ISSN 1330-3651
UDC/UDK 658.7.012.12

MULTI-CRITERIA APPROACH TO RANKING SUPPLIERS IN THE SUPPLY CHAINS CONCEPT

Harun Bronja

Preliminary notes

This paper presents a new, transformed, multi-criteria mathematical model for ranking suppliers in the supply chains concept. The problem was treated as a problem of procurement of companies with raw materials in multi-supplier environment, with different offers and different supply conditions. In the circumstances of uncertainty of raw materials procurement, selection of suppliers and ranking performances of criteria and alternatives is a very important decision of a company for a successful business operation on the market. The work depicts the procedure of transformation of values of the proposed criteria on the principle of maximal value and the ranking done by the principle of geometric mean. The values obtained by ranking are placed in descending order, and suppliers are sorted by priority. An illustrated example is also presented.

Keywords: *company, multi-criteria analysis, ranking, suppliers, supply chain*

Višekriterijski pristup rangiranja dobavljača u konceptu opskrbnog lanaca

Prethodno priopćenje

Ovaj rad predstavlja novi, transformirani, višekriterijski matematički model za rangiranje dobavljača u konceptu opskrbnog lanaca. Problem je tretiran kao problem nabave tvrtki sa sirovinama u okruženju više dobavljača, s različitim ponudama i različitih uvjetima opskrbe. U uvjetima neizvjesnosti nabave sirovina, izbor dobavljača i rangiranje svojstava kriterija i alternativa je vrlo važna odluka tvrtke za uspješno poslovanje na tržištu. Rad prikazuje postupak transformacije vrijednosti predloženih kriterija, po principu maksimalne vrijednosti i rangiranja obavljenog po načelu geometrijske srednje vrijednosti. Vrijednosti dobivene rangiranjem nalaze se u silaznom redoslijedu, a dobavljači su razvrstani prema prioritetima. Također je predstavljen ilustriran primjer.

Ključne riječi: *dobavljači, opskrbni lanac, rangiranje, tvrtka, višekriterijska analiza*

1 Introduction
Uvod

In order to maintain their positions in the market and to become competitive among the rivals, companies should make great efforts to achieve competitive production. Competitive production means competition in several spheres of business, first of all in the following areas: quality, JIT (Just-in-Time) production, quick response, low cost, flexibility, standardization of products and services, cooperation with suppliers and customers, and so on.

The very term supply chain denotes a complex system whose structural parts: material suppliers, production operators, distribution services and customers are connected through the material flow and backflow of information. Practically, every participant in a series (chain) is a clip that connects the source of raw material to the customer. The term supply chain was created in that way. Linking different companies into a single supply chain is done in order to meet the basic needs of the participants and to ensure competitive superiority.

It is known that the main goal of any enterprise is acquiring the largest possible profit. Profit – making can be achieved only if a buyer purchases the right product. But, to make a buyer choose a particular company's product, not its competitor, the mentioned product must satisfy his needs, must have the proper quality and minimal cost price.

The main idea of supply chain management is applying an approach of a complete system to manage the flow of information, materials and services, starting from the raw material suppliers, through retailers and warehouses to the final customer [44]. The reason for the recognition of its importance to many companies is that the purchased materials and parts are a growing percentage of production cost items. In many companies the cost of raw materials and purchased parts is 60 – 70 % of the total cost of the product.

The trend of using larger suppliers and logistic costs made the management focus its concern on procurement function. The traditional understanding of procurement, where the company concentrated on cheap suppliers, has been replaced by a strategy which is based on the quality and concentrated on developing long term relationships with suppliers, the establishments of partnerships and a continuous improvement of product quality and reducing costs.

The design and supply chains management (SC) are nowadays one of the most active research matters in management and decision making in supply chains. There are quantitative and precise definitions of supply chains in literature. It is usually defined as an integrated process in which several businesses, such as suppliers, manufacturing plants, warehouses and users work together on planning, coordination and control of raw materials in the production process, as well as the finished products from a supplier to a buyer [5].

Supply chain includes all the participants and processes: from a raw materials producer to the customer, but from the point of view of operative management, the three basic components are elaborated: supply, storage and distribution [4].

Supply Chain Management can be divided into the three main activities: purchase, production and transportation (Thomas et al. 1996) [1].

Logistics means managing operative tasks aimed at clients' needs (Tilanus 1997) [2].

The definition given by Johnson and Wood (cited in Tilanus 1997) pointed out "five key terms", and they are: logistics, input logistics, material management, physical distribution and delivery chain management [2].

Mentzer (2001) defines supply chain as a set of three or more entities (organizations or individuals) directly involved in the upstream and downstream flows of products, services, finances, and/or information from a source to a customer.

He defines supply chain management as the systemic, strategic coordination of the traditional, business functions and tactics across these business functions within a particular company and across businesses within the supply chain, for the purpose of improving the long-term performance of the individual companies and the supply chain as a whole.

Min and Zhou (2002) see supply chain as integrated system which synchronizes a series of inter-related business processes in order to: (1) acquire raw materials and parts; (2) transform these raw materials and parts into finished products; (3) add value to these products; (4) distribute and promote these products to either retailers or customers; (5) facilitate information exchange among various business entities (such as suppliers, manufacturers, distributors, third-party logistics providers and retailers).

Frazelle (2002) thinks that supply chain is the network of facilities (warehouses, factories, terminals, ports, stores and homes), vehicles (lorries, trains, planes and ocean vessels) and logistics information systems connected by an enterprise's suppliers and its customer's customers.

Hensher and Brewer think that supply chain management comprises all business and management activities that are used for transforming input resources into products and services.

According to Vlajic (2005), that is a consequence of supply chain complexity and diversity – concerning product/industry type and characteristics, target market (national or global), politics and supply resources, number of members and their influence on chain functioning, geographical position, dimension, way of information flow realization, comprising or not comprising financial and reverse goods flow, etc. Yet, it can be concluded that supply chain comprises all participants from starting supplier to final user, all connected by material and reverse material flow, information flow (managing and controlling), and financial flow. It can also be concluded that supply chain management is related to all members' activities and processes of integration, coordination and synchronization, on different levels – from strategic, through tactical to operational activities, always respecting the fact that any member of chain influences the expenses and value of products/services to the ultimate user. Naturally, the aim of supply chain management is raising its profitability, which can be done only through raising or maintaining its level of competitiveness, namely through raising the user service level on one hand, and lowering the total chain expenses on the other hand. To achieve the designated aim, it is necessary to fulfill many prerequisites related to smooth flows of goods, information and finances.

Social, economic, technological and some other changes in the world of business require changes in supply chain operation. Complexity of decision making in coordinated management has been persistently increasing. By application of coordinated management and control of the total costs in supply chain it can be significantly decreased [7]. In supply chain management there are many various problems. It is hard to make a unique classification in management and control, since most researchers refer to the same address of supply chains [10, 3, 8]. According to the classification [10, 3, 8], there has been treated a problem belonging to the system, technical level and relation buyer-seller respectively.

In literature "supply management" has not been unanimously defined yet. The function of purchase has recently appeared as an important issue in management and decision making. There is no doubt the most important activity of supply function is selection of order policy [3, 6, 7]. Nowadays, supply chains draw attention to quality, lowering costs, clients' satisfaction and partnership. Strategic origin, supply partnership and risks analysis in such a partnership are the main points in the relation buyer – seller.

In production theory and practice purchase in supply chains, of one or more sources is applied, no matter if the purchase refers to one or more raw materials. One source means supply with raw materials from one reliable supplier. In this case, the highest level of suppliers' partnership could be obtained. It has been denoted as "supplier network", meaning that supply chains and suppliers have the same objectives and means [10]. For purchases in the circumstances with no reliable supplier, in terms of delivering goods in sufficient quantities and on time, several sources offer an attractive alternative.

From what was previously said it is clearly seen that one of the most important functions of a company is supply function. That is why supply has been the subject of study of many world scientists in recent years. Supply function study is done for finding out about eligibility (validity) of a supplier. A supplier's validity can be deduced only by making comparisons among two or more suppliers. Comparison of suppliers is done by comparing fulfilling a supplier's factors towards his clients. In order to make a selection of supplier, it is necessary to define the factors in advance. Defining the supplier's factors is not the same for all companies, but it depends on the terms and conditions of a company. For one company the cost is a very important and crucial factor, for another company the price is on the second or third place, but the range of supply is on the first one. A huge responsibility of a company's managers lies on defining the factors of supply and its priorities. Some authors cite the key factors for the selection of a supplier as follows: cost, services, capacity, location, previous contacts and reciprocity.

In his paper [11], W. L. Ng proposes 5 key factors for selection of suppliers: supply variety, quality, distance, delivery and price.

H. Ahmet Akdeniz [12] in his work proposes 7 key criteria for selection of a supplier: product quality and performance (PDQ), lead time (LT), price (PRC), punctuality (PNC), quality practices (QLP), flexibility (FLX) and level of cooperation (LOC).

Ranking of suppliers is of better quality if the number of influential factors is bigger. In that sense the impact of each factor contributes to the total rank of suppliers. However, one should not exaggerate in determination of the number of factors, but select the most influential ones and place them on the basis of their priorities. Determination of the importance of factors is done on the basis of weight of factor transformed value and ranking done on the basis of the total weight as a sum of all weights of all influential factors.

The author of this paper proposed suppliers ranking according to the following criteria: Range of supply (RS), Price (PR), Quality (QT), Performance (PF), Lead Time (LT), Locations (LO), Flexibility (FX) and Delivery (DV).

In literature there are several definitions of supply chain management and materials flows through supply chains, and some of them are presented in the text that follows.

2 Literature review
Pregled literature

In literature there are many papers dealing with the study of suppliers ranking aiming at the selection of a supplier meeting optimal requirements for cooperation. Ranking suppliers in the papers was based on mathematical, statistical or simulation techniques, while the matter of multi criteria analysis was based on application of cross-evaluation matrixes, AHP (Analytic Hierarchy Process) method, multi-criteria statistical technique or simulation. Furthermore, there were presented some of the papers dealing with suppliers ranking.

The cross-evaluation matrix was first developed by Sexton et al. (1986), inaugurating the subject of ranking in DEA (Data Envelopment Analysis). Indeed, as Doyle and Green (1994) argued, decision-makers do not always have a reasonable mechanism from which to choose assurance regions, thus they recommend the cross-evaluation matrix for ranking units. The cross-efficiency method simply calculates the efficiency score of each DMU (Decision Making Unit) in times, using the optimal weights evaluated by the n LPs. The results of all the DEA cross-efficiency scores can be summarized in a cross-efficiency matrix.

Andersen and Petersen (1993) developed a new procedure for ranking efficient units. The methodology enables an extreme unit to achieve an efficiency score greater than one by removing the k-th constraint in the primal formulation.

Torgersen et al. (1996) achieved a complete ranking of efficient DMUs by measuring their importance as a benchmark for inefficient DMUs. The benchmarking measure is evaluated in a two-stage procedure, whereby the additive model is first used to evaluate the value of the slacks. The set of efficient units, V, is identified as those units whose slack values equal zero. In the second stage, the model is applied to all decision making units.

This is somewhat similar to the results reported in Sinuany-Stern et al. (1994), in which an efficient DMU is highly ranked if it is chosen as a useful target by many other inefficient units. The technique developed in this paper is applied to all DMUs in two stages. In the first stage, the efficient units are ranked by simply counting the number of times they appear in the reference sets of inefficient units, an idea first developed in Charnes et al. (1985). The inefficient units are then ranked, in the second stage, by counting the number of DMUs that need to be removed from the analysis before they are considered efficient. However, a complete ranking cannot be assured since many DMUs may receive the same ranked score.

Y. Grama, R. Pascal and A. Torres (2004), proposed the optimum method of procurement in the presence of discount on the amount of alternative products. The author believes that ordering large quantities of material should bring the price discounts or other discounts that are relevant to the company's operations.

In 2008 Wang Lung Ng – proposed an efficient and multi-criteria supplier selection. In his model Ng used transformed multi-criteria method for selection of 18 suppliers, considering 5 criteria important for a company's operation. The role of a decision maker is not subjective as it is in AHP model. Transformation of criteria value was done by linear transformation, and selection done by arithmetic mean. The values obtained were arranged into a descending order, in a scale from 1 to 0,21. Ranks mean priority of suppliers, the rank (1) means the highest priority of supplier and the lowest rank (0,21) means the lowest priority of supplier.

Danijela Tadic (2005) proposed Fuzzy multi-criteria approach to ordering policy ranking in a supply chain. The author of the paper performs ranking of three suppliers on the basis of three significant criteria: unit price of raw material, lead time and method of payment.

Knemeyer and Murphy (2004) evaluated 3PL performance from the perspective of marketing relationships and proposed six dimensions: trust, communications, opportunistic behavior, reputation, satisfactory relation and specific investments in formation of the model for evaluation of 3PL services.

Previous researches in the field of ranking suppliers can be divided into 6 groups.

The first group of papers is based on cross-efficiency matrix. By evaluating DMUs through both self-and peer pressure, one can attain a more balanced view of the decision-making units. The second group of papers is based on the super-efficiency approach, in which the efficient units can receive the score greater than one, through the unit's exclusion from the column being scored in the linear program. The third grouping is based on benchmarking, in which a DMU is highly ranked if it is chosen as a useful target for many other DMUs. This is of substantial use when looking to benchmark industries. The fourth group of papers developed a connection between multivariate statistical techniques and DEA. Canonical correlation analysis and discriminate analysis were each used to compute common weights, from which the set of DMUs can be ranked. In practice, non-parametric statistical tests showed a strong correlation between the final ranking and the original DEA dichotomous classification. The fifth section discussed the ranking of inefficient units. One approach, dealing with a measure of inefficiency dominance, ranks the inefficient units according to their average proportional inefficiency in all inputs and outputs. In the last set of papers, which crosses multi-criteria decision-making models with DEA, some concepts used additional, preferential information in order to aid the ranking process. The additional information can be incorporated into or alongside the standard DEA results through the use of fuzzy logic, assurance regions or discrimination intensity functions.

The models presented have some weaknesses reflecting in the following things:

One major weakness of the application-oriented AHP literature is that it tends to focus on the mechanics of AHP, instead of on the theoretical and practical results associated with implementing AHP. For example, these articles describe in great detail the manipulation of square reciprocal symmetric matrices, but, aside from the cursory nod to their problem context, rarely mention how theory and practice are advanced by the AHP solution.

The second stream of study deals with the mathematics of AHP to prove its soundness as a problem solving method. The debate has raged for more than a decade concerning whether AHP is robust enough to be unaffected by the addition or deletion of "irrelevant alternatives" (Schenkerman, 1997). In addition to the unresolved problem of rank reversal, AHP also can induce a rank order when none exists (Schenkerman, 1997). There has not been sufficient time for the pro-AHP camp to respond to this assertion, so it would be premature to dismiss AHP as a valuable tool for multi-criterion decision analysis. However, issues of validity must be acknowledged. One major advantage of AHP is that the construction of the hierarchy diagram forces the decision-maker to structure

the problem. Requiring the decision-maker to explicitly define the objective and relevant criteria, and to assign numerical values for their relative importance forces the decision-maker to consider trade-offs in some detail.
Since managers typically rely on only a subset of information (e.g. heuristics), AHP helps managers make "more rational" decisions by structuring the decision as they see it and then fully considering all available information on the criteria and alternatives. In other words, the process of developing the AHP model provides value on its own, independent of the final evaluation of the alternatives.

To overcome the weaknesses by application of classical DEA and statistical models, we suggest a simple model of multi-criteria supplier ranking.

In this paper is proposed a multi-criteria approach to ranking suppliers in the supply chain concept, by the application of statistical techniques in alliance with the DEA, in order to close the gap between DEA and traditional statistical techniques. The work has practical application and it eliminates any mathematical approximations, while it increases the participation of decision-makers in determining the criteria and alternative suppliers.

3 Mathematical formulation
Matematička formulacija

Analytical Hierarchical Process (AHP) is one of the best known methods of scientific analysis and decision making by consistent hierarchy evaluation whose elements are: goals, criteria, sub-criteria and alternatives.

In many opinions AHP is a decision making system support, i.e. DSS. Since it contains a correct mathematical model and it was realized as shaped software for PC platforms with a full technical support – generally, there are enough reasons in computer version Expert Choice 2000 to be considered a commercial DSS of general purpose in the field of multi-criteria decision making. The producers' references and web browsers show AHP is intensively used for decision making in the field of management, allocation and distribution.

Thomas Saaty (Saaty, 1980) presented mathematical setting up of AHP. The owner of the license for DSS software realization, in the versions for individual and group decision making is the company Expert Choice, Inc. from Pittsburgh in USA. Cooperation with this company was established in 1999.

Analytical Hierarchical Process belongs to the class of methods for soft optimization. Basically, it is about a specific tool for formation and analysis of decision making hierarchy. AHP method enables an interactive movement of hierarchy of problems as a preparation of decision making scenario, and then evaluation in elements pairs hierarchy (goals, criteria and alternatives) in top-down direction. Finally, the synthesis of all evaluations is done and weighted coefficients of all the hierarchy elements are determined. The sum of weight coefficients of elements at each level of hierarchy is 1, what enables a decision maker to rank all elements, both in horizontal and vertical terms.

In methodological terms, AHP is a multi-criteria technique based on decomposition of a complex problem into a hierarchy with goal at the top of hierarchy, and criteria, sub-criteria and alternatives at the lower levels of hierarchy. The Figure below is an illustration of a hierarchy consisting of 8 criteria and twenty alternatives.

The author of this paper proposed a weighted linear model for ranking suppliers by multi-criteria classification. We consider the situation where a set of suppliers is available for a company. One should select the suppliers having the biggest weight (meeting the criteria best) from the set of suppliers. Let us mark the I set of suppliers with i ($i = 1, 2, 3,..., I$). Let us evaluate these suppliers by criterion J ($j = 1, 2, 3,…, J$). Evaluation (ranking) of suppliers will be done by converting multiple measures (criteria) of suppliers into a single measure S_i. By this measure (values of measure S_i) we will do the ranking of suppliers from the best to the worst one.

The values of measures to be compared in multi-criteria classification were converted, ranging from 0 to 1. The supplier whose total value is 1, has maximal recommendations for cooperation (he is the best one), and the supplier having value 0 is not desirable for cooperation. The measure of suppliers i under criteria j is denoted as X_{ij} ($i = 1, 2, 3,…, I; j = 1, 2, 3,…, J$). We proposed normalization of measures X_{ij} into a 0 – 1 scale. Let us transform them into the values Y_{ij}. The transformation of measures is done by formula:

$$y_{ij} = 1 - \frac{\max_{j=1,2,3,...,J}\{x_{ij}\} - x_{ij}}{\max_{j=1,2,3,...,J}\{x_{ij}\}}.$$

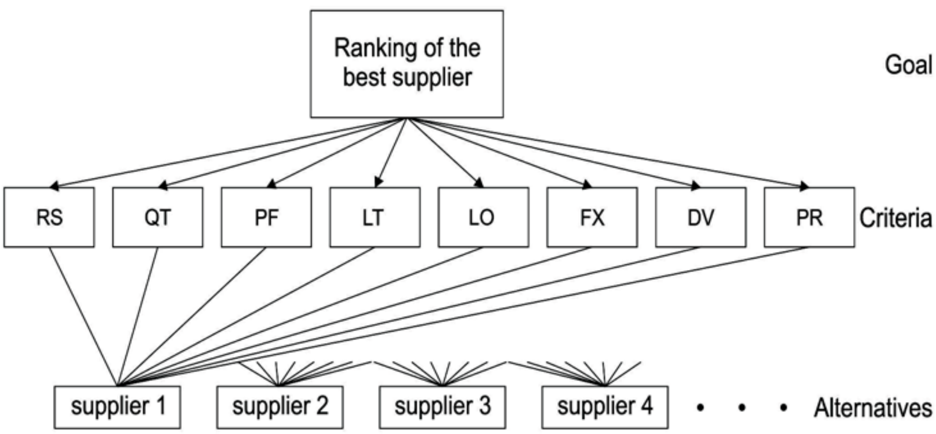

Figure 1 *Model of multi-criteria ranking suppliers*
(RS – range of suppliers, PR – price, QT – quality, PF – performance, LT – lead time , LO – locations, FX – flexibility, DV – delivery)
Slika 1. *Model višekriterijskog rangiranja dobavljača*
(RS – rang dobavljaèa, PR – cijena, QT – kvaliteta, PF – svojstva, LT – rok, LO – lokacija, FX – fleksibilnost, DV - dostava)

The scores of ranked suppliers are expressed as weighted sum of transformed values,

$$S_i = \sum_{j=1}^{J} W_{ij} y_{ij}$$

where W_{ij} (j=1, 2, 3,…, J) is the weight of criterion j from the supplier I.

In our model the criteria are arranged in the descending order of importance ($W_{i1} \geq W_{i2} \geq W_{i3} \geq \ldots \geq W_{ij}$). The same way, we are assuming weights W_{ij} are negative and normalized, so that

$$\sum_{j=1}^{J} W_{ij} = 1.$$

All the normalization scores S_{ij} (i=1, 2, 3,..., I) are always between 0 – 1. We propose a multi-criteria model for ranking suppliers by using the following formula:

$$\max S_i = \sum_{j=1}^{J} y_{ij} W_j$$

$$\text{s.t.} \quad W_{ij} - W_{i(j+1)} \geq 0,\ j = 1,2,3,...,(J-1)$$

$$\sum_{j=1}^{J} W_{ij} = 1$$

$$W_{ij} \geq 0,\ j = 1,2,3,...,J$$

$$y_{ij} = 1 - \frac{\max_{j=1,2,3,...,J} \{x_{ij}\} - x_{ij}}{\max_{j=1,2,3,...,J} \{x_{ij}\}}.$$

The geometric mean G of set of numbers $x_1, x_2, x_3, \ldots, x_N$, is N^{th} root of their products.

$$G = \sqrt[N]{x_1 \cdot x_2 \cdot x_3 \cdots x_N}.$$

Geometric mean can be easily calculated by logarithm:

$$\log G = \frac{1}{N}\left(f_1 \cdot \log x_1 + f_2 \cdot \log x_2 + \cdots ..... + f_n \cdot \log x_n\right).$$

Geometric mean can also be used as a measure of speed of changes in certain phenomena in time.

$$U_{ij} = W_{ij} - W_{i(j+1)};\ i = 1,2,3,...,I \text{ and } j = 1,2,3,...,(J-1)$$

$$U_{ij} = W_{ij};\ i = 1,2,3,...,I$$

$$\sum_{j=1}^{J} jU_{ij} = 1;\ i = 1,2,3,...,I$$

$$U_{ij} \geq 0;\ i = 1,2,3,...,I;\ j = 1,2,3,...,J.$$

The procedure of multi-criteria ranking suppliers is a simple and fast procedure and it is performed in the following steps:

Step 1 To make a selection of characteristic company's factors for supplier selection and present their values in terms of fulfilling obligations towards their associates.

Step 2 To transform the values of items RS, PR, QT, PF, LT, LO, FX and DV into the values by the following formula:

$$y_{ij} = 1 - \frac{\max_{j=1,2,3,...,J} \{x_{ij}\} - x_{ij}}{\max_{j=1,2,3,...,J} \{x_{ij}\}},$$

where $\min_{i=1,2,3,...,J} \{Y_{ij}\}$ and $\max_{i=1,2,3,...,J} \{Y_{ij}\}$ minimal and maximal value of the items of a certain factor, or by their reciprocal index value.

Step 3 To calculate all partial average weights by the formula:

$$\frac{1}{j} \cdot \sum_{k=1}^{j} x_{ik};\ j = 1,2,3,...,J$$

$$G = \sqrt[N]{x_1 \cdot x_2 \cdot x_3 \cdots x_N}.$$

Step 4 To find maximal values of partial average values of weigh coefficients, max y_{ij}, j=1,2,3,…,J.

Step 5 Calculate maximal values by formula:

$$\max S_i = \sum_{j=1}^{J} y_{ij} \cdot W_j.$$

Step 6 To aline S_i items in a descending order from the highest to the lowest one.

Step 7 Selection of the best ranked suppliers (with highest weight).

4 An illustrative example
Ilustrativni primjer

For the purpose of illustration, we observe a hypothetical example of supplying a private company for making mechanical assemblies for car industries. For performing its operation the company cooperates with 20 suppliers, on the permanent or occasional bases, purchasing necessary raw materials, intermediates, finished products or some other materials necessary for work. Purchasing the necessary raw materials is done in dependence of the company's needs, while selection of a supplier is done according to the procurement managers' estimation or according to the currently estimated criterion (price, quality, lead time, previous cooperation, etc.), not taking care of all criteria accompanying raw materials purchase. The purchased quantities are often of different qualities, different prices, different delivery deadlines and other factors accompanying regular procurement.

For optimization of the supply process and selection of the best supplier/suppliers we proposed a model of multi-criteria ranking of suppliers in the supply chain concept. The process of ranking suppliers will be done by multi-criteria classification of weighting AHP method. We rank all 20 suppliers that the company cooperates with, for the reason of selecting the best one among the 20 of them, or a few best among the 20 ones. By introspecting the circumstances in which the company operates, its priorities and goals, as well as cooperation with supply managers, production managers and sales managers, we have determined 8 key criteria that are crucial for a successful operation of a company that we will use for ranking suppliers. The criteria for suppliers' selection were shown in Tab. 1, and their priority in order of setting.

We do the calculations by the principle of multi – criteria AHP method and by the proposed procedure (Chapter 3, Steps 1 to 7).

Table 1 *Factors for the ranking of suppliers*
Tablica 1. *Faktori za rangiranje dobavljača*

Factors for the ranking of suppliers	Mark
Range of supply	RS
Price	PR
Quality, %	QT
Performance	PF
Lead Time	LT
Locations	LO
Flexibility, %	FX
Delivery, %	DV

Maximal weight value is calculated as a sum of all criteria weights.

$$MaxScore = W_{i1} + W_{i2} + W_{i3} + W_{i4} + W_{i5} + W_{i6} + W_{i7} + W_{i8}$$
$$W_{i1}, W_{i2}, W_{i3}, W_{i4}, W_{i5}, W_{i6}, W_{i7}, W_{i8} \geq 0$$

where:
W_{i1} – Range of supply (RS)
W_{i2} – Price (PR)
W_{i3} – Quality (QT)
W_{i4} – Performance (PF)
W_{i5} – Lead Time (LT)
W_{i6} – Locations (LO)
W_{i7} – Flexibility (FX) and
W_{i8} – Delivery (DV).

We consider 20 suppliers that the company cooperates with, every day, or from time to time. According to the principles of AHP method, we obtain conditionality shown in Fig. 1.

Table 2 *Values of suppliers and their criteria*
Tablica 2. *Vrijednosti dobavljača i njihovih kriterijuma*

ITEM	RS	QT / %	PF	LT	LO / km	FX / %	DV / %	PR / %
1	5	70	7	1	30	20	20	80
2	11	96,55	15	3	125	87	70	100
3	52	99,82	22	5	220	75	90	100
4	4	79	7	2	30	50	30	80
5	11	100	15	4	43	85,3	100	100
6	30	99,49	19	2	170	65	80	100
7	7	80	8	1	78	50	55	80
8	50	93,22	20	5	60	45	100	100
9	45	100	11	3	620	52	60	100
10	10	100	10	4	480	63	100	80
11	33	97,32	16	5	65	80	75	100
12	6	100	9	4	30	86	80	100
13	6	99,44	8	5	31	92,3	80	80
14	41	100	8	3	100	100	65	100
15	11	97,25	12	4	82	73	82	100
16	27	100	17	2	30	66,8	95	100
17	15	98,27	9	1	275	69,3	100	100
18	5	80	12	1	30	50,0	20	80
19	9	100	15	5	70	91,4	100	100
20	22	94,20	20	5	200	71,5	90	100

Values of factors for selection of suppliers are transformed into the values from 0 to 1, for an easier calculation. The transformation was done by the formula

$$y_{ij} = 1 - \frac{\max_{j=1,2,3,\ldots,J}\{x_{ij}\} - x_{ij}}{\max_{j=1,2,3,\ldots,J}\{x_{ij}\}}.$$

The transformed values range from 0 to 1 and are placed in Tab. 3. The values of the transformed criteria for the mentioned suppliers are the matrix $\boldsymbol{m} \times \boldsymbol{n}$ that is further used in ranking, by the procedure of AHP method.

Table 3 *Matrix of the transformed values*
Tablica 3. *Matrica transformiranih vrijednosti*

Item	RS tran.	QT tran.	PF tran.	LT tran.	LO tran.	FX tran.	DV tran.	PR tran.
1	0,10	0,70	0,32	0,20	1,00	0,20	0,20	1,00
2	0,21	0,97	0,68	0,60	0,79	0,87	0,70	0,00
3	1,00	1,00	1,00	1,00	0,62	0,75	0,90	0,00
4	0,08	0,79	0,32	0,40	1,00	0,50	0,30	1,00
5	0,21	1,00	0,68	0,80	0,93	0,85	1,00	0,00
6	0,58	0,99	0,86	0,40	0,71	0,65	0,80	0,00
7	0,13	0,80	0,36	0,20	0,87	0,50	0,55	1,00
8	0,96	0,93	0,91	1,00	0,90	0,45	1,00	0,00
9	0,87	1,00	0,50	0,60	0,00	0,52	0,60	0,00
10	0,19	1,00	0,45	0,80	0,18	0,63	1,00	1,00
11	0,63	0,97	0,73	1,00	0,89	0,80	0,75	0,00
12	0,12	1,00	0,41	0,80	1,00	0,86	0,80	0,00
13	0,12	0,99	0,36	1,00	0,95	0,92	0,80	1,00
14	0,79	1,00	0,36	0,60	0,83	1,00	0,65	0,00
15	0,21	0,97	0,55	0,80	0,86	0,73	0,82	0,00
16	0,52	1,00	0,77	0,40	1,00	0,67	0,95	0,00
17	0,29	0,98	0,41	0,20	0,53	0,69	1,00	0,00
18	0,10	0,80	0,55	0,20	1,00	0,50	0,20	1,00
18	0,17	1,00	0,68	1,00	0,88	0,91	1,00	0,00
20	0,42	0,94	0,91	1,00	0,62	0,72	0,90	0,00

The transformation of values in Tab. 3 was carried out by the pattern of geometric mean.

$$G = \sqrt[N]{x_1 \cdot x_2 \cdot x_3 \cdots x_N}.$$

The values obtained make the matrix $\boldsymbol{m} \times \boldsymbol{n}$. We carry out ranking and determine the final SCORE by the proposed mathematical procedure. These values are presented in Tab. 4.

Table 4 *The total scores of the ranked suppliers*
Tablica 4. *Ukupni rezultati rangiranih dobavljača*

ITEM	RS	QT	PF	LT	LO	FX	DV	PR	SCORE
1	0,10	0,26	0,28	0,26	**0,34**	0,31	0,29	0,34	0,34
2	0,21	0,45	0,52	0,54	0,58	0,62	**0,63**	0,00	0,63
3	**1,00**	1,00	1,00	1,00	0,91	0,88	0,88	0,00	1,00
4	0,08	0,25	0,27	0,30	0,38	0,40	0,38	**0,43**	0,43
5	0,21	0,46	0,52	0,58	0,64	0,67	**0,71**	0,00	0,71
6	0,58	0,76	**0,79**	0,67	0,68	0,67	0,69	0,00	0,79
7	0,13	0,33	0,34	0,30	0,37	0,39	0,41	**0,46**	0,46
8	**0,96**	0,95	0,93	0,95	0,94	0,83	0,85	0,00	0,96
9	0,87	**0,93**	0,76	0,71	0,00	0,00	0,00	0,00	0,93
10	0,19	0,44	0,44	0,51	0,42	0,45	0,50	**0,55**	0,55
11	0,63	0,79	0,77	0,82	0,83	**0,83**	0,82	0,00	0,83
12	0,12	0,34	0,36	0,44	0,52	0,56	**0,59**	0,00	0,59
13	0,12	0,34	0,35	0,45	0,52	0,58	0,60	**0,64**	0,64
14	0,79	**0,89**	0,66	0,64	0,68	0,72	0,71	0,00	0,89
15	0,21	0,45	0,48	0,55	0,60	0,62	**0,64**	0,00	0,64
16	0,52	0,72	**0,74**	0,63	0,69	0,69	0,72	0,00	0,74
17	0,29	**0,53**	0,49	0,39	0,41	0,45	0,51	0,00	0,53
18	0,10	0,28	0,35	0,30	0,38	0,40	0,36	**0,41**	0,41
19	0,17	0,42	0,49	0,59	0,64	0,68	**0,71**	0,00	0,71
20	0,42	0,63	0,71	**0,78**	0,74	0,74	0,76	0,00	0,78

If we sort suppliers by the values SCORE in a descending order, we will get Tab. 6. The supplier with highest rank (1) is on the first place, and that is the supplier with reference S3. On the second place is the supplier with rank of 0,96, that is the supplier with reference S8, and so on, up to the last supplier. The supplier with rank 0,34 is on the last place, and that is the supplier with reference S1. The value SCORE denotes the value of the supplier's rank. The

***Table 5** Aligned suppliers from the best to the worst one*
***Tablica 5.** Rang dobavljača od najboljeg do najgoreg*

ITEM	RS	QT	PF	LT	LO	FX	DV	PR	RANK
S3	52	99,82	22	5	220	75	90	100	1,00
S8	50	93,22	20	5	60	45	100	100	0,96
S9	45	100	11	3	620	52	60	100	0,93
S14	41	100	8	3	100	100	65	100	0,89
S11	33	97,32	16	5	65	80	75	100	0,83
S6	30	99,49	19	2	170	65	80	100	0,79
S20	22	94,20	20	5	200	71,5	90	100	0,78
S16	27	100	17	2	30	66,8	95	100	0,74
S5	11	100	15	4	43	85,3	100	100	0,71
S19	9	100	15	5	70	91,4	100	100	0,71
S13	6	99,44	8	5	31	92,3	80	80	0,64
S15	11	97,25	12	4	82	73	82	100	0,64
S2	11	96,55	15	3	125	87	70	100	0,63
S12	6	100	9	4	30	86	80	100	0,59
S10	10	100	10	4	480	63	100	80	0,55
S17	15	98,27	9	1	275	69,3	100	100	0,53
S7	7	80,00	8	1	78	50	55	80	0,46
S4	4	79,00	7	2	30	50	30	80	0,43
S18	5	80,00	12	1	30	50	20	80	0,41
S1	5	70,00	7	1	30	20	20	80	0,34

best rank is 1 and the worst one is 0,34.

The rank of suppliers from the highest S3 to the lowest S1, was illustrated in the histogram of Fig. 2.

5 Conclusion
Zaključak

In this work we presented a multi-criteria model of ranking suppliers by linear optimization of metalworking industry. We presented I =20 suppliers, with J=8 criteria, that are considered the crucial ones in this field and for such type of business. We marked suppliers with ordinal numbers from 1 to 20, by the order of recordings performed. We also presented 8 criteria: range of supply (RS), price (PR), quality (QT), performances (PF), lead time (LT), location (LO), flexibility (FX) and delivery (DV), that are, in the author's opinion, dominant for such type of business.

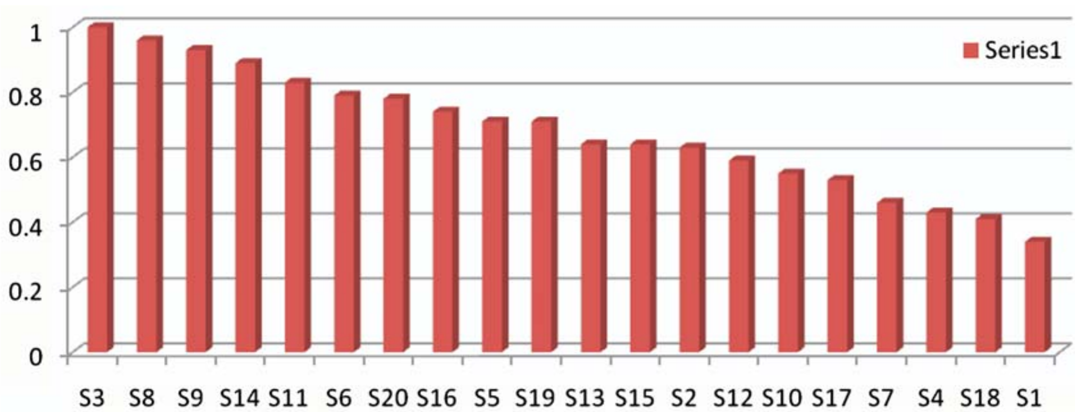

***Figure 2** Histogram of the ranked suppliers*
***Slika 2.** Histogram rangiranih dobavljača*

***Table 6** The ranks of the suppliers*
***Tablica 6.** Rang dobavljača*

Rank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Supplier	S3	S8	S9	S14	S11	S6	S20	S16	S5	S19	S13	S15	S2	S12	S10	S17	S7	S4	S18	S1
Reliability / %	100	96	93	89	83	79	78	74	71	71	64	64	63	59	55	53	46	43	41	34

The values of suppliers and their criteria are presented in Tab. 2, calculated gradually from step 1 to step 7, and led to the final values (score), that are presented in the last column of Tab. 6. The values of the final scores are placed in a descending order, from the highest to the lowest one. The first column contains ordinal numbers of the suppliers analogous to their weights. Now, the supplier S3 with the highest weight of 1,00 is on the first place. According to mathematical model assumptions and AHP criteria, this supplier is absolutely the best one, fulfilling all the company's conditions and he has the maximal recommendations for cooperation. The supplier with number S8 and weight 0,96 is on the second place. This supplier is less reliable than the first one by 4 %. If the company needs cooperation with more than one supplier, then, after S3 supplier, the next one, in terms of priority, is the supplier S8. The third place belongs to the supplier S9 with weight 0,93 (less reliable than the first supplier by 7 %).

Furthermore, suppliers are placed on the basis of rank, as it is shown in Tab. 5. The last supplier is the one with ordinal number S1 and weight 0,34. According to the principle of mathematical model and AHP criteria, this supplier is unreliable and invalid, so one should not cooperate with him. Tab. 5 gives a clear image of the suppliers' ranks. The highest rank means the highest reliability, the lowest rank – the lowest reliability.

The ranks and reliability of the suppliers in percentages are presented in Tab. 6.

After performing transformation and mathematical procedure, as it was presented in the procedure (step 1-7), we obtained the final scores presented in Tab. 6. We can see the supplier with ordinal number 3 maximally meets all the criteria and he got the maximal weight value (1). So, the supplier 3 is the supplier that one should always, and in any occasion, cooperate with, because he is the best one. On the basis of priority, the next supplier is the one with number 8 and weight 0,96, then the supplier 9 with weight 0,93, and so on. The suppliers least satisfying the company's criteria are the suppliers with the lowest weights and ordinal numbers 1, 18, 4, 7, etc. The last supplier is the supplier with ordinal number 1 and weight 0,34. This supplier is not reliable and one should not cooperate with him.

The rank of suppliers from the highest S3 to the lowest

S1 is presented in the histogram of the Fig. 2.

This ranking gives a clear picture about suppliers, their conditions, potentials and activities in terms of chances for cooperation. By knowing this weighted list, managers can easily decide about the directions of their business cooperation, as well as about the people to make long term plans with.

Ranking suppliers for selection of the "best" one is a multi – criteria decision. We propose a model of multi criteria decision making by weighting linear programming. The proposed model retains advantages of nonparametric DEA procedure. It allows a decision maker's participation in ranking relative importance of criteria. Apart from that, the role of a decision maker is not subjective as in some other AHP approaches or MOP models.

The model can help buyer determine an optimal set of suppliers to cooperate with. Using the proposed model can help improving decisions in terms of selection of suppliers.

The buyer can use it as a tool in the process of ranking "best" supplier. The supplier can use these results from a marketing perspective. A specific supplier, who achieves a high mean score, when compared to the other suppliers, can use these results for promoting his product. On the other hand, if a particular supplier is poorly ranked, then the supplier can use the results for the benchmarking purposes. This research can determine which supplier must provide better performance levels at the same input.

- To focus on theoretical and practical results.
- A decision maker's demand to define goal and appropriate criteria precisely, as well as to assign numerical value to their relative importance.
- In this paper, ranking is still at an initial stage of investigation. Many more researches can be carried out on the basis of the results from this paper. Recommendations for further work:
- Similar researches can be repeated when the transformation of performance values is carried out by arithmetic mean, square or cubic means.
- Model of research when fuzzy data are used.

The disadvantage of this method is that two suppliers may happen to have the same weight and we cannot say precisely which of the two suppliers is better. These are the suppliers with ordinal numbers S5 and S19 with weights 0,71, and S13 and S15 with weight 0,64. Further researches should be aimed at elimination of this disadvantage.

6 Literature
Literatura

[1] Thomas, D. J.; Griffin P. M. Invited review coordinated supply chain management. // Europena Journal of Operation Research, 94, 1(1996), 1-15.

[2] Tilanus, B. Information Systems in Logistics and Transportation, Elsevier, Science Ltd., UK, 1997.

[3] Ballou, H. R. Basic Business Logistics, Prentice-Hall, Inc. Englewood Cliffs, USA, 1992.

[4] Chopra, S.; Meindl, P. Supply Chain Management: Strategy, Planning and Operation, Prentice Hall Inc., 2001.

[5] Werner, D.; Albers, S. Supply chain management in the global context, Working Paper No.102, University of Koeln, 2002.

[6] Dobler, D. W. Purchasing and material Management: Text and Cases, McGraw-Hall, USA, 1990.

[7] Dooley, K. Purchasing and supply. // Operational Research, 8, 3(1995) 21-25.

[8] Fazel Zarandi, H. M. et al. Supply chain: Crips and fuzzy aspects, Int. J. Appl. Math. Comput. Sci., 12, 3(2002), 423-435.

[9] Mackey, M. Achieving inventory reduction through the use of partner-shipping. // Industrial Engineering, 24, 5(1992), 36-38.

[10] Thomas, J.; Griffin, M. P. Coordinated supply chain management. // European Journal of Operations Research, 94, 1(1996), 1-15.

[11] Ng, W. L. An efficient and simple model for multiple criteria supplier selection problem. // European Journal of Operation Research, 186, 3(2008), 1059-1067.

[12] Akdeniz, H. A. Supplier selection on retail: Analysis with two multi-criteria evaluation methodologies. // Review of social, Economic & business studies, 9/10, 11-28.

[13] Šimunović, K. et al. Application of different quantitative techniques to inventory classification. // Technical Gazette 15, 4(2008), 41-47.

[14] Šimunović, K. et. al. Application of Artificial Neural Networks to Multiple Criteria Inventory Classification. // Strojarstvo, 51, 4(2009), 313-321.

[15] Tukel, O. I.; Wasti, S. N. Analysis of supplier relationships using resource constrained project scheduling strategies. // European Journal of Operation Research, 129, (2001), 271-276.

[16] Reza Ferzipoor Saen, Suppliers selection in the presence of both cardinal and ordinal data. // European Journal of Operation Research, 183, (2007), 741-747.

[17] Burke, J. G.; Carrillo, J.; Vakharia, A. J. Heuristic for sourcing from multiple suppliers with alternative quantity discounts. // European Journal of Operation Research, 186, (2008) 317-329.

[18] Wu, T.; Shunk, D. AIDEA: a methodology for supplier evaluation and selection in a supplier-based manufacturing environment. // Int. J. Manufacturing Technology and Management, 11, 2(2007), 174-192.

[19] Bayazit, O.; Karpak, B. An AHP application in vendor selection, ISAHP 2005, Honolulu, Hawaii, July 8-10, 2005.

[20] Grama, Y.; Paskual, R.; Torres, A. Optimal procurement decisions in the presence of total quantity discounts and alternative product recipes. // European Journal of Operational Research, 159, (2004), 364-378.

[21] Güler, M. E. Incorporating multi-criteria considerations into supplier selection problem using analytical hierarchy process: A case study. // Journal of Yasar Universiti, 3, 12(2008), 775-798.

[22] Kar, A. K. Modeling of Supplier Selection in e-Procurement as a Multi-Criteria Decision Making Problem. // Working Papers on Information Systems ISSN 1535-6078.

[23] Saranga, H. The Indian auto component industry – Estimation of operational efficiency and its determinants using DEA. // European Journal of Operational Research, 196, (2009), 707-718.

[24] Saen, R. F. A New Model for Ranking 3PL Providers. // Australian Journal of Basic and Applied Sciences, 4, 8(2010), 3762-3769.

[25] Saen, R. F. The Use of AR-IDEA Approach for Supplier Selection Problems. // Australian Journal of Basic and Applied Sciences, 4, 8(2010), 3053-3067.

[26] Thanaraksakul, W.; Phruksaphanrat, B. Supplier evaluation framework based on balanced scorecard with integrated corporate social responsibility perspective. // Proceedings of the International MultiConference of Engineers and Computer Scientists, 2009, Vol II, IMECS 2009, March 18 - 20, 2009, Hong Kong.

[27] Mishra, R. K.; Patel, G. Supplier development strategies: A data envelopment analysis approach, Mishra R. K., Patel G. - Supplier Development Strategies: A Data Envelopment Analysis, 2009.

[28] Samaras, G. D.; Matsatsinis, N. F.; Zopounidis, C. A multicriteria DSS for stock evaluation using fundamental analysis. // European Journal of Operational Research, 187, (2008), 1380-1401.

[29] Adler, N.; Fridman, L.; Sinuani-Stern, Z. Review of ranking methods in the data envelopment analysis context. // European Journal of Operational Research, 140, (2002), 249-265.
[30] Aguezzoul, A.; Ladet, P. A nonlinear multi-objective approach for the supplier selection, integrating transportation policies, UFR ESM-IAE, 3, place Edouard BRANLY, Technopole Metz 2000, 57070 METZ
[31] Verdecho, M. J.; Alfaro, J. J.; Rodriguez-Rodriguez, R. Supplier selection for collaborative new product development process: An application to the automotive industry, CIGIP (Research Centre on Production Management and Engineering), Universidad Politecnica de Valencia, Valencia, Spain, Proceedings of the International Symposium on the Analytic Hierarchy Process 2009.
[32] Lorentziadis, P. L. Post-objective determination of weights of the evaluation factors in public procurement tenders. // European Journal of Operational Research, 200, (2010), 261–267.
[33] Saen, R. F. Suppliers selection in the presence of both cardinal and ordinal data. // European Journal of Operational Research, 183, (2007), 741–747.
[34] Xia, W.; Wu, Z. Supplier selection with multiple criteria in volume discount environments. // Omega, 35, (2007), 494–504.
[35] Handfield, R.; Walton, S. V.; Sroufe, R.; Melnyk, S. A. Applying environmental criteria to supplier assessment: A study in the application of the Analytical Hierarchy Process. // European Journal of Operational Research, 141, (2002), 70–87.
[36] Aron, R.; Ungar, L.; Valluri, A. A model of market power and efficiency in private electronic exchanges. // European Journal of Operational Research, 187, (2008), 922–942.
[37] Siskos, Y.; Matsatsinis, N. F.; Baourakis, G. Multicriteria analysis in agricultural marketing: The case of French olive oil market. // European Journal of Operational Research, 130, (2001) 315-331. and European Journal of Operational Research, 187, (2008), 415–428.
[38] Lin, H.-T.; Chang, W.-L. Order selection and pricing methods using flexible quantity and fuzzy approach for buyer evaluation. // European Journal of Operational Research, 187, (2008), 415–428.
[39] Yang, J. B.; Wang, Y.M.; Xu, D.L.; Chin, K.S. The evidential reasoning approach for MADA under both probabilistic and fuzzy uncertainties. // European Journal of Operational Research, 171, (2006), 309–343.
[40] Saaty, T. L. How to make a Decision: The Analytic Hierarchy Process. // Interfaces, 24, 6(1994) (November-December), 19-43.
[41] Tadić, D. Fuzzy Multi-criteria approach to ordering policy ranking in a supply chain. // YJOR, 15, 2 (2005), 243-258.
[42] Pupovac, D. Optimizacija proizvodnje unutar logističkog lanca za 21. stoljeće. // Zbornik radova, Ekonomskog fakulteta Rijeka, 2006, 24, 2(2006), 291–304.
[43] Pupovac, D. Marketing logističkog sustava, Izvorni znanstveni članak. // Naše more, Rijeka, 50, 1-2(2003), 61-67.
[44] Vouk, R. Uloga menadžmenta opskrbnog lanca u povećanju konkurentnosti poduzeća. // Ekonomski pregled, Ekonomski fakultet, Zagreb, 56, 11(2005), 1013-1030.

Author's address
Adresa autora

Mr. sc. Harun Bronja
State University of Novi Pazar
Vuk Karadzic b.b.
36300 Novi Pazar, Serbia
Phone: +381638177450
E-mail: harunbronja@gmail.com