +$$
$$+\left(\left(0.707, 1.316, 2.115; 1\right), \left(0.963, 1.316, 1.749; 0.75\right)\right) +$$
$$+\left(\left(1.189, 2.213, 3.162; 1\right), \left(1.456, 2.213, 2.817; 0.75\right)\right) =$$
$$= \left(\left(2.696, 4.704, 7.386; 1\right), \left(3.323, 4.705, 6.2780; 0.75\right)\right)$$

$$\tilde{\tilde{w}}_1 = \frac{\left(\left(0.327, 0.536, 0.841; 1\right), \left(0.386, 0.536, 0.759; 0.75\right)\right)}{\left(\left(2.696, 4.704, 7.486; 1\right), \left(3.323, 4.705, 6.280'0.75\right)\right)} =$$
$$= \left(\left(0.327/7.486, 0.536/4.704, 0.841/2.696; 1\right)\right),$$
$$\left(\left(0.386/6.280.0.536/4.705, 0.759/3.323; 0.75\right)\right)$$

$$\tilde{\tilde{w}}_1 = \left(\left(0.044, 0.114, 0.312; 1\right), \left(0.061, 0.114, 0.228; 0.75\right)\right)$$

In the same way, the weight of the other considered performances are obtained, and they are:

$$\tilde{\tilde{w}}_2 = \left(\left(0.063, 0.136, 0.470; 1\right), \left(0.082, 0.136, 0.287; 0.75\right)\right)$$

$$\tilde{\tilde{w}}_3 = \left(\left(0.094, 0.279, 0.784; 1\right), \left(0.153, 0.279, 0.526; 0.75\right)\right)$$

$$\tilde{\tilde{w}}_4 = \left(\left(0.161, 0.471, 1.173; 1\right), \left(0.232, 0.471, 0.848; 0.75\right)\right)$$

The estimated KPI values (Step 2 of the developed Algorithm) are accounted for in Table 1.

Table 1 The estimated value of the KPIs at the level of each enterprise

	Enterprise								
	e=1	e=2	e=3	e=4	e=5	e=6	e=7	e=8	e=9
Complexity	GS	M	GS	M	M	GS	M	GS	GS
	GV	S	GV	S	S	GV	S	GV	GV
	S	S	GV	S	S	GV	S	GV	GV
	GV	S	V	GV	GV	V	GV	V	V
Uncertain demand	M	M	M	M	VM	VM	VM	VM	VM
	M	M	M	M	VM	VM	VM	VM	VM
	GS	GS	M	M	M	M	M	VM	VM
	M	M	M	M	M	VM	VM	M	M
	VM	M	M	VM	VM	VM	M	VM	M
Quality	V	V	VV	V	V	V	V	VV	VV
	VV	VV	VV	VV	V	V	VV	V	VV
	VV	VV	VV	V	VV	V	V	V	V
	V	VV	VV	VV	V	VV	V	VV	V
Additional value	V	VV	V	VV	VV	V	VV	V	V
	VV	VV	V	V	VV	VV	VV	VV	VV
	V	VV	V	V	V	V	V	VV	VV
	V	V	V	V	V	V	VV	VV	V
	V	V	GV	V	V	GV	V	V	V

Source: Authors

The aggregated performance values are calculated according to the expression (3) and they are presented in Table 2.

The weighted performance values at the level of each enterprise are calculated according to the expression (5). The multiplication process of the two interval triangular fuzzy type-2 numbers is illustrated by the following example:

$$\tilde{\tilde{d}}_{63}=\left(\left(5.7,7.2,8.4;1\right),\left(6.2,7.2.8;0.6\right)\right)\cdot$$
$$\cdot\left(\left(0.094,0.279,0.784;1\right),\left(0.153,0.279,0.526;0.75\right)\right)=$$
$$=\left(\left(0.54,2.01,6.59;1\right),\left(0.95,2.01,4.21;0.6\right)\right)$$

The fuzzy decision matrix (Step 4 of the developed Algorithm) is shown in Table 3

The PIS and NIS values are calculated according to the decision matrix (Step 5 of the developed Algorithm) and shown in Table 4.

The values of the approximation coefficient and the rank of the considered enterprises are obtained according to the developed Algorithm (Step 6 to Step 8) and accounted for in Table 7.

Table 4 The decision matrix PIS and NIS

	p = 1	p = 2	p = 3	p = 4
e = 1	0.6443	0.5827	2.3937	3.5967
e = 2	0.6153	0.6430	2.4763	4.5957
e = 3	0.7673	0.6070	2.5593	3.4340
e = 4	0.7673	0.5713	2.3937	3.5967
e = 5	0.6443	0.4267	2.3103	3.7187
e = 6	0.7673	0.3670	2.3103	3.5210
e = 7	0.6443	0.4267	2.3103	3.9320
e = 8	0.7673	0.3670	2.3937	4.5957
e = 9	0.7673	0.4267	2.3937	3.7187
PIS	0.6153	0.3670	2.5593	4.5957
NIS	0.7673	0.6430	2.3103	3.4340

Source: Authors

Table 2 The aggregated performance values

	p = 1	p = 2	p = 3	p = 4
e = 1	((3.25,4.75,6.25;1), (3.75,4.62,5.75;0.6))	((1.6,2.8,4.3;1), (2,4,2.8,3.8;0.6))	((6.5,8,8.75;1), (7,8,8.5;0.6))	((5.9,7.4,8.6;1), (6.4,7.4.8;0.6))
e = 2	((3,4.5,6;1), (3.5,4.5,5.5;0.6))	((1.7,3.2,4.7;1), (2.2,4.3.2,4.2;0.6))	((7,8.5,8.87;1), (7.5,8.5,8.75;0.6))	((6.7,8.2,8.8;1), (7.2,8.2,8.6;0.6))
e = 3	((4.25,5.75,7.25;1), (4.75,5.75,6.75;0.6))	((1.5,3,4.5;1), (2,3.8,4;0.6))	((7.5,9,9;1), (8,9,9;0.6))	((5.3,6.8,8.3;1), (5.8,6.8.7.8;0.6))
e = 4	((4.25,5.75,7.25;1), (4.75,5.75,6.75;0.6))	((1.4,2.6,4.4;1), (1.8,2.6,3.6;0.6))	((6.5,8,8.75;1), (7,8,8.5;0.6))	((5.9,7.4,8.6;1), (6.4,7.4.8;0.6))
e = 5	((3.25,4.75,7.25;1), (3.75,4.75,5.75;0.6))	((1.2,1.8,3.3;1), (1.4,1.8,2.8;0.6))	((6,7.5,8.62;1), (6.5,7.5,8.25;0.6))	((6.3,7.8,8.7;1), (6.8,7.8.8.4;0.6))
e = 6	((4.25,5.75,7.25;1), (4.75,5.75,6.75;0.6))	((1. 1,1.4,2.9;1), (1.2,1.4,.2.4;0.6))	((6,7.5,8.62;1), (6.5,7.5,8.25;0.6))	((5.7,7.2,8.4;1), (6.2,7.2.8;0.6))
e = 7	((3.25,4.75,7.25;1), (3.75,4.75,5.75;0.6))	((1.2,1.8,3.3;1), (1.4,1.8,2.8;0.6))	((6,7.5,8.62;1), (6.5,7.5,8.25;0.6))	((7.1,8.6,8.9;1), (7.6,8.6.8.8;0.6))
e = 8	((4.25,5.75,7.25;1), (4.75,5.75,6.75;0.6))	((1. 1,1.4,2.9;1), (1.2,1.4,.2.4;0.6))	((6.5,8,8.75;1), (7,8,8.5;0.6))	((6.7,8.2,8.8;1), (7.2,8.2,8.6;0.6))
e = 9	((4.25,5.75,7.25;1), (4.75,5.75,6.75;0.6))	((1.2,1.8,3.3;1), (1.4,1.8,2.8;0.6))	((6.5,8,8.75;1), (7,8,8.5;0.6))	((6.3,7.8,8.7;1), (6.8,7.8.8.4;0.6))

Source: Authors

Table 3 The fuzzy decision matrix

	p = 1	p = 2	p = 3	p = 4
e = 1	((0.14,0.54,1.95;l), (0.22,0.53,1.31;0.6))	((0.1,0.38,2.02;1), (0.19,0.38,1.09;0.6))	((0.61,2.23,6.86;1), (1.07,2.23,4.47;0.6))	((0.95,3.49,10.09;1), (1.48,3.49,6.78;0.6))
e = 2	((0.13,0.51,1.87;1), (0.21,0.51,1.25;0.6))	((0.11,0.44,2.21;1), (0.18,0.44,1.21;0.6))	((0.66,2.37,6.95;1), (1.15,2.37,4.61;0.6))	((1.08,3.86,15.23;1), (1.67,3.38,7.29;0.6))
e = 3	((0.19,0.66,2.26;1), (0.29,0.66,1.54;0.6))	((0.09,0.41,2.11;1), (0.16,0.41,1.15;0.6))	((0.71,2.51,7.06;1), (1.22,2.51,4.73;0.6))	((0.85,3.21,9.74;1), (1.35,3.21,6.78;0.6))
e = 4	((0.19,0.66,2.26;1), (0.29,0.66,1.54;0.6))	((0.09,0.35,2.07;1), (0.15,0.35,1.03;0.6))	((0.61,2.23,6.86;1), (1.07,2.23,4.47;0.6))	((0.95,3.49,10.09;1), (1.48,3.49,6.78;0.6))
e = 5	((0.14,0.54,2.26;1), (0.23,0.54,1.31;0.6))	((0.08,0.24,1.55;1), (0.11,0.24,0.8;0.6))	((0.56,2.09,6.76;1), (0.99,2.09,4.34;0.6))	((1.01,3.67,10.21;1), (1.58,3.67,7.12;0.6))
e = 6	((0.19,0.66,2.26;1), (0.29,0.66,1.54;0.6))	((0.07,0.19,1.36;1), (0.09,0.19,.0.69;0.6))	((0.56,2.09,6.76;1), (0.99,2.09,4.34;0.6))	((0.92,3.39,9.85;1), (1.44,3.39,6.78;0.6))
e = 7	((0.14,0.54,2.26;1) (0.23,0.54,1.31;0.6))	((0.08,0.24,1.55;1), (0.11,0.24,0.8;0.6))	((0.56,2.09,6.76;1), (0.99,2.09,4.34;0.6))	((1. 14,4.05,10.44;1), (1.76,4.05,7.46;0.6))
e = 8	((0.19,0.66,2.26;1), (0.29,0.66,1.54;0.6))	((0.07,0.19,1.36;1), (0.09,0.19,.0.69;0.6))	((0.61,2.23,6.86;1), (1.07,2.23,4.47;0.6))	((1.08,3.86,15.23;1), (1.67,3.38,7.29;0.6))
e = 9	((0.19,0.66,2.26;1), (0.29,0.66,1.54;0.6))	((0.08,0.24,1.55;1), (0.11,0.24,0.8;0.6))	((0.61,2.23,6.86;1), (1.07,2.23,4.47;0.6))	((1.01,3.67,10.21;1) (1.58,3.67,7.12;0.6))

Source: Authors

Table 5 The values of the approximation coefficient and the rank of the enterprises

	y_p^+	y_p^-	k_e	Rang
e = 1	1.0356	0.2285	0.1103	9
e = 2	0.2882	1.1833	0.8041	2
e = 3	1.1959	0.2516	0.5000	3
e = 4	1.0442	0.1964	0.1583	8
e = 5	0.9141	0.3781	0.2714	6
e = 6	1.1136	0.2894	0.2063	7
e = 7	0.7119	0.5487	0.4353	4
e = 8	0.2248	1.1970	0.8419	1
e = 9	0.9073	0.3671	0.2880	5

Source: Authors

DISCUSSION ON RESULTS

Respecting the results presented in Table 7, it can be concluded that the enterprises (e = 8) and (e = 2) are the most efficient in the considered LS because they are ranked the first and the second, respectively. The enterprise (e = 1) is ranked the last. Since the closeness coefficient value of the enterprise (e = 1) is almost equal to the closeness coefficient value of the enterprise (e = 4) and the enterprise (e = 6), it can be said that the management should simultaneously undertake appropriate measures for improving the performance of the enterprises (e = 1, e = 4 and e = 6), which are ranked the last, the 8th and the 7th. In all of the three enterprises, the quality performance (p = 3) values and added value (p = 4) have the smallest weighted values. Hence, it can be concluded that it is necessary for the management team to take the first steps that should lead to the improvement of these performances. Improving the quality of the performance (p = 3) can be achieved through the improvement of the supply strategy, the introduction of new leadership concepts, etc. The improvement of the supply strategy can be realized through the realization of a partnership relationship with the suppliers of repro materials, the introduction of the information systems that may improve communication between all the entities in the SC, the use of inventory management and production systems, etc. An increase in the added value (p = 4) of the enterprises (e = 1, e = 4, and e = 6) can be achieved by using the lean principle, such as the pull system.

The weighted complexity performance value (p = 1) in the enterprises (e = 4) and (e = 6) is higher than the value of the same performance in the enterprise that is the 1st ranked (e = 8). Therefore, the management team should take appropriate measures to reduce complexity in the enterprises (e = 4) and (e = 6). Complexity reduction can be realized through the improvement of the value-stream map. By determining the value-stream map, it is possible to see all the unnecessary subprocesses and activities of the production process. Their elimination reduces the complexity of the enterprise. The complexity of the SC can also be reduced by applying the method of reengineering processes and products.

CONCLUSION

The management and improvement of SC performances represents one of the most important management tasks. A solution to this problem should lead to the enhancement of the competitiveness and sustainability of the SC over a longer period of time. By simultaneously improving the performances of all of the SC entities, the effectiveness of the SC will surely increase. Also, if this scenario is applied, there is a great deal of resource usage (time, money, etc.). In order to achieve the enhancement of the effectiveness of the SC, with the least possible use of resources, it is necessary to identify the SC enterprises whose performance needs to be improved. It has been demonstrated that the use of the analytical methods in the evaluation and ranking of enterprises generates more accurate results than the use of intuitive decision-making methods does.

The main contribution of this paper is the development of the model for the evaluation and ranking of the enterprises integrated in the SC respecting the performance of the SC, as well as their weights. Since the SC exists in a rapidly changing environment, the relative importance of the performances and their values are described by the interval triangular fuzzy numbers of the type-2. It can be assumed that this approach in the modeling of uncertain and imprecise data is quite appropriate when there is not enough information about the nature of uncertainties. It has been shown that the ranking of enterprises can be posed as a multiple-criteria decision-making problem. Based on the obtained rank of enterprises, the priority of the enterprises in which performance improvement is to be performed is determined. The priority of the measures in the considered enterprises is determined by comparing the current and the target performance values.

The proposed model was tested on the real data obtained from the automotive industry SC that exists in Central Serbia. This paper makes a contribution to both the theoretical and the practical domains. The modeling of uncertainties and the modifications of the conventional TOPSIS method represent the basic contributions to the theoretical domain. The developed model is flexible in terms of changing the number of performances, their importance and values, and therefore can be applied to solve similar problems that exist in different industrial branches. In the practical domain, the contribution of this work can be identified as a reduction in the resources that need to be spent in order to improve the businesses effectiveness of the enterprises integrated in the SC.

The main limitation of the model is the non-existence of a unique SC performance classification.

Future research should include the development and application of exact methods for determining the improvements of optimal performances. The developed model can also be applied to the SCs of different industrial branches.

REFERENCES

Anitha, J. (2014). Determinants of employee engagement and their impact on employee performance. *International journal of productivity and performance management, 63*(3), 308-323. doi.org/10.1108/IJPPM-01-2013-0008

Baas, S. M., & Kwakernaak, H. (1977). Rating and ranking of multiple-aspect alternatives using fuzzy sets. *Automatica, 13*(1), 47-58. doi.org/10.1016/0005-1098(77)90008-5

Beamon, B. M. (1999). Measuring supply chain performance. *International journal of operations & production management, 19*(3), 275-292. doi.org/10.1108/01443579910249714

Behery, M., Jabeen, F., & Parakandi, M. (2014). Adopting a contemporary management system: A fast-growth small-to-medium enterprise (FGSME) in the UAE. *International Journal of Productivity and Performance Management, 63*(1), 22-43. doi.org/10.1108/IJPPM-07-2012-0076

Bezuidenhout, C. N., Bodhanya, S., Sanjika, T., Sibomana, M., & Boote, G. L. N. (2012). Network-analysis approaches to deal with causal complexity in a supply network. *International Journal of Production Research*, *50*(7), 1840-1849. doi.org/10.1080/00207543.2011.575088

Bolstorff, P., & Rosenbaum, R. (2003). *Supply chain excellence*. New York, NY: American Management Association.

Castillo, O., & Melin, P. (2012). *Recent advances in interval Type-2 fuzzy systems.* (Vol. 1), New York, NY: Springer Science & Business Media.

Chang, D. Y. (1996). Applications of the extent analysis method on fuzzy AHP. *European journal of operational research*, *95*(3), 649-655. doi.org/10.1016/0377-2217(95)00300-2

Chen, S. M., & Lee, L. W. (2010). Fuzzy multiple attributes group decision-making based on the interval type-2 TOPSIS method. *Expert systems with applications*, *37*(4), 2790-2798. doi.org/10.1016/j.eswa.2009.09.012

Cheng, C. Y., Chen, T. L., & Chen, Y. Y. (2014). An analysis of the structural complexity of supply chain networks. *Applied Mathematical Modelling*, *38*(9-10), 2328-2344. doi.org/10.1016/j.apm.2013.10.016

Cocca, P., & Alberti, M. (2010). A framework to assess performance measurement systems in SMEs. *International Journal of Productivity and Performance Management, 59*(2), 186-200. doi.org/10.1108/17410401011014258

Dubois, D., & Prade, H. (1980). *Fuzzy sets and systems*. New York, NY: Academic Press.

Feili, H. R., Farahani, N. V., & Vesaghi, N. (2011). Integration of fuzzy analytic hierarchy process (FAHP) with balance score card (BSC) in order to evaluate the performance of information technology in industry. *The Journal of Mathematics and Computer Science*, *2*(2), 271-283.

Felfel, H., Ayadi, O., & Masmoudi, F. (2016). Multi-objective stochastic multi-site supply chain planning under demand uncertainty considering downside risk. *Computers & Industrial Engineering*, *102*, 268-279. doi.org/10.1016/j.cie.2016.10.025

Frohlich, M. T., & Westbrook, R. (2002). Demand chain management in manufacturing and services: Web-based integration, drivers and performance. *Journal of Operations Management*, *20*(6), 729-745. doi.org/10.1016/S0272-6963(02)00037-2

Hakimollahi, M., Naini, S. J., Bagherpour, M., Jafari, S., & Shahmoradi, A. (2012). Balanced scorecard with fuzzy inference as a performance measurement in an automotive manufacturing line. *International Journal of Automotive Engineering*, *2*(4), 276-283.

Kahraman, C., Öztayşi, B., Sarı, İ. U., & Turanoğlu, E. (2014). Fuzzy analytic hierarchy process with interval type-2 fuzzy sets. *Knowledge-Based Systems*, *59*, 48-57. doi.org/10.1016/j.knosys.2014.02.001

Kaplan, S. R., & Norton, P. D. (2008). *The execution premium: Linking strategy to operations for competitive advantages*. Boston, USA: Harvard Business School Publishing Corporation.

Kuei, C. H., & Madu, C. N. (2001). Identifying critical success factors for supply chain quality management (SCQM). *Asia Pacific Management Review*, *6*(4), 409-423.

Kupers, R. (2000). What organizational leaders should know about the new science of complexity. *Complexity*, *6*(1), 14-19. doi:10.1002/1099-0526(200009/10)6:1<14::aid-cplx1002>3.0.co;2-6

Lootsma, F. (1997). *Fuzzy logic for planning and decision making.* New York, NY: Springer. doi:10.1007/978-1-4757-2618-3

Maiti, T., & Giri, B. C. (2017). Two-period pricing and decision strategies in a two-echelon supply chain under price-dependent demand. *Applied Mathematical Modelling*, *42*, 655-674. doi.org/10.1016/j.apm.2016.10.051

Mendel, J. M., & Liu, F. (2007). Super-exponential convergence of the Karnik-Mendel algorithms for computing the centroid of an interval type-2 fuzzy set. IEEE Transactions on Fuzzy Systems, 15(2), 309-320. doi:10.1109/tfuzz.2006.882463

Merigó, J. M., & Casanovas, M. (2008). Using fuzzy numbers in heavy aggregation operators. *International Journal of Information Technology*, *4*(3), 177-182.

Neely, A. D., Gregory, M., & Platts, K. (1995). Performance measurement system design: A literature review and research agenda. *International Journal of Operations & Production Management, 15*(4), 80-116. doi.org/10.1108/01443579510083622

Nestic, S., Djordjevic, A., Puskaric, H., Zahar Djordjevic, M., Tadic, D., & Stefanovic, M. (2015). The evaluation and improvement of process quality by using the fuzzy sets theory and genetic algorithm approach. *Journal of Intelligent and Fuzzy Systems, 29*(5), 2017-2028. doi:10.3233/ifs-151679

Pal, P., & Kumar, B. (2008). "16T": Toward a dynamic vendor evaluation model in integrated SCM processes. *Supply Chain Management: An International Journal*, *13*(6), 391-397. doi.org/10.1108/13598540810905642

Pathak, S. D., Day, J. M., Nair, A., Sawaya, W. J., & Kristal, M. M. (2007). Complexity and adaptivity in supply networks: Building supply network theory using a complex adaptive systems perspective. *Decision sciences*, *38*(4), 547-580. doi:10.1111/j.1540-5915.2007.00170.x

Pawlak, Z. (1998). Rough set theory and its applications to data analysis. *Cybernetics & Systems, 29*(7), 661-688. doi.org/10.1080/019697298125470

Presutti, W. D. (2003). Supply management and e-procurement: Creating value added in the supply chain. *Industrial marketing management*, *32*(3), 219-226. doi.org/10.1016/S0019-8501(02)00265-1

Ramesh, V., & Kodali, R. (2012). A decision framework for maximising lean manufacturing performance. *International Journal of Production Research, 50*(8), 2234-2251. doi.org/10.1080/00207543.2011.564665

Saaty, T. L. (1990). How to make a decision: The analytic hierarchy process. *European journal of operational research*, *48*(1), 9-26. doi.org/10.1016/0377-2217(90)90057-I

Sadikoglu, E., & Zehir, C. (2010). Investigating the effects of innovation and employee performance on the relationship between total quality management practices and firm performance: An empirical study of Turkish firms. *International journal of production economics*, *127*(1), 13-26. doi.org/10.1016/j.ijpe.2010.02.013

Saranga, H., & Moser, R. (2010). Performance evaluation of purchasing and supply management using value chain DEA approach. *European Journal of Operational Research*, *207*(1), 197-205. doi.org/10.1016/j.ejor.2010.04.023

Shih, H. S., Shyur, H. J., & Lee, E. S. (2007). An extension of TOPSIS for group decision making. *Mathematical and Computer Modelling*, *45*(7), 801-813. doi.org/10.1016/j.mcm.2006.03.023

Tadic, D., Aleksic, A., Mimovic, P., Puskaric, H., & Misita, M. (2016). A model for evaluation of customer satisfaction with banking service quality in an uncertain environment. *Total Quality Management & Business Excellence*, 1-20. doi.org/10.1080/14783363.2016.1257905

Tadić, D., Đorđević, A., Erić, M., Stefanović, M., & Nestić, S. (2017). Two-step model for performance evaluation and improvement of New Service Development process based on fuzzy logics and genetic algorithm. *Journal of Intelligent and Fuzzy Systems, 33*(6), 3959-3970. doi:10.3233/jifs-17802

Wong, C. Y., & Boon-itt, S. (2008). The influence of institutional norms and environmental uncertainty on supply chain integration in the Thai automotive industry. *International Journal of Production Economics*, *115*(2), 400-410. doi.org/10.1016/j.ijpe.2008.05.012

Xu, L., Li, Y., Govindan, K., & Xu, X. (2015). Consumer returns policies with endogenous deadline and supply chain coordination. *European Journal of Operational Research*, *242*(1), 88-99. doi.org/10.1016/j.ejor.2014.09.049

Yoon, K., & Hwang, C. L. (1981). *Multiple attribute decision making: Methods and applications*. Berlin, BRD: Springer-Verlag Berlin An. doi:10.1007/978-3-642-48318-9

Zadeh, L. (1975). The concept of a linguistic variable and its application to approximate reasoning. *Information Sciences, 8*(4), 301-357. doi.org/10.1016/0020-0255(75)90046-8

Zhai, L. Y., Khoo, L. P., & Zhong, Z. W. (2009). Design concept evaluation in product development using rough sets and grey relation analysis. *Expert Systems with Applications, 36*(3), 7072-7079. doi.org/10.1016/j.eswa.2008.08.068

Zhang, Z., & Zhang, S. (2017). Comments on "A note on "A novel approach to multi attribute group decision making based on trapezoidal interval type-2 fuzzy soft sets"". *Applied Mathematical Modelling, 41*, 702-710. doi.org/10.1016/j.apm.2016.09.011

Zimmermann, H. (2001). *Fuzzy Sets Theory - And Its Applications*. Amsterdam, Netherlands: Springer-Verlag. doi:10.1007/978-94-010-0646-0

Received on 17th November 2017,
after revision,
accepted for publication on 22nd December 2017.

Published online on 29th December 2017.

Danijela Tadic is a Professor at the Faculty of Engineering, University of Kragujevac, Kragujevac, the Republic of Serbia. She obtained her PhD degree at the Faculty of mechanical engineering, University of Belgrade. Her field of research includes operational research and supply chain management.

Aleksandar Djordjevic is a Research Associate at the Faculty of Engineering, University of Kragujevac, Kragujevac, the Republic of Serbia, where he received his PhD degree. His field of research includes operational research and information management.