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Supplier Selection Using a Multiple Criteria Decision Making Method

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In the present conditions of market globalization and thus increased market competition, the purchasing department and management structure of the company, in addition to answering questions what, how many and when to buy at what price, has also to be answered the question about an appropriate supplier. Supplier selection as well as the efficient inventory control can bring significant savings to a company. For the purpose of systematic evaluation of suppliers, criteria and multiple criteria AHP model (analytic hierarchy process) for selecting the best supplier have been proposed in the paper. The model is illustrated by the example of supplier selection to purchase parts for assembly of the agricultural machine. Multiple criteria and systematic quantitative approach to the supplier selection problem, significantly improve the decision-making process.

Izbor dobavljača primjenom metode višekriterijskog odlučivanja

Izvornoznanstveni članak

U današnjim uvjetima globalizacije tržišta, a time i povećanja tržišnog natjecanja, služba nabave i upravljačke strukture u poduzeću, pored odgovora na pitanja što, koliko i kada nabaviti, te po kojoj cijeni, moraju znati i odgovor na pitanje od koga nabaviti. Izbor dobavljača, uz učinkovito upravljanje zalihama, može donijeti značajne uštede poduzeću. S ciljem sustavnog i objektivnog vrednovanja dobavljača, u radu su predloženi kriteriji i višekriterijski AHP model (analitički hijerarhijski proces) za izbor najpovoljnijeg dobavljača. Model je ilustriran na primjeru izbora najpovoljnijeg dobavljača dijelova za montažu poljoprivrednog stroja. Višekriterijskim i sustavnim kvantitativnim pristupom problemu, olakšano je donošenje objektivne odluke.

1. Introduction

Nowadays more attention is paid to the supplier selection because cooperation with a reliable supplier can decrease direct and indirect costs as well as influence global market competition. Different criteria must be included in the supplier selection process. Some criteria have emerged with new market conditions, but some completely lost. The distance, as one criteria that had previously been very significant, is now perhaps of no great importance. But the use of information and communication technology is much more important now than before.

The supplier selection problem is a challenge for scientists and professionals in the purchasing department, but also for the entire company.

It can be concluded from the review papers [1-3]. The paper [2] gives an overview of even 177 literature references. The authors of paper [1] suggest one systematic approach to the supplier selection problem which must include problem definition, criteria formulation, screening selection of suppliers, evaluation of suppliers and final selection of suppliers from the smaller group.

In the paper [2], six very important approaches to making decision in the purchase process are presented. These are: make or buy, supplier selection, contract negotiation (short term or long term), cooperation with supplier in phase of product or service design, procurement and analysis of total efficiency of purchase process. Based on data from the questionnaire sent to 273 employers of purchasing departments (USA and Canada) it can be concluded that there are 23 important quantitative and qualitative criteria. Among them cost (price), delivery, quality, ability of the supplier to meet the demands (requirements) of the customer, on time delivery, supplier production capacity and technical capability appear to be the most important criteria.

In the paper [3] flexibility in meeting customer needs (response to changing the order) as a criterion is proposed. The well-known AHP (analytical hierarchy process)

Symbols/Oznake

a	- local priority of alternative with respect to the first criterion - lokalni prioritet alternative za prvi kriterij	p	- total priority of alternative - ukupni prioritet alternative
b	- local priority of alternative with respect to the second criterion - lokalni prioritet alternative za drugi kriterij	RI	- random indexs - slučajni indeks
c	- local priority of alternative with respect to the third criterion - lokalni prioritet alternative za treći kriterij	x	- weight of the first criterion - težina prvoga kriterija
CI	- consistency index - indeks konzistencije	y	- weight of the second criterion - težina drugoga kriterija
CR	- consistency ratio - omjer konzistencije	z	- weight of the third criterion - težina trećega kriterija
n	- number of criteria (or alternatives) - broj kriterija (ili alternativa)	λ_{max}	- maximum value of matrix of relative importance - maksimalna vrijednost u matrici relativne važnosti

methodology is used and its variants and modifications are applied by the authors in the papers [4-5, 7-9]. The AHP methodology is integrated with nonlinear integer programming and nonlinear integer goal programming in the paper [4]. Constraints were as follows: price discount influenced order quantity, total quantity, supplier capacity and the total budget. A very interesting proposed criterion in the paper is cooperation with the supplier which includes communication openness, after selling service of supplier, possibility to visit the supplier, financial assets and design capability.

An integrated approach to supplier selection through the application of AHP methodology and grey relational analysis is presented in the paper [5]. The grey system theory has been developed by Deng. It is applied for solving the uncertainty problems with incomplete and discrete information. Criteria weights are derived by the use of AHP methodology (as in the previous discussed paper) and used as coefficients in the relational model. Four quantitative criteria (cost, delivery, distance and turnover) and six qualitative criteria (quality, finance, service quality, capacity, technical and development capability and use of information technologies) are involved.

An analytic network process, ANP (developed by Thomas Saaty [6]) is the generalization of AHP methodology. The author in the paper [7], uses ANP methodology for making decision on supplier selection. The criterion, not mentioned previosly, is personnel capability.

Linear programming as one of the techniques of operational research, integrated with other methods, is applied in the papers [8-11]. Integration of linear programming with the above-mentioned AHP methodology is presented in paper [8]. As in paper [4], AHP methodology is applied for calculation of criteria weights and alternative's priorities. Linear programming and AHP methodology are used in the paper [9] too. The authors propose one new criterion – after sale service of supplier. The AHP methodology is used to calculate criteria and alternative weights which are applied in linear mathematical model with three objective functions (minimal purchasing costs, quality – minimal total amount of defect or scrap and rejected quantity and reliability of delivery – minimal deviation from delivery time. Criteria for evaluation of suppliers are as follows: purchasing costs, quality of product, reliability of delivery, services of supplier, cooperation and partnership, financial status.

The authors in the paper [10] suggest supplier selection and calculation of economic order quantity by use of linear programming and multi attribute utility theory, but under the conditions of group decision making. The paper [11] also deals with linear programming. The weighed linear optimization model is proposed.

Artificial intelligence methods - neural networks, genetic algorithms, expert systems and fuzzy logic are used in the papers [12-17]. Back propagated neural network is applied to the problem of supplier selection in the paper [12]. For four main criteria, cost, quality, delivery and service, four different networks are trained by using history data form the different departments of companies for 86 suppliers. The input layer of each network consisted of neurons (the number of neurons was equal to the number of subcriteria of each criterion). After the phase of learning and training, evaluation of 20 new suppliers was performed.

Neural network and genetic algorithms are applied in the paper [13] for managing the supply chain and supplier selection. Fuzzy neural networks (hybrids of fuzzy logic and neural network) are applied for prediction of demand, and these results then used as an input to genetic algorithms to optimise the inventory control models. The authors in the paper [14] suggest application of genetic algorithms to search for the optimal combination of supplier and order quantity, constrained by the supplier capacity.

A fuzzy multi-objective model with three objective functions (cost, quality and service) is developed in the paper [15], with the possibility of setting the different weights for different objectives. The authors in [16, 17] suggest using case based reasoning and expert systems for collection, saving, sharing and processing of data about suppliers. There is a need for effective and intelligent management of large amount of data about suppliers. It is the so-called management of supplier intelligence. The new system for the selection and evaluation of suppliers in the phase of new product development which uses case based reasoning is presented in the paper [16].

Some new criteria, payment delay and quotation of alternative material are proposed in the paper [17].

From the literature review it can be seen that supplier selection is the multicriteria problem dealing with cost, delivery and quality as the most important traditional criteria. But the new criteria as cooperation with supplier should be taken into consideration, because the supplier can be a very important business partner even in the process of new product design. Apart from the supplier selection, many papers deal with the calculation of economic order quantity from the supplier.

The authors of the present paper propose criteria and the AHP model for supplier selection. The model is demonstrated by supplier selection to purchase the parts for assembly of the agricultural machine. Some specific criteria for the region (deferred payment) and for the assembly line (packing) are proposed.

The structure of the paper is organised as follows. Section 2 contains description of used AHP (analytical hierarchy process) methodology. Proposed criteria and AHP model for supplier selection are presented in Section 3. Section 4 includes illustration and discussion of proposed AHP model on supplier selection to purchase parts for assembly of the agricultural machine. Finally, the conclusion and the recommendations for further research are presented.

2. AHP methodology

The AHP methodology was developed by Thomas Saaty [18, 19]. It is a commonly used multicriteria decision making method. The AHP methodology has three basic steps [18-20]:

- Decomposition of the defined decision problem to the hierarchic structure - building an AHP model with the overall goal at the top of the hierarchy (the first level), the evaluation criteria and finally the alternatives at the bottom of the hierarchy (the last level).
- Pair wise comparisons of the criteria and alternatives based on Saaty's scale of numbers from 1 to 9, Table 1. The value 1 means equal importance of two criteria (alternatives), while the value 9 stands for extreme importance of one criterion (alternative) to another. Pair wise comparisons of the criteria are performed with respect to the goal or criteria at higher level. The weights of the criteria present the ratio of how much more important one criterion is than another, with respect to the goal or criterion at higher level. Pair wise comparisons of the alternatives are performed against each criterion and present the ratio of how much more important one alternative is than another, taking into account each criterion. The local priorities of alternatives are derived. Testing the consistency of subjective judgements is also performed (further explained).
- Synthesising the results is carried out by calculation of the total priorities of alternatives. The total priority of each alternative is calculated by the multiplication of the local priority of alternative by the weight of corresponding criterion and then summing all the products for each criterion. Example of calculation of total priority of alternative is shown by the following expression:

$$p = a \cdot x + b \cdot y + c \cdot z. \tag{1}$$

Sensitivity analysis can also be performed and it gives a response of the alternative priorities to the change of input data.

Table 1. Saaty's scale for pair wise comparisons [18-20]

Tablica 1. Saaty-eva skala za usporedbu u parovima [18-20]

Scale / Skala	Description of the importance / Opis intenziteta važnosti
1	equal / jednako važno
3	moderate / umjereno važnije
5	strong / važnije
7	very strong / puno važnije
9	extreme / ekstremno važnije
2, 4, 6, 8	intermediate values / međuvrijednosti

The AHP methodology facilitates monitoring of consistency at every moment of making pair wise comparisons [18-21]. Through the consistency index *CI*, expression (2):

$$CI = (\lambda_{max} - n)/(n\text{-}1), \quad (2)$$

it is possible to calculate the consistency ratio, *CR*, expression (3).

$$CR = CI/RI. \quad (3)$$

Values of RI (it stands for random index) which represent consistency index for the *n* order matrices of randomly generated pair wise comparisons, are presented in Table 2.

Table 2. Values of RI random indexes [18-21]

Tablica 2. Vrijednosti RI slučajnih indeksa [18-21]

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

If for the matrix of relative importance (pair wise comparisons matrix) the relation $CR \leq 0{,}10$ is true, estimation of relative importance of criteria (or alternatives), is acceptable. Contrary, the reasons for the high inconsistency of estimation should be found (revision of pair wise comparisons).

The AHP methodology is widely used in almost every field of human activity, for example economy [22], traffic [23], inventory classification [24-26], raw materials selection [27], agriculture [28], information technologies [29], environmental evaluation [30] and many others.

3. Criteria suggestion and AHP model

Supplier selection is the multicriteria decision making problem. Different criteria must be involved, not only cost. Many of the criteria are strongly influenced by the specific field of the company.

In this paper, for the company dealing with the assembly of agricultural machines, five criteria for the final phase supplier selection are proposed: cost, delivery time, deferred payment (further the term payment will be used), parity and packing. It should be mentioned that selection will be done for alternative suppliers that are already on the list of capable suppliers (according to past performance including capability, general characteristics, quality assurance system, quality of products and quality of previous deliveries).

Delivery time is one of the important criteria. There is a need for very short and safe delivery time to avoid the large warehouses and to enable production time to be as short as possible.

Payment to suppliers is one of the requirements that is difficult to negotiate. The customer wants late payment, or long delays with no interests, while for the supplier it is the opposite situation - convenient for them is to pay in advance to make investments as small as possible.

Packing is an important criterion for safe delivery, without rejection. The customer needs no spoilage, otherwise a delay in the production or assembly line can happen. Therefore quality packing is needed. Packing costs are very often a matter of negotiation. For the cheaper products there is usually no packing charge (euro pallets interchangeable with the suppliers), but for expensive products there are usually some additional costs (fixed or disposable).

Parity is a very important criterion, too. There are many combinations; the supplier transports the products to the customer and this is the best situation for the customer. There is also the situation when the customer transports the products; the supplier is only preparing the items and output documentation. There is a possibility of so-called aggregate storage too. The suppliers are delivering material to the aggregate storage and according to the production plan and needs or the quantity on aggregate storage the customer organizes transport once or twice per week and buys the necessary goods.

Taking into account these five proposed and discussed criteria, the authors of this paper define the AHP model with the goal (the supplier selection), criteria and alternatives (three suppliers), shown in Figure 1.

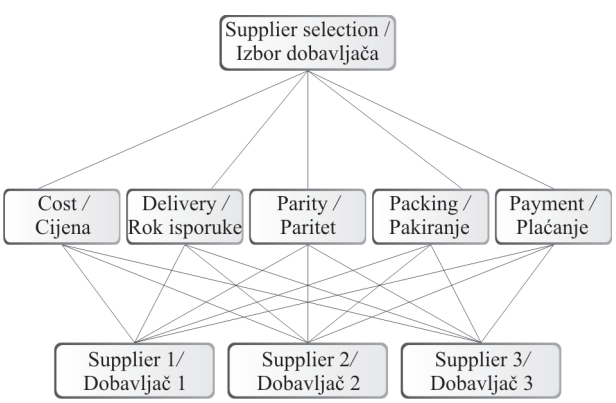

Figure 1. AHP model for the supplier selection

Slika 1. AHP model za izbor najpovoljnijeg dobavljača

After the AHP model is defined, it is necessary to determine the weights of each proposed criterion by the pair wise comparison using Saaty's scale (Table 1) as well as local and total priorities of alternatives (suppliers). Local priorities of suppliers are calculated by pair wise comparisons with respect to each criterion, using Saaty's scale. Total priority for every alternative is calculated by the extended expression (1) with five criteria, not only three.

The next section of this paper deals with demonstration of the proposed AHP model on supplier final phase selection to purchase the part for assembly of the agricultural machine.

4. Application and discussion of the results of AHP model

Suggested model is demonstrated and discussed by the example of purchasing a hub on the rear axle. That is the item which is classified to the class A according to the multicriteria ABC classification performed in the paper [24]. The data for the three suppliers are shown in Table 3. The objective is to determine the alternative (supplier) with the highest total priority, using the suggested model.

Making pair wise comparisons of criteria (Table 4), criteria weights are determined by using Saaty's scale (Table 1). Criteria weights, calculated according to the step 2 described in section 2, are shown in normalised matrix (Table 5). Criterion payment has the highest weight, cost and packing follows, while the criteria delivery and parity have the smallest weights.

Pair wise comparisons of alternatives with respect to each criterion and local priorities are presented in tables 6, 7, 8, 9 and 10.

Table 3. Values and rates of criteria for the alternatives (suppliers)

Tablica 3. Kriteriji i vrijednosti kriterija za alternative (dobavljače)

	Delivery, working days/ Isporuka, radni dani	Payment, days/ Odgoda plaćanja, dani	Parity*/ Paritet	Packing**/ Pakiranje	Cost, €/piece/ Cijena, €/kom
Supplier 1/ Dobavljač 1	15	120	3	3	56
Supplier 2/ Dobavljač 2	5	90	1	3	45
Supplier 3/ Dobavljač 3	15	90	5	3	49.1

* 1 - supplier pays and performs transport to the customer, 2 - supplier pays for transport, and the customer pays customs clearance, 3 - supplier transports to the location 1, then the customer transports, 4 - supplier transports to the location 2, then the customer transports, 5 - the customer is responsible for the transport

** 3 - packing is included in the cost, 6 - packing is not included in the cost, 7 – pallets.

Table 4. Pair wise comparisons of criteria

Tablica 4. Uspoređivanje kriterija u parovima

	Delivery/ Isporuka	Payment/ Odgoda plaćanja	Packing/ Pakiranje	Parity/ Paritet	Cost/ Cijena
Delivery/ Isporuka	1	1/3	1/2	2	1/3
Payment/ Odgoda plaćanja	3	1	1	2	2
Packing/ Pakiranje	2	1	1	3	1/2
Parity/ Paritet	1/2	1/2	1/3	1	1
Cost/ Cijena	3	1/2	2	1	1

Table 5. Normalised matrix and criteria weights

Tablica 5. Normalizirana matrica i težine kriterija

	Delivery/ Isporuka	Payment/ Odgoda plaćanja	Packing/ Pakiranje	Parity/ Paritet	Cost/ Cijena	Weights/ Težine
Delivery/ Isporuka	0,11	0,10	0,10	0,22	0,07	0,12
Payment/ Odgoda plaćanja	0,32	0,30	0,21	0,22	0,41	0,29
Packing/ Pakiranje	0,21	0,30	0,21	0,33	0,10	0,23
Parity/ Paritet	0,05	0,15	0,07	0,11	0,21	0,12
Cost/ Cijena	0,32	0,15	0,41	0,11	0,21	0,24

Table 6. Pair wise comparison of alternatives with respect to the criterion delivery time

Tablica 6. Uspoređivanje alternativa u parovima po kriteriju vrijeme isporuke

	Supplier 1/ Dobavljač 1	Supplier 2/ Dobavljač 2	Supplier 3/ Dobavljač 3	Local priorities/ Lokalni prioriteti
Supplier 1/ Dobavljač 1	1	1/3	1	0,2
Supplier 2/ Dobavljač 2	3	1	3	0,6
Supplier 3/ Dobavljač 3	1	1/3	1	0,2

Table 7. Pair wise comparison of alternatives with respect to the criterion payment

Tablica 7. Uspoređivanje alternativa u parovima po kriteriju odgoda plaćanja

	Supplier 1/ Dobavljač 1	Supplier 2/ Dobavljač 2	Supplier 3/ Dobavljač 3	Local priorities/ Lokalni prioriteti
Supplier 1/ Dobavljač 1	1	3	3	0,6
Supplier 2/ Dobavljač 2	1/3	1	1	0,2
Supplier 3/ Dobavljač 3	1/3	1	1	0,2

Table 8. Pair wise comparison of alternatives with respect to the criterion packing

Tablica 8. Uspoređivanje alternativa u parovima po kriteriju pakiranje

	Supplier 1/ Dobavljač 1	Supplier 2/ Dobavljač 2	Supplier 3/ Dobavljač 3	Local priorities/ Lokalni prioriteti
Supplier 1/ Dobavljač 1	1	1	1	0,333
Supplier 2/ Dobavljač 2	1	1	1	0,333
Supplier 3/ Dobavljač 3	1	1	1	0,333

Table 9. Pair wise comparison of alternatives with respect to the criterion parity

Tablica 9. Uspoređivanje alternativa u parovima po kriteriju pariteta

	Supplier 1/ Dobavljač 1	Supplier 2/ Dobavljač 2	Supplier 3/ Dobavljač 3	Local priorities/ Lokalni prioriteti
Supplier 1/ Dobavljač 1	1	1/2	2	0,297
Supplier 2/ Dobavljač 2	2	1	3	0,539
Supplier 3/ Dobavljač 3	1/2	1/3	1	0,164

Table 10. Pair wise comparison of alternatives with respect to the criterion cost

Tablica 10. Uspoređivanje alternativa u parovima po kriteriju cijena

	Supplier 1/ Dobavljač 1	Supplier 2/ Dobavljač 2	Supplier 3/ Dobavljač 3	Local priorities/ Lokalni prioriteti
Supplier 1/ Dobavljač 1	1	1/3	1/2	0,159
Supplier 2/ Dobavljač 2	3	1	3	0,589
Supplier 3/ Dobavljač 3	2	1/3	1	0,252

Total priorities of alternatives, calculated by use of expression (1), are presented in Table 11.

Table 11. Criteria weights (in parentheses), local and total priorities of alternatives

Tablica 11. Težine kriterija (u zagradi), lokalni i ukupni prioriteti alternativa

	Delivery/ Isporuka (0,12)	Payment/ Odgoda plaćanja (0,29)	Packing/ Pakiranje (0,23)	Parity/ Paritet (0,12)	Cost/ Cijena (0,24)	Total priorities/ Ukupni prioriteti
Supplier 1/ Dobavljač 1	0,2	0,6	0,33	0,297	0,159	0,347
Supplier 2/ Dobavljač 2	0,6	0,2	0,33	0,539	0,589	0,411
Supplier 3/ Dobavljač 3	0,2	0,2	0,33	0,164	0,252	0,238

It can be seen from Table 11 that supplier 2 is the most appropriate. It has the highest total priority (for the three criteria - delivery time, parity and cost, it has the highest local priorities). Supplier 1 has the highest local priority for the criterion payment so the total priority is high. Supplier 3 is the last in ranking scale (there is no highest local priority).

5. Conclusion

Based on the results of investigation, it can be concluded that the multicriteria approach to the problem of supplier selection helps to make a more objective decision. The criteria are highly specific situations. For example, criterion packing should not even be taken into account in some cases, but here in assembly problem it is very important. Criterion payment is maybe specific for Croatia or other developing countries. The proposed AHP model and criteria have significant importance and applicability in industry. Purchase departments are the likely users.

Regarding the used AHP methodology and its application, it is clear that the approach of T. Saaty is widely applicable. However, in every field, it is important to define appropriate criteria and objectively determine the criteria weights and perform the ranking. Determination of criteria weights and alternative priorities, using Saaty's scale, may be carred act subjectively. However, comparisons in pairs can be done by a person with extensive experience in a given area, so the final weight or local priorities, in fact represent a numeric, objective expression of enormous experience. Also, Saaty's scale has nine ratings for comparison in pairs, which, if compared with, for example, digital logical method that has a grade 1 and 0, gives the possibility of more accurate comparisons.

Further investigation will include possibility of supplier evaluation by the application of an expert system. In the expert system model, when comparing with AHP model, the alternatives (suppliers) will not be able to compare, but for each supplier the total rating can be calculated. Comparison of AHP and expert system models and investigation of the efficient implementation of both of models to the ERP system of the company can be one of the possibilities for further research. The possibility of integration of the above-mentioned models with the multicriteria inventory classification model defined in the paper [24], to select the supplier for A class of inventories only, will also be revealed. Introduction of the sub criteria can also be considered.

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