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A fuzzy model for the evaluation of suppliers of material resources to machine-building enterprises

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Introduction

In the global economy, industrial companies are continuously forced to improve their quality and reduce costs to improve the competitiveness of their products. The effective selection process of supplier of material resources has an important influence on the competitiveness of the organization, as this is the first process in the supply chain. Expenses on the acquisition of material resources are, on average, 30–60% of the cost of finished products of the enterprise. The quality and reliability of the supply of material resources depends on the efficiency of the organization of production processes and production cycles. Thus, improving the procurement process can help the manufacturer increase their profits. It is an important factor affecting the economic efficiency of enterprises. The aim of this work is to identify factors that improve the process of supplier selection for material resources of large enterprises.

The problem of supplier selection of machine-building enterprises in the international market

Many companies operating in the engineering sector want to expand the boundaries of their markets and enter international markets. In this situation, they are faced with the challenge of finding international suppliers. In addition, large

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machine-building enterprises operating on the domestic market often purchase material resources abroad. For example, Russian machine-building enterprises buy Swedish steel. Most often this necessity is caused by the need to deliver to the international market goods of high quality and low price, or there is a lack of necessary material resources in the domestic market. Low price and high quality international procurement is possible due to the international division of labor.

When determining the country with which it will be the most profitable and convenient to engage in the import and export of goods or services, it is necessary to take into account the following factors: political and economic stability, costs of production, transport infrastructure, state benefits and incentives, the availability of both a skilled and relatively cheap labor force, the market capacity of the country, the presence of trade barriers, and the availability of necessary suppliers of raw materials.

In addition to these factors, it is necessary to consider trade and political ties with select countries. Preference is given to a country which has normal business relations. After identifying the relevant country, the next step is to evaluate the potential partners-suppliers, taking into account the following criteria: the scale of operations, solvency, share of production, the number of enterprises with which the provider is working, business reputation, position of the supplier on the international market, financial situation, price, quality, and regularity of deliveries, etc.

The initial choice of supplier in the international market will allow an enterprise to carrying out the analysis and choose applicants. Then, the methods described in this article should be used.

The search for and ranking of suppliers in both the international and domestic markets is quite similar, the only difference being a change in the scale of the necessary information. With such providers, there is a need to find mutual benefits which will establish a good relationship between the parties and will lead to greater confidence in the integrity of their duties.

The problem of organizing the procurement process in modern machine-building enterprises attracted the attention of many scientists. In their works, several authors (Ageev 2007, Bulanov 2009, Vostrikov 2009, Kostyuk 2010, Pleschenko 2011 etc.) note the existence of business relations with a wide variety of suppliers to large industrial enterprises.

The importance of the supplier selection process at machine-building enterprises is confirmed by the data on the number of their real suppliers. For the American automotive company Ford, in 2013 there were 750 suppliers, Toyota Manufacturing UK had 800 suppliers, while General Motors had a very large number of suppliers – in 1986 there were 35,000. At that time, the number of suppliers for Toyota was 224. In Belarus, there is a large enterprise which interacts with hundreds of suppliers. 97% of the components for this Belarusian automobile plant, which produces dump trucks, are produced outside the country.

The actual number of suppliers of JSC "AvtoVAZ" in recent years reached 990, while the list of purchased products reached about 29,000 (Vostrikov 2009, Pleschenko 2011). In 2012, Ivanovo-based machine-building enterprises JSC "AVTOKRAN" and JSC "KRANEKS" acquired 2,500 and 3,000 listed items, respectively, with the number of their real suppliers varying from 400 to 450. In 2011, JSC "KAMAZ" had about 600 suppliers, and JSC "NPO Saturn" had 880 suppliers (Pleschenko 2011).

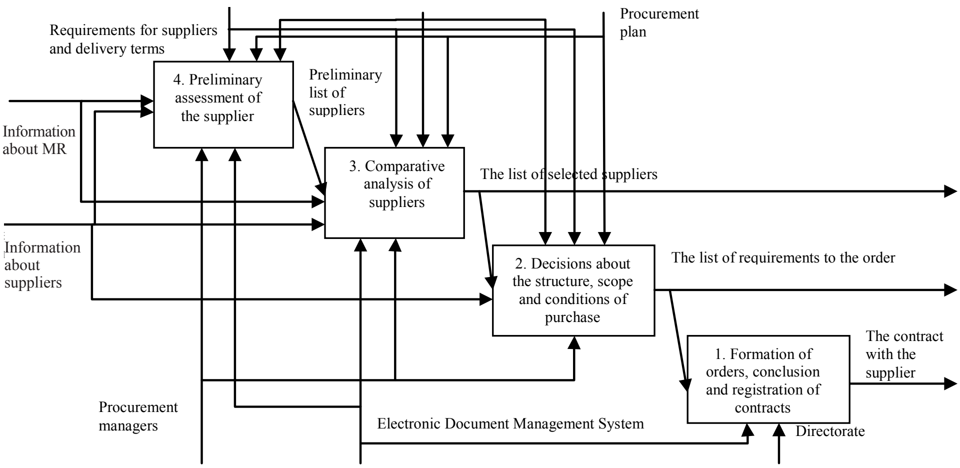
In the scientific and educational literature, one can identify a number of papers (Bulanov 2009, Grishchenko 2012, Kozin 2006, Kravets 2013, Lukinskiy 2007, Olgin 2013, Rybalko,2011 etc.) which provide different algorithms for supplier selection. Broadly speaking, the process of selecting a supplier includes the following steps: search for potential suppliers, analysis and selection of suppliers, and evaluation of the results of working with a supplier (Eremina 2013).

Modeling the business process of supplier selection

After examining the approaches, algorithms, and models for supplier selection (Bulanov 2009, Grishchenko 2012, Kozin 2006, Kravets 2013, Lukinskiy 2007, Olgin 2013, Rybalko 2011 etc.) a functional model of the business process of supplier selection of material resources in IDEF0 notation was developed, shown in Figure 1.

It is recommended that the stage of analysis and supplier selection be divided into four consecutive stages: preliminary assessment of the provider, comparative analysis of suppliers, decisions about the conditions of purchase, and formation of orders, conclusion and execution of contracts.

Figure 1. The business process of supplier selection



Source: authors' own elaboration.

Preliminary assessment of the supplier

The majority of scientific papers in our field of research are devoted to the description of the process of the comparative analysis of vendors by different methods. However, in a number of publications (Bulanov 2009, Grishchenko 2012, Kozin 2006, Olgin 2013, Valeyeva 2012) one can find individual elements of a preliminary assessment phase. For example, Grishchenko (2012) describes the process of supplier selection under a leasing transaction, where, first of all, offers to start cooperation with potential suppliers are invited, then there is an analysis of limitation factors, and only after this can there be a comparative analysis of suppliers. Salikov and Gorbaneva (2011) talk about the mechanism for the development of procurement strategies, which sequentially includes four key phases: opportunity analysis, analysis of the procurement category, strategy development and its implementation. Bulanov (2009) proposed an algorithm of supplier selection which allocated the stage "definition of the structure and characteristics of the resource". Olgin (2013) drew special attention to the need to analyze the list of purchased products in the sphere of public catering. Analysis of the scientific literature showed that, to date, the preliminary assessment phase in the process of supplier selection remains little developed and not sufficiently formalized, which leads to inadequate final supplier evaluation.

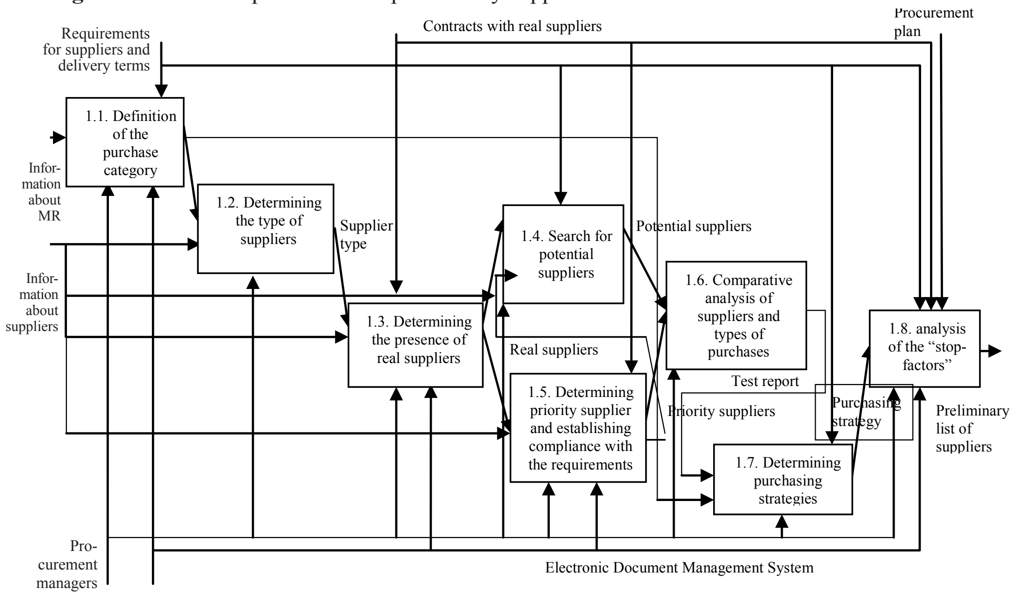
The algorithm of preliminary supplier assessment

The supplier selection process begins with the identification of needs for material resources, operational planning of production, the formation of an operational plan of purchases, orders for suppliers, requirements to the supplier, and delivery terms. This information is the basis of the selection procedure. Figure 2 describes the key stages of preliminary supplier assessment (processes 1.1–1.8).

At the of the preliminary assessment stage, the purchase category (see Figure 2, p. 1.1) and the provider type (see Figure 2, p. 1.2.) are determined. Procurement strategy (see Figure 2, p. 1.7) is formed based on the type of purchased material resource, the results of the analysis of the real suppliers and requirements for them. However, the procurement strategy should be aimed at ensuring lower costs for the purchase of material resources, as well as improving the quality of the final product and being able to secure the supply.

At the final stage (see Figure 2, p. 1.8) of the preliminary assessment of suppliers, an initial evaluation of suppliers is carried out in accordance with the selected procurement strategy. The initial assessment involves gathering information about the suppliers and their conduct on the basis of its analysis of "stop factors" (see Figure 2, p. 1.8). Depending on the specifics of the purchase, it can have "stop factors" relating to economic and financial standing, ability and technical capacity of suppliers (Grishchenko 2012). The analysis of the “stop factors” formed the provisional list of suppliers of material resources.

Figure 2. Model the process of the preliminary supplier assessment



Source: authors’ own elaboration.

Categories of purchases

The range of purchased material resources of large enterprises reaches several thousand units. For convenience of the process of supplier selection, all purchases should be divided into categories of purchases. Certainty in this matter greatly affects the planning and organization of the procurement process. However, scientists who study the problem of supplier selection rarely address the question of the classification of procurement. Usually they do not associate the type of procurement with the supplier selection process.

The category of purchases includes the aggregate of purchased materials, equipment or services that are similar in characteristics and purpose (Salikov 2011). Scientists have not reached a consensus on the issue of the classification of procurement groups (Christopher 2004, Malochko 2003, Olgin 2013, Pleschenko 2012, Rudzki 2008, Salikov 2011, Urazova 2009). Rudzki (2008) divides all purchases into four groups: reinforcing, non-critical, strategic and critical. Molochko (2003) groups them: problematic, routine, critical and “generating” profit procurements. Urazova (2009) talks about ordinary, qualified, reliable, and strategic procurement. Such a wide range of names of procurement categories causes confusion. In some works (Malochko 2003, Olgin 2013, Rudzki 2008, Urazova 2009) very different concepts of the semantic contentmay hide under the same name. According to the criterion of duration, Pleschenko (2012) classifies: established, modified and new procurements.

For ease of comparative analysis of suppliers, it is recommended that all purchases of machine-building enterprises be split into the following categories: low value, key, problematic and critical. The proposed classification allows us to separate purchases of special complexity, as well as purchases of the highest and lowest significance.

Particular difficulties arise when making critical and problematic procurements. Critical purchases are characterized by the scarcity of procurement opportunities, a small number or complete absence of goods suppliers, and the average cost of purchases. Violation of delivery time and technical requirements can have a negative impact on the production process. Due to the fact that it is very difficult for the supplier to find a replacement, the emphasis is on the development of mutually beneficial relationships.

Material resources belonging to the category of problem purchases are highly specialized, so the list of potential suppliers is not great. Most often there are various difficulties in the delivery of the material resource in the procurement, storage, handling and transportation stages.

Highly complex supplies are key purchases. Key purchases are characterized by high annual expenditure to purchase them. Usually, there is a great variety of proposals on the market of these resources which are able to satisfy the requirements of the customer. In this situation, the manager tries to negotiate more favorable terms of delivery. The delivery of defective goods or a delay in delivery time can lead to a process shutdown.

The group of low-value procurements include purchases which are characterized by a variety of suppliers and relatively low costs. They are resources that can be easily replaced with counterparts. Their absence will not lead to production losses or to the loss of the enterprise's competitiveness. A comparative analysis of procurement categories is presented in Table 1.

Table 1. Characteristics of categories of purchased material resources

	Categories procurement			
Indicators	Low value purchases	Key purchases	Problematic purchases	Critical purchases
Number of suppliers	A lot	A lot	Little	Little
Relationships with suppliers	Single	Regular	Regular	Regular
The value of the relationship	Minimum	High	Very high	Critically high
The effect on the production process	Minimum	High	High	High
Risks	Minimum	High	High	Very high
Acquisition costs	Low	High	Moderate	High
Information exchange	Don't assume	Minimum	Active	Active

	Categories procurement			
Indicators	Low value purchases	Key purchases	Problematic purchases	Critical purchases
Transaction costs	Low	High	High	Very high
The complexity of the procurement	Reasonable	High	Special	Special
Type of supplier	Normal	Qualified	Reliable	Strategic
Purchasing strategy	A simple selection on the basis of a small set of key criteria	Careful selection of the best candidate from a set of alternatives. Negotiating the most favorable terms of delivery	A thorough analysis of the capabilities of existing suppliers on the basis of a special set of criteria	A thorough analysis of the capabilities of existing suppliers on the basis of a special set of criteria
Type of relationship with suppliers	A simple transaction	Basic and strategic partnership	Purchase of shares the supplier. Strategic Partnership	Purchase of shares the supplier

Source: authors' own elaboration.

Methods of determining categories of purchases

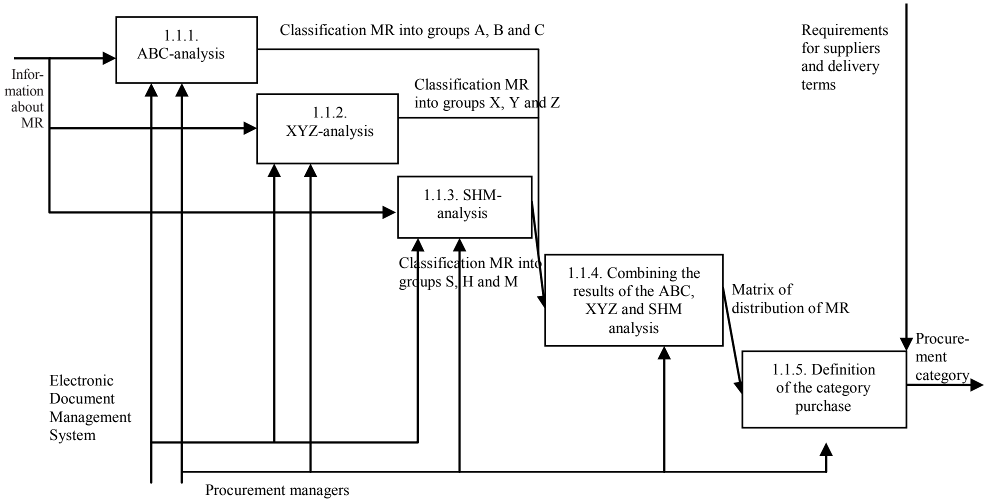
The process of determining categories of procurement for previously acquired material resources is different from that when dealing with materials acquired the first time. Analysis of previously acquired material resources is easier, as the purchasing managers have comprehensive information about them. Analysis of new material resources requires a large investment of time and resources.

The process of determining the category of procurement includes five stages (Figure 3) and involves consistent implementation of ABC, XYZ and SHM analysis. The category of purchase is determined by the subsequent combining of the results obtained and the formation of a three-dimensional matrix.

An important element in the analysis of repeat and new purchases is ABC analysis (p. 1.1.1) (Kulakov 2014, Lukinskiy 2007, Maizlish 2014). For new purchases, ABC analysis is conducted based on the planned volume of purchases and current prices, as well as old ones – based on data for the last period on the volume of purchases and prices.

XYZ-analysis (p. 1.1.2) involves the assessment of the significance of purchasing by the coefficient of variation (Kulakov 2014, Lukinskiy 2007, Maizlish 2014). Consideration of the dynamics of procurement over a long period of time allows you to set the number of purchases that have stable demand; procurement, demand for which is subject to fluctuations; procurement, the demand for which is random. For new purchases, classification by groups X, Y and Z is performed on the basis of the planned frequency of acquisition, and old purchases – based on the dynamics of their acquisition for the previous time period.

Figure 3. Model of the process of determining the category purchase



Source: authors' own elaboration.

SHM-analysis (1.1.3) complements ABC and XYZ analysis of the materials and resources procurement. It allows us to determine an indicator such as the complexity of the procurement, i.e. assess the level of difficulty of the preliminary negotiations and the process of selecting suppliers based on the past experience of the company. This type of analysis allows us to divide all the physical resources into three groups: special complexity (S – Special), high complexity (H – High) and moderate complexity (M – Moderate). The complexity of the procurement is determined using the rating estimation (Table 2).

Table 2. The main criteria for assessing the complexity of procurement

	Criteria	Significance	Point
1	Cost elements (C1)	direct material costs	1
		overhead costs	2
		general running costs	3
2	The number of real providers (C2)	5 and more	1
		from 2 to 4	2
		one	3
3	The frequency of purchases of material resources (C3)	regular purchases	1
		periodic purchase	2
		one-time purchase	3

	Criteria	Significance	Point
4	To consolidate the delivery of material resources (C4)	no	0
		yes	1
5	The presence of specific requirements for the purchase (C5) (scarcity, originality, novelty, delivery time, etc.)	yes	0
		no	1

Source: authors' own elaboration.

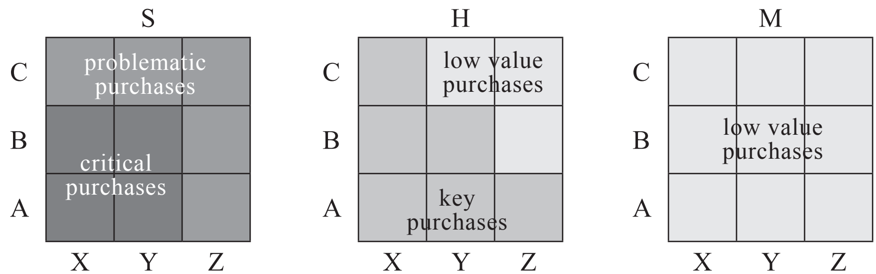
The complexity of procurement (C) is calculated by the formula (1):

$$C = (C1 + C2 + C3) \cdot C4 \cdot C5 \quad (1)$$

To interpret the results of the calculation, they are divided into 3 categories:
C = 0 points – the special complexity of the procurement;
C = 1–6 points – the high complexity of the procurement;
C = 7–9 points –the moderate complexity of the procurement.

The next stage (see Figure 3, p. 1.1.4) is to combine the results of the ABC, XYZ and SHM analyses and forma three-dimensional matrix (see Figure 3, p. 1.1.5) with the following axes: the nature of the purchase (XYZ), cost characteristics (ABC) and the complexity of the procurement (SHM). Based on the obtained results, matrices were determined for the different purchasing categories. In this paper, we propose a mechanism for determining the complexity of the procurement in Figure 4.

Figure 4. Cross-section of a three-dimensional matrix along the axis of the complexity of the purchase (SHM)



Source: authors' own elaboration.

Classification of suppliers

To solve the problem of suppler selection, the procuring entity shall take into account the characteristics specific to each of them. On the basis of the presence/ absence of ownership of the delivered object, the suppliers are divided into the following groups: regular wholesalers, industrial distributors, suppliers of individual parts, wholesalers such as “cash and carry”, travelling salesmen, stallholders, hardware wholesalers, trade (sales) agents, industrial agents, commission merchants, and auction companies. Sales policy providers are divided by type into: exclusive, selective, or intense (Volynsky 2011).

Traditionally, the selection of a supplier is carried out in two ways:

1) the selection of a supplier to a number of companies that have already established business relationships (real suppliers);
2) the selection of a new supplier (potential suppliers).

In the matter of classification of suppliers, scientists have not observed differences (Malochko 2003, Olgin 2013, Rybalko 2011, Eremin 2013). Suppliers of large enterprises can be divided into four groups according to their role: normal, qualified, reliable, or strategic.

Normal suppliers specialize in the supply of material resources belonging to the category of low-value purchases. The purchasing manager shall carry out periodic monitoring of the market and have several potential suppliers in the event of a disruption of supply from real suppliers.

Qualified suppliers deliver material resources belonging to the category of key purchases. In most cases, the frequency of such regular deliveries is regular. The purchasing manager must continually analyze new proposals for these supplies, but the focus is on the development of partnerships with selected suppliers.

A reliable supplier should supply material resources that are related to the category of problematic purchases. When choosing a reliable supplier, preference should be given to one who previously showed a willingness to become a partner, and who was ready to integrate. The purchasing manager must have at least one alternative supplier in the case of force majeure.

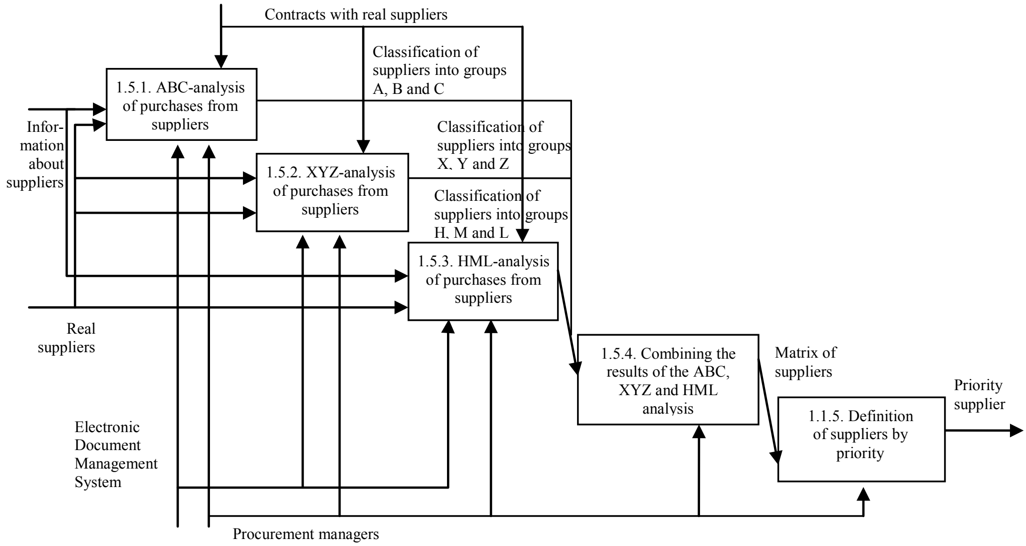
A strategic supplier supplies the material resources belonging to the category of critical procurement. Usually they are specially developed according to individual customer requirements. A strategic supplier is very difficult to find and replace, thus, there is a focus on developing mutually beneficial relations.

Methods of determining the type of suppliers

The process of determining the type of suppliers includes five stages (p. 1.5.1–1.5.5). First we conducted the ABC analysis (p. 1.5.1). Data from the most recent years on volumes of orders at each supplier are the basis of this analysis. The share of the material resources bought from suppliers in the total number of purchases and the accruing result of the share of objects of material resources are parameters of the analysis.

XYZ analysis (p. 1.5.2) of the volume of orders from suppliers involves the assessment of their significance for the coefficient of variation.

Figure 5. Model the process of determining the priority of the supplier



Source: authors' own elaboration.

The third parameter used for classifying suppliers is the priority of the supplier. The priority of the supplier is the indicator which allows us to define the quality of the relationship with suppliers based on previous experience with it. The priority of the supplier is determined in accordance with the proposed HML-analysis (p. 1.5.3). The criteria for assessing the priority of suppliers is presented in Table 3.Their values are defined by the method of rating estimates. The integrated indicator of priority of the supplier is defined by the method of additive convolution of criteria. The weight coefficient is defined by an expert method.

Table 3. Criteria of an assessment of priority of the supplier

	Criteria	Significance	Point(P_{ij})	Weighting coefficient (K_i)
1	The frequency of purchases from suppliers (D1)	regular purchases	1	0.47
		periodic purchase	2	
		one-time purchase	3	
2	Long-term relationships with suppliers (D2)	3 years and more	1	0.32
		1–2 years	2	
		less than 1 year	3	
3	The growth rate of purchases from suppliers (D3)	positive	1	0.21
		negative	2	

Source: authors' own elaboration.

The calculation of an integrated indicator of priority of the supplier (R_j) is made on the formula:

$$R_j = \sum_{i=1}^{m=3} P_{ij} K_i \tag{2}$$

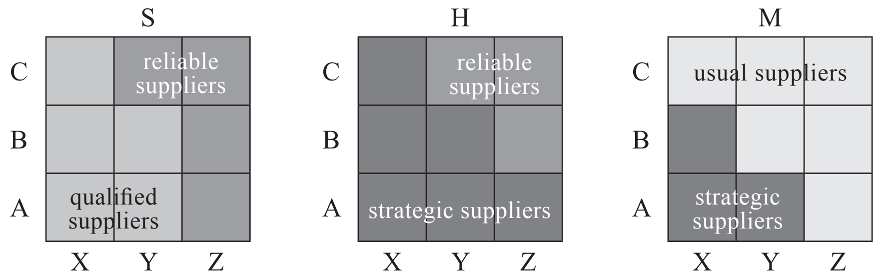
where:

P_{ij} – is the i-th rating index of the j-th supplier; K_i – weight coefficient; R_j – integrated indicator of j-th of the supplier.

To interpret the results of the calculation are divided into:
R_j = 0.00–1.00 points – high priority of the supplier (H – high);
R_j = 1.01–2.00 points – medium priority of the supplier (M – Medium);
R_j = 2.01–2.42 points – low priority of the supplier (L – low).

The next phase is to combine the results of the ABC, HML and XYZ-analyses (p. 1.5.4). For clarity, a three-dimensional matrix (p. 1.5.5) is formed from the following axes: the nature of purchases from suppliers (XYZ), the cost characteristics of the volume of orders with suppliers (ABC) and the priority of the supplier (HML). On the basis of the matrix, strategic, usual, qualified and reliable types of providers have been identified. Cross-sections of a three-dimensional matrix along the axis of a priority vendor with the distribution of provider types are presented in Figure 6.

Figure 6. Cross-section of a three-dimensional matrix along the axis of the priority of supplier (HML)



Source: authors' own elaboration.

Criteria for supplier selection

Conducting the comparative analysis of suppliers (Figure 1, p. 2) begins with the process of determining the selection criteria. Evaluating suppliers is a complex process that involves consideration of many criteria. Most scientists (Dixon, Lin, Gonzalez, Quesada, Teng etc.) believe that the definition of supplier evaluation criteria is one of the key steps in the selection process (Sagar & Singh 2012). One of the first to become interested in the problem of supplier selection was Dixon. In the 1960s, he identified 23 supplier selection criteria on the basis of a questionnaire survey of 273 commercial organizations (mostly manufacturing enterprises). Purchasing managers defined the criteria which are of the greatest importance for supplier selection. The quality of the object of delivery, terms of delivery and performance were seen as the most important selection criteria (see Table 4).

Weber, Current and Benton in 1991 investigated 74 articles published during the period from 1966 to 1990 devoted to the problem of choosing a supplier (Sagar & Singh 2012).They note that a large number of criteria significantly complicates the process of assessing suppliers. Similar research was conducted by Zhang, who studied 49 articles from 1992 to 2003. The survey results confirm that in the early 1980s there was great importance put on the price criterion. In the early 1990s, the speed of reaction to inquiries of clients and control of time was added to the price. In the late 1990s and early 2000s, researchers and practitioners realized the importance of the criterion of flexibility, and attribute it to a number of key criteria. Thus, all scientists noted the importance of the assessment of the supplier on several aspects, for example, the quality of the object of delivery, the productivity of the supplier, the reliability of delivery, etc. Chan declares that, besides general criteria such as cost and price, it is necessary to pay attention to such indicators as flexibility and innovations (Sagar & Singh, 2012).

The research carried out show that priorities in selection criteria of suppliers can change over time. This process is influenced by the political, economic, and social situation in the country and around the world, as well as the size of the company and characteristics of the industry.

The review of a large amount of scientific literature allows us to allocate more than one hundred selection criteria. In their work, the Indian scientists Sagar and Singh (2012) allocated 21 selection criteria for a supplier as applied to the Indian automotive industry. In Table 4 there is a list of these criteria (in descending order of importance) compared with the views of other researchers.

Table 4. Ranks of criteria for the evaluation of suppliers

Grade	Criteria	Dickson (1966)	Weber et al. (1991)	Zhang et al. (2004)	Leenders & Fearon (2006)	Tahriri et al. (2008)
1	Cost	6	1	1	3	2
2	Quality	1	3	2	1	2
3	The quality standards	–	–	–	–	–
4	The reputation and position in the industry	11	8	12	–	–
5	Delivery conditions	2	2	3	2	3

6	Financial situation	8	9	6	8	4
7	The quality system	–	–	–	–	–
8	Technical capabilities	7	6	5	6	6
9	Production capacity	5	4	4	6	6
10	Time cooperation	–	–	–	–	–
11	Credibility	–	–	–	–	1
12	Compliance with the rules	9	15	13	–	–
13	Responsiveness	–	–	–	4	–
14	Reviews	17	15	21	–	–
15	System communications	10	15	7	–	–
16	Guarantees	4	23	13	–	–
17	Quality Management System	–	–	–	–	–
18	Relationships	16	12	19	–	–
19	Management and organization	13	7	7	8	4
20	Performance History	3	9	7	–	8
21	Packaging ability	18	13	13	–	–

Source: authors' own elaboration.

Tahriri et al. in their work (2008) presented the importance of estimated criteria for the company on the production of steel. Leenders and Fearon (2002) proposed a scale of criteria for the selection of potential supplier: product quality, timely delivery, price, services, repeated proposals for the development of products or services, technical, engineering, and production capacity, score distribution capabilities, detailed assessment of finances, and management. This scale of criteria is used by most foreign manufacturers of products for the selection of suppliers of material resources. When selecting new suppliers, foreign companies have focused on the assessment of their financial situation and the organization of management, as well as the technical, engineering and production capacity of suppliers (Volynsky 2011).

After reviewing about 50 articles on the topic of this research, we systematized the criteria for supplier assessment in eight key groups. They reflect the activities of suppliers from different sides: quality of the object of delivery, the price of the delivery items, terms of delivery and payment, properties of the object of delivery, the level of communication and culture, competence of the supplier, obligations of the supplier, and financial condition.

Figure 7. Classification of the key criteria for supplier selection

C1 The price of the delivery item	C2 Terms of delivery and payment	C3 Quality of the object of delivery	C4 Properties of the object of delivery
A1 price; A2 amount of discount; A3 customs duties; A4 currency risks.	A5 delivery times; A7 cost of delivery; A6 payment term; A8 norm of shipments.	A9 the percentage of returns for the first year of warranty; A10 quality A11 warranty period; A12 Quality Management System.	A13 the presence of specific properties of the object of delivery; A14 assortment; A15 quality of raw materials used to make the object of delivery; A16 outward appearance.

C5 The level of communication and culture	C6 Competence of the supplier	C7 Obligations of the supplier	C8 Financial condition
A17 the duration of cooperation; A18 the response time to customer requests; A19 the availability of the supplier's interest; A20 transaction costs.	A21 the location of the supplier; A22 period on the market; A23the presence of positive reviews; A24 production technology.	A25 service during the warranty period; A26 responsiveness to requests; A27 quality technical assistance; A28 service after the warranty period.	A29 the stability of their financial situation; A30 debt to the Internal Revenue Service; A31 annual cash flow; A32 the ratio of the value of the supplies and assets.

Source: authors' own elaboration.

For different categories of procurement a different set of evaluation criteria must be used (Table 5).

Table 5. Basic requirements for the procurement categories

Key purchases	Low-value purchases
• guaranteed high quality of the delivered product • regular supply to the necessary extent • the possibility of deferral of payment	• low price • the standard quality • convenient location • short delivery times

Critical purchases	Problematic purchases
• high financial stability • optimal organization of its own production • focus on innovation • capacity and capability to carry out research activities • the ability to take responsibility and take risks • reliable subcontractors • readiness for active mutually beneficial cooperation	• the ability to provide safe transportation and safety of the product • the ability to change the volume of deliveries and their frequency • the ability to take on the manufacture of the processing • technological consulting • proximity of the supplier • availability of warehouses in close proximity to the consumer • long-term prospect of collaboration

Source: authors' own elaboration.

At the stage of the comparative analysis of suppliers (Figure 1, p. 2) is the formation of a list of evaluation criteria in accordance with the purchase strategy. The process of choosing the best supplier from those available can be made by one or several methods. The results of the study will allow us to judge the seriousness and integrity of the analyzed suppliers (Grishchenko 2012).

Decisions on the structure, volumes, and terms of purchase, as well as the formation of orders, conclusion, and execution of contracts (Figure 1, p. 3, 4), is made on the basis of the results that will be obtained at the stage of the comparative analysis of suppliers.

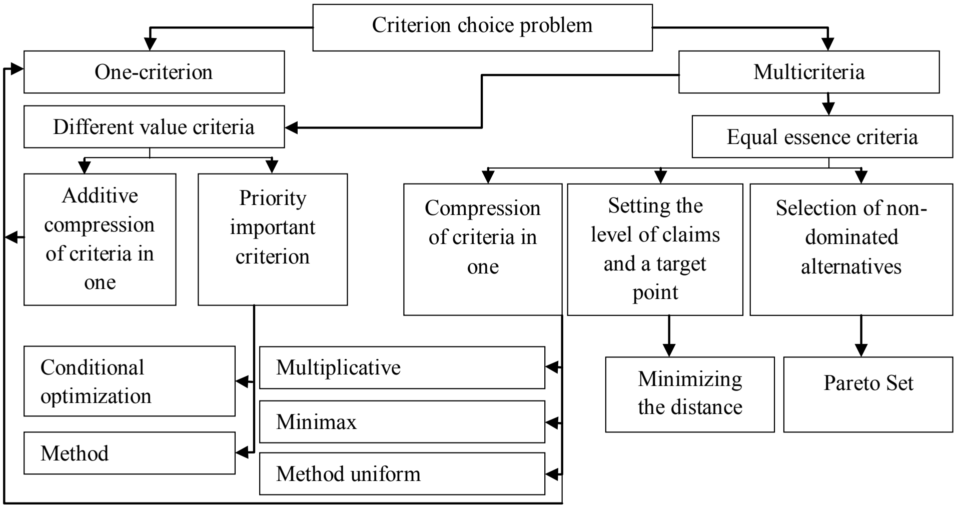
The review of modern models and methods of supplier selection

In the field of developing methodical recommendations on the selection of supplier, we must note the work of domestic and foreign scientists, like Lukinsky, Grischenko, Vostrikov, Leszczynski, Kozin, Saati, Dixon, Leenders and others.

In supply chain management, one can identify a number of methods to make a decision in choosing the best from several alternatives available. Under conditions of certainty, optimization methods, random selection and ordering apply, while in the face of uncertainty one should consider game theory, fuzzy set theory, utility theory and the model, taking into account the stochastic solutions, among others.

To describe the choice of supplier (Kozlova 2015) there are three approaches: criteria based, binary relations and functional choice. The easiest and most popular is the criterial approach (see Figure 8). Depending on the number of criteria, the selection can be one-criterion or multi-criteria. One-criterion tasks are solved by the analytical method. First one should form an objective function, then set the constraints and find solutions that will fit the best value of the objective function. Multicriteria problems are solved in different ways.

Figure 8. Taxonomy for solving the problem of supplier selection



Source: authors' own elaboration.

The approach based on the language of binary relations doesn't assume research of separate alternatives. For each pair of alternatives, they can establish their equivalence or superiority of one over the other. The ratio of preferences of several alternatives doesn't depend on other alternatives. The approach based on the language of choice features, takes into account the relationship of preference of one alternative over another with other alternatives.

Based on the data (Lukinskiy 2007), analytical and expert approaches to the choice of supplier can be distinguished. The analytical approach uses a formula that includes the parameters characterizing the supplier. This approach is universal, but the selection of the parameters may require expert estimates. The complexity of the approach is associated with obtaining analytical dependences.

The expert approach is based on ratings from experts of the parameters that characterize the supplier. It describes the procedure for obtaining integrated expert assessments. There are many algorithms and examples of calculation of supplier ratings (Lukinskiy 2007).

The supplier selection can be made on the basis of a multicriteria problem solution. One way of solving the problem is reducing it to a single-criterion type. Additive compression is applied at different importance of criteria. The method of a uniform optimality in combination with multiplicative or minimax compression is used at equal importance of criteria. In practice, there is often a situation when one solution is better for one criterion but worse in another way (Lukinskiy 2007).

The method of rating estimates is the most widespread for choosing a supplier. The main criteria for selecting a supplier are first determined, then the experts determine their significance. The final choice of supplier is based on their rating.

The method of estimating costs is made in several stages: the business process is divided into several business functions; for each function all income and expenses are calculated, taking into account possible risks, then the data obtained are compared and a decision is made about the preferred supplier. The disadvantages of this method is the large amount of input data and the complexity of the analysis.

The method of the dominating characteristics assumes the emphasis of attention is on one chosen criterion (for example, price, quality, etc.).The advantage of this method is its simplicity. The disadvantage of this method is the neglect of other factors that could have a dominant position.

Method Preference presupposes extensive information from various sources, which allows us to consider each factor on a par with the others.

The analytic hierarchy process (AHP) method was developed by the American mathematician Saaty. AHP is used to solve poorly structured problems based on a systematic approach (Kozlova 2015, Kutuzov 2008).

Lukinsky in 2007 offered the choice of supplier general algorithm in which he tried to minimize the work of experts. It divided all criteria into three groups: quantitative, qualitative and relay. For their ranging, the author offered a method of pair comparisons. Also to determine weighting coefficients, the probability density functions (Poisson law, normal law, etc.) can be used. Processing quantitative indicators is made in accordance with the methods of qualimetry. To generate estimates of quality indicators, Harrington's desirability function is proposed.

Valeeva (2012) and Eremin (2013) proposed a model based on the method of fuzzy inference for supplier selection. The process of selecting suppliers includes: the definition of criteria for assessing the supplier, the computation of values of membership functions, determining the level of satisfactory alternatives, and selecting the best alternative. Kuimova (2013) also used the theory of fuzzy sets in the choice of supplier. The values of weight coefficients are determined by constructing a matrix of pair wise comparisons of criteria. The weighting factor is determined by calculating the value of the right eigenvector matrix.

In the work by Ware (2012) Indian scientists submitted are view of publications by scientists dealing with the problem of choosing a supplier (from 1991 to 2011). They testify to the increasing interest of scientists in this problem. The first fuzzy techniques applied to the solution of the problem appeared in 2003–2004 in the works of scientists Kahraman (2003) and Manoj (2004).

A general multipurpose model for supplier selection was generated by Weber (1998) in 1993. It was supposed to minimize the negative goal (for example: price) and to maximize the positive purposes (for example: quality). The received linear model has to be limited to consumer demand, opportunities of the supplier, or other indicators. On the basis of this model, in 2006, Amid presented a fuzzy multipurpose linear model to solve problems. This model allows one to find vector x that minimizes target function Z_k (3) and the other objective function maximizes Z_l (4).Values (C_{ki}, C_{li}) at the same time can be specified in a clear and fuzzy form.

$$Min\, Z_k = \sum_{i=1}^{n} c_{ki}x_i\, , k = 1,2, \dots , p; \tag{3}$$

$$Max\, Z_l = \sum_{i=1}^{n} c_{li}x_i\, , l = p + 1, p + 2, \dots , q. \tag{4}$$

Cheng-Yuan Ku in 2009 offered a model on the basis of integrating fuzzy and hierarchical approaches, and also a program approach to the fuzzy purpose. The mathematical formulation of its model looks as follows (5):

$$\mu_k\big(f_k(X)\big) = \begin{cases} 1, & \text{if } f_k(X) \geq g_k, \\ \dfrac{(f_k(X) - l_k)}{g_k - l_k}, & \text{if } l_k < g_k \text{ for } f_k(X) \geq g_k, \\ 0, & \text{if } f_k(X) \leq l_k \end{cases}$$

$$\mu_k\big(f_k(X)\big) = \begin{cases} 1, & \text{if } f_k(X) \leq g_k, \\ \dfrac{(\mu_k - (f_k(X))}{\mu_k - g_k}, & \text{if} g_k < f_k(X) < \mu_k \text{ for } f_k(X) \leq g_k, \\ 0, & \text{if } f_k(X) \geq \mu_k \end{cases} \tag{5}$$

where, $f_k(X)$ – a linear function of k-th purpose; $\mu_k(f_k(X))$ – membership function for the k-th purpose, l_k and μ_k – upper and lower limits of the k-th purpose, g_k level of aspiration.

In 2008 Chan presented a model based on fuzzy hierarchical process for a choice of supplier at the global level. The model assumed the use of a method of expanded analysis to calculate scales of various criteria and subcriteria. The hierarchical method was used to calculate the final weights of suppliers. The method of extended analysis at the first stage involves the calculation of the means of fuzzy arithmetic sums across the rows of a fuzzy matrix ($RS_i = \sum^{n}_{j=1} \tilde{a}_{ij}$) , where $\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$ is a triangular fuzzy matrix equation; l_{ij}, m_{ij}, u_{ij} are triangular fuzzy numbers.

The second step is to normalize the results obtained from the formula (6):

$$\tilde{S}_i = RS_i / \sum_{j=1}^{n} RS_j \tag{6}$$

In the third step, calculate the degree of possibility that $\tilde{S}_i \geq \tilde{S}_j$ (7) where, $\tilde{S}_i = (l_i, m_i, u_i)$, $\tilde{S}_j = (l_j, m_j, u_j)$ – triangular fuzzy numbers.

$$V(\tilde{S}_i \geq \tilde{S}_j) = \begin{cases} 1, & \text{if } m_i \geq m_j, \\ \dfrac{(u_i - l_j)}{(u_i - m_i) + (m_j - l_j)}, & \text{if} l_i \leq u_j; i, j = 1, \dots , n; j \neq 1, \\ 0, & \text{in other cases.} \end{cases} \tag{7}$$

The fourth step is the degree of possibility that S_i is preferred over all of the remaining ($n–1$) fuzzy numbers (8):

$$V(\tilde{S}_i \geq \tilde{S}_j | j = 1, \dots, n; j \neq i) = \min \ V(\tilde{S}_i \geq \tilde{S}_j | i = 1, \dots, n; \ j \in \{1, \dots, n\}, j \neq i) \quad (8)$$

The vector priorities fuzzy matrix is defined by the formula (9):

$$w_i = \frac{V(\tilde{S}_i \geq \tilde{S}_j | j = 1, \dots, n; j \neq i)}{\sum_{k=1}^{n} V(\tilde{S}_k \geq \tilde{S}_j | j = 1, \dots, n; j \neq k)}. \quad (9)$$

In the fuzzy TOPSIS method (Technique for Order Preference by Similarity to Ideal Solution), the ranking of different alternative suppliers and the importance weights of all attributes are assessed in linguistic values represented by fuzzy numbers. These linguistic ratings can be expressed in triangular fuzzy numbers. According to the concept of TOPSIS, a closeness coefficient is defined to determine the ranking order of all suppliers by calculating the distances to both fuzzy positive and fuzzy negative ideal solutions simultaneously. Chu and Lin (2003) in their mathematical fuzzy TOPSIS model proposed the following algorithm: the aggregation weights of importance; the determination is a positive ($I^+ = S^+_1, \dots, S^+_t, \dots, S^+_k$)) and negative ideal solution ($I^- = S^-_1, \dots, S^-_t, \dots, S^-_k$)); the calculation of distances of each alternative ($d^+_i[\sum^k_t = {}_1(S_{it} - S^+_t)^2]^{1/2}$); ($d^-_i[\sum^k_t = {}_1(S_{it} - S^-_t)^2]^{1/2}$);the calculation of the coefficient of proximity (10):

$$C_i = \frac{d_t^-}{d_t^+ + d_t^-} \ (0 < C_i < 1) \quad (10)$$

The factor of proximity can be considered as the value of estimating an alternative A_i. Thus, the more C_i, the higher the priority of an alternative A_i. Aguezzoul and Ladet in 2007 proposed a multi-purpose non-linear model of supplier selection, taking into account transport policy. This model involves calculating the total cost and time of executing the order. Among other indicators, the following are involved in the calculations: the values of the buyer's demand (D), the pace of the buyer and the supplier (r, r_i), average time of transportation of products from the supplier to the buyer (T_i), the distance between them (d_i), the cost of the order (A_i) and delivery (Cf (fixed)$_i$; Cv_i (variable)). The mathematical formulation of the nonlinear multi-purpose programming involves the minimization of the total cost C_{total} (11) and lead time LT_{total} (12) (Min Z = (C_{total}, LT_{total})).

$$C_{total} = \sqrt{2D\left(\sum_{i=1}^{n} (A_i + d_i Cf_i) Y_i\right)\left(\sum_{i=1}^{n} P_i X_i^2 (r_i + r)\right)} + \sum_{i=1}^{n} DX_i(rt_i T_i P_i + Cv_i) \quad (11)$$

$$LT_{total} = \sum_{i=1}^{n} l_i X_i \quad (12)$$

Russian scientists Kuimov et al. in their work (2013) considered the issues of decision-making on the selection of a supplier based on the theory of fuzzy sets. A set of optimal alternatives taking into account the importance of various quality criteria is determined by a weighted intersection of fuzzy sets: $B = F_{1\beta 1} \cap F_{2\beta 2} F_{3\beta 3} F_{4\beta 4}$; $\mu_B(a) = max\ \mu_B(a_j)$; .Where, β_i – weight criterion F_i.

Eremina (2013) carried out an analysis of methods and approaches to the problem of supplier selection. Based on the developed fuzzy model, a computer program "Information system of supplier selection" was created. She shows the practical implementation of this model on the example of machine-building enterprises. In this model, the sufficiency of an alternative which is described by a fuzzy subset *A* of *W*, is defined on the basis of the composite rule of a conclusion: $G = A°D$, where, *G* – a fuzzy subset of an interval of *I*. A comparison of the alternatives takes place on the basis of point estimates. For a fuzzy set, $C \subset I$ is defined ($\alpha \in [0, 1]$): $C_\alpha = \{i \mid \mu_c(i) \geq \alpha \in I\}$. For every C_α it is possible to calculate the average of the elements $-M(C_\alpha)$ for a set from *n* elements. Then the point value for set *C* can be written down in the form of (13):

$$F(C) = \frac{1}{\alpha_{max}} \int_0^{\alpha_{max}} M(C_\alpha) d\alpha, \tag{13}$$

where, α_{max} – the maximum value in set *C*. The best alternative is selected.

Leszcznsyki and Konkin (2008) presented a model of supplier selection under various data types. They used an approach based on the theory of fuzzy sets. The authors propose finding the values of the membership functions through the direct or indirect method. The direct method involves obtaining information from an expert in accordance with the proposed scale. The second method greatly simplifies the task, requiring only a comparison of pairs of real suppliers.

The decision on supplier selection is made based on the values of membership functions of convex combinations of fuzzy sets corresponding to the measured parameters $\mu_{\tilde{c}}(a_i) = \sum^m_{j=1} \beta_j \cdot \mu_j(a_i)$. Where $\beta_1, \beta_2, ..., \beta_m$ – the non-negative numbers ($\sum^m_{j=1} \beta_j = 1$) characterizing relative importance of parameters $c_1, c_2, ..., c_m$; $\mu_j(a_i)$ – the value of the membership function from [0,1] for each supplier $a_i \in A$ on the value of each c_j ($j = \overline{1, m}$) parameter which characterizes to what extent this supplier corresponds to the concept "the best at parameter j" according to the expert. The best supplier is considered to be the option with the maximum value of the membership function (14).

$$\mu_{\tilde{c}}(a^*) = max \mu_{\tilde{c}}(a_i) \mid a_i \in A \tag{14}$$

Okolelova in her work (2012) developed a model of enterprise management in the field of optimization of logistics strategies in the face of uncertainty. The author proposed an algorithm for optimizing the choice of the supplier of material resources on the basis of game theory. In the first step of the algorithm the data is structured and all kinds of costs for the purchase of material resources are presented in the form of a table. Then the so-called „reference" of the enterprise is formed. Further calculation is based on finding the largest deviation of each value from the reference ($\Delta З = З_{эТ} - З_i$), and then determining the variance ($D = \sum^n_{i=1} \Delta З^2$), standard deviation ($\sigma = \sqrt{D}$) and coefficient of the variation ($v = \sigma / З_{эТ}$). Where $З_{эт}$ – total costs by „reference" of the enterprise, and $З_i$ – the total cost for the i-th supplier. The choice of the optimal variant of the decision is made on the basis of Wald's Maximin Model. This model allows the user to minimize the number of expert assessments as a subjective factor.

In an article by Vostrikov (2009) he proposed and built a few examples of non-classical models using the "transportation task" model in the choice of supplier. This model is different to the classical model of "a transport task". In the traditional presentation, the scope of supply is always equal to the number of procurement buyers. In this model, there is a situation which is characteristic of a market economy – supply exceeds demand.

Kozin (2006) offered the integrated model of a choice of supplier of goods and services, taking into account the risk factor. He proposed a new algorithm and a system of mathematical conditions which consider a cumulative assessment of the category of risk. This approach minimizes the risk of choosing an unreliable supplier. The author suggests alternative effective methods of selection: the "Bayes-Laplace probability" (BL), the principle of "maximum entropy utility functions" (MEUF), the principle of "minimum variance utility functions" (MV) and the "modal principle" (MP).The decision to choose conditions of risk assumes that the probabilities of possible options of an economic situation are known. This technique includes the calculation of efficiency criterion and definition of weight (ψ_i) for each method of choice of a decision-making procedure. Rationing and the calculation of the provided coefficients is determined by formula (15), where $э_{(mn)}$ – a calculated value of efficiency of a separate method, *m* – the accepted method of an assessment of efficiency, and *n* – the number of offers. The following defines a comprehensive integral performance criterion (16).

$$\bar{Э}_{(mn)} = \psi_i \frac{Э_{(mn)}}{\sum_{i=1}^{m} Э_{(mn)}} \tag{15}$$

$$Э_{INT} = \frac{\bar{Э}_{(BL)} \bar{Э}_{(MP)}}{\bar{Э}_{(MEUF)} \bar{Э}_{(MV)}} \tag{16}$$

The review of the majority of scientific works doesn't allow us to state a preference for this or that model for choosing a supplier in a certain field of activity. Such absence testifies to their universality. The choice of method or model is influenced by the following factors: industry characteristics of the enterprise, the category and specifics of the bought resources, the concrete period of commission of the purchase, etc. As a rule, the most difficult and thorough models are intended for the selection of strategic suppliers.

The study showed that in recent years there has been a proliferation of models based on fuzzy logic, the analytic hierarchy process, and linear and nonlinear programming. Today we can distinguish several directions of research in this area: fuzzy modeling, fuzzy programming, the fuzzy hierarchical approach, the fuzzy TOPSIS method, etc.

The development of the system architecture of fuzzy inference

The theory of fuzzy sets is the basis for the development of decision support systems for badly formalized problems. They allow one to take into account both the qualitative and quantitative indicators. The most constructive use of fuzzy modeling is to construct models that take into account the inaccuracy and incompleteness of the initial data. Currently, fuzzy modeling is one of the most promising areas of applied research in the field of decision-making. Fuzzy logic allows you to select from a variety of information that is only directly relevant to the analyzed issue.

The process of choosing a supplier for a machine-building enterprise should be carried out on the basis of a wide range of estimated criteria. Thus, it is suggested, that a practical model of knowledge representation is created with a hierarchical architecture. The hierarchical architecture of a fuzzy system assumes the possibility of an indistinct conclusion for intermediate variables for the purpose of the subsequent transfer of accurate values of these variables to systems of the subsequent level of hierarchy. The structure of the developed hierarchical model of an indistinct conclusion for the assessment of suppliers of machine-building enterprise is presented in Figure 9.

The evaluation of suppliers of machine-building enterprise includes the determination value of 32 criteria. They are divided into eight groups (see Figure 7). The first level of the model is represented by the fuzzy inference system for evaluating suppliers on the evaluation criteria. The output variables of the first level are the input to the second level of the system. The output of the entire system is determined by an integral indicator of supplier assessment.

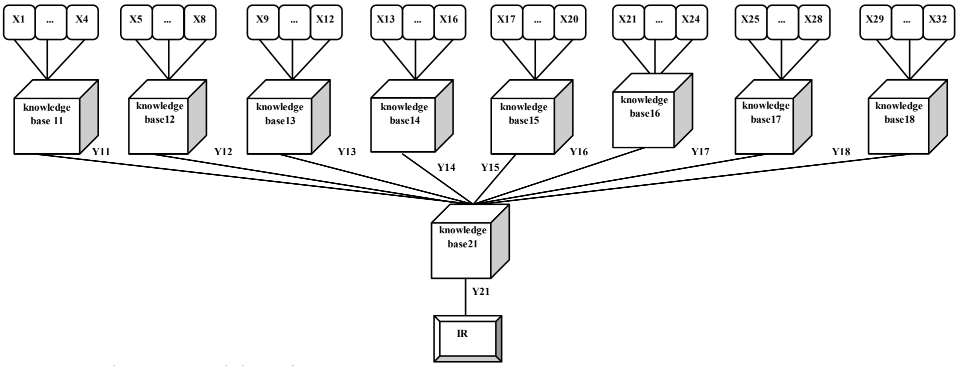
The elements of the tree inference are interpreted as:

IR – the root of the tree; the integral indicator of assessment of the supplier;

1) X1, X2, …, X32 – terminal tops; the criteria influencing the assessment of the supplier;
2) Knowledge base 11, …, knowledge base 18 and knowledge base 21 – non-terminal tops of level 1 and 2; production knowledge bases on processes and a total assessment of the supplier;

3) Y11, …, Y18 and Y21 – arcs emerging from the non terminal nodes of levels1 and 2; the value of performance indicator processes and the final assessment of the supplier.

Figure 9. The hierarchical model of fuzzy inference system for evaluating the suppliers of a machine-building enterprise



Source: authors' own elaboration.

When constructing a fuzzy model, inputs and outputs will be presented in the form of linguistic variables. The values of terminal nodes X1, X2, ..., X32 can be defined by such terms as "very low", "low", "medium", "high", "very high", and for all Y_{ij} – "negative", "neutral" and "positive."

In order to develop a fuzzy model, the Fuzzy Tech program was selected. Figure 11 is a graphic interpretation of a hierarchical knowledge base for the assessment of suppliers.

Definition of functions of accessory and their terms

To solve the problem of choosing a supplier, you need to:

1. to define a suitable conclusive algorithm in which all entrance variables have to be specified;
2. to define the list and type of fuzzy variables (terms) according to linguistic input variables;
3. establish an effective set of rules, which is the basis for the fuzzy model.

The objective function $Y(x_i)$ for the decision support system to evaluate vendors tends to the maximum (17):

$$Y(\bar{x}_i) \rightarrow \max \tag{17}$$

where, $\bar{x}_i$ – parameters of the evaluation criteria, each of which is a vector, $i = 1,\ldots,32$; Y – the value of the performance indicator's processes and the final assessment of the supplier.

The length of vector $\overline{x}_i$ depends on the productivity value of an indicator, thus, the number of these indicators for an assessment of the supplier is rather large. Because of this, the problem of "large dimension" may appear. Thus, part of the input parameters are qualitative, and others quantitative. To unify the processing of these indicators, they need to be normalized (Orlovsky 1981, Rotshteyn 2002, Norwich 1986).

Triangular and trapezoidal functions of accessory were the most popular thanks to their simplicity.

For the description of a triangular function, formula (18) is used:

$$\mu_A(x)=\begin{cases} 0, & u \le a, u \ge c \\ \dfrac{u-a}{b-a} & a \le \mathrm{u} \le b, \\ \dfrac{\mathrm{c - u}}{\mathrm{c - b}}, & b \le u \le c \end{cases} \tag{18}$$

where (a, c) – pessimistic evaluation of the fuzzy number; fuzzy set medium; b – optimistic assessment of fuzzy number; maximum coordinate.

For the description of the trapezoid function, formula (19) is used:

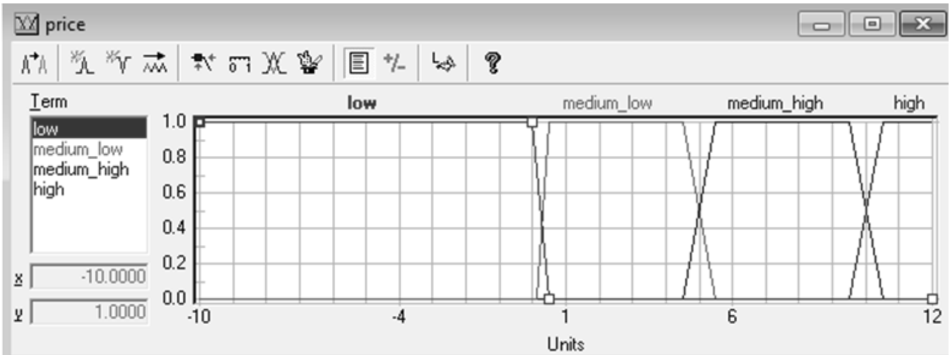
$$\mu_A(x)=\begin{cases} 0, & u \le a, u \ge d \\ \dfrac{u-a}{b-a} & a \le \mathrm{u} \le b, \\ 1 & \mathrm{b \le u \le c} \\ \dfrac{\mathrm{d - u}}{\mathrm{d - c}}, & c \le u \le d \end{cases} \tag{19}$$

where (a, d) – pessimistic evaluation of the fuzzy number; fuzzy set medium; [b, c] – optimistic assessment of fuzzy number; the core of a fuzzy set.

At the preliminary stage, the method of indirect expert assessment was used to define the type of functions of accessory and the values of their qualitative parameters. Depending on the type of the parameter have been identified, the types of triangular and trapezoidal membership functions of all quality indicators.

As an example, we will consider the function of the accessory of the „Price" criterion (C1). To assess the linguistic criterion the terms used are "unsatisfactory", "satisfactory", "good", "excellent". The value of this criterion is evaluated as a percentage of the average market price. For each variable, utilized membership functions are defined by fuzzy sets. Functions of the accessory of fuzzy sets for the C1 criterion are presented in Figure 10.

Figure 10. The membership functions for the "Price" variable



Source: authors' own elaboration.

$$\mu_{C1}^{low}(x)=\begin{cases}0, & x\le -10.00,\quad x\ge 0.50\\ 1, & -10.00\le x\le 0\\ \dfrac{0.50-x}{0.50-0}, & 0\le x\le 0.50\end{cases}$$

$$\mu_{C1}^{medium\_low}(x)=\begin{cases}0, & x\le 0.10,\quad x\ge 5.50\\ \dfrac{x-0.10}{0.50-0.10}, & 0.10\le x\le 0.50\\ 1, & 0.50\le x\le 4.50\\ \dfrac{5.50-x}{5.50-4.50}, & 4.50\le x\le 5.50\end{cases}$$

(20)

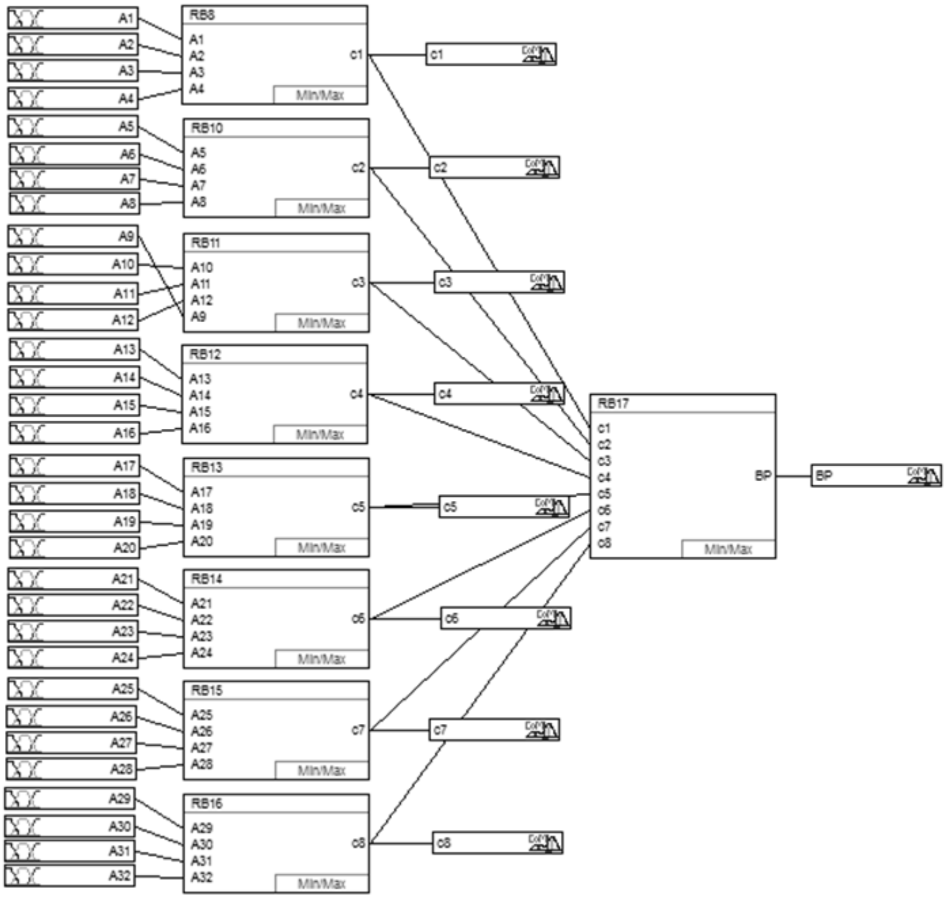
$$\mu_{C1}^{medium\_high}(x)=\begin{cases}0, & x\le 4.50,\quad x\ge 10.50\\ \dfrac{x-4.50}{5.50-4.50}, & 4.50\le x\le 5.50\\ 1, & 5.50\le x\le 9.50\\ \dfrac{10.50-x}{10.50-9.50}, & 9.50\le x\le 10.50\end{cases}$$

$$\mu_{C1}^{high}(x)=\begin{cases}0, & x\le 9.50,\quad x\ge 12.00\\ \dfrac{x-9.50}{10.50-9.50} & 9.50\le x\le 10.50\\ 1, & 10.50\le x\le 12.00\end{cases}$$

The function “low” has parameters: a = 10, b = –10, c = 0, d = 0.5.
The function “medium_low” has parameters: a = 0.1, b = 0.5, c = 4.5, d = 5.5.
The function “medium_high” has parameters: a = 4.5, b = 5.5, c = 9.5, d = 10.5.
The function “high” has parameters: a = 9.5, b = 10.5, c = 12, d = 12.

The hierarchical architecture of building the knowledge base for the fuzzy inference decision system on the selection of an engineering enterprise is shown in Figure 11.

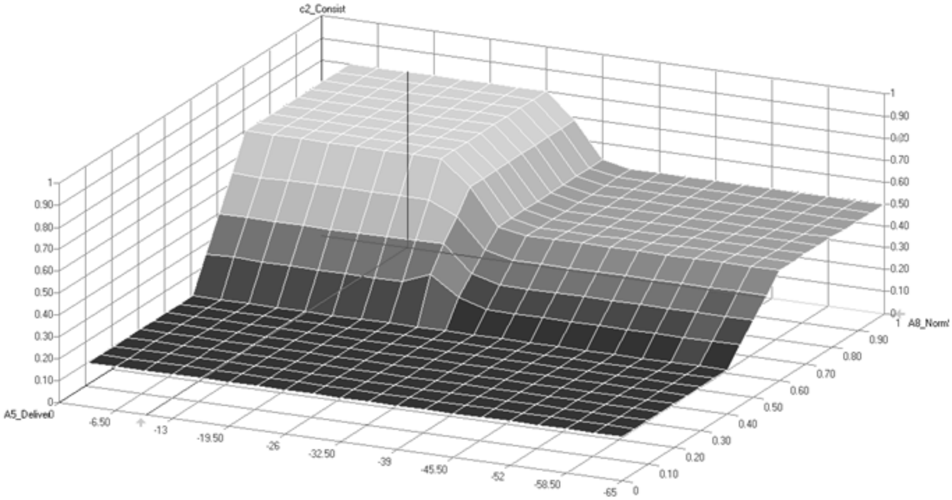
Figure 11. The hierarchical architecture of building the knowledge base for the fuzzy inference decision system to assess a supplier of machine-building enterprises in Fuzzy Tech



Source: authors’ own elaboration.

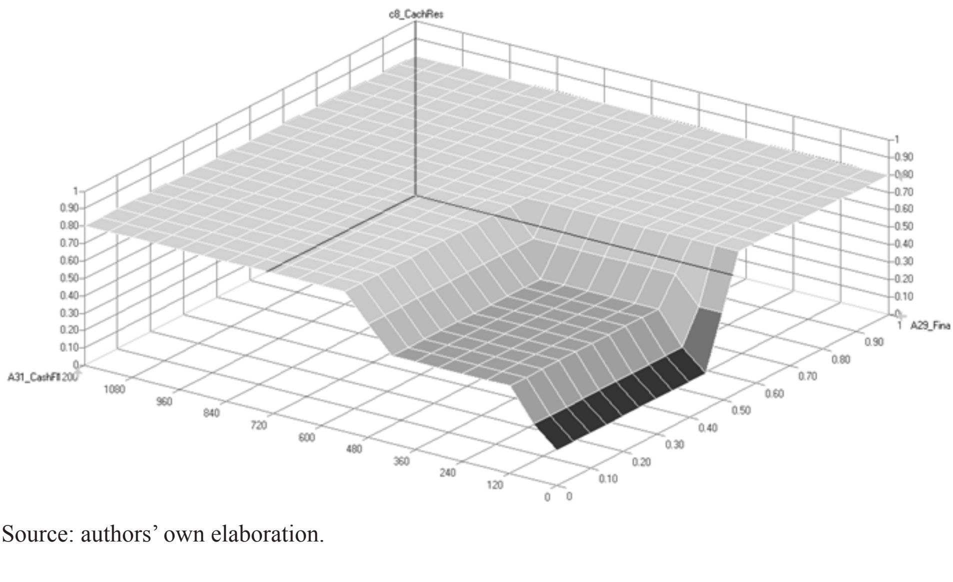
A detailed analysis of the developed fuzzy model was carried out in the construction of three-dimensional surfaces of the set of fuzzy inference. In Figures 12 and 13 there are two examples.

Figure 12. Type of three-dimensional surface of the “Terms of delivery and payment” fuzzy inference process which depends on “Delivery times” and “Norm of shipments” performance for the year 2012 for a steel supplier



Source: authors’ own elaboration.

Figure 13. Type of three-dimensional surface of the “Financial condition” fuzzy inference process which depends on the indicators “Annual cash flow” and “Stability of their financial situation” for the year 2012 for a steel supplier



Source: authors’ own elaboration.

Despite the fact that the proposed architecture is a hierarchical knowledge base and has a rather complex structure, it allows the rapid assessment of suppliers according to 32 criteria.

Conclusion

Improving the procurement process helps the manufacturer to increase their profits and is an important factor affecting the economic efficiency of enterprises. The use of international supply sources can become a powerful weapon in the competition.

The preliminary assessment of the supplier plays a special role in this model. We developed a functional model of the business process of supplier selection for material resources. For convenience of the process of supplier selection, all purchases should be divided into categories of purchases.The process of determining the category of procurement involves consistent implementation of ABC, XYZ and SHM analyses. The category of purchase is determined by subsequently combining the results obtained and forming a three-dimensional matrix. Decisions on the structure, volumes and terms of purchase, as well as the formation of orders, conclusion and execution of contracts, is made on the basis of the results that will be obtained at the stage of the comparative analysis of suppliers.

The review of the majority of scientific works doesn't allow us to allocate preference in the use of this or that model for the choice of supplier in a certain field of activity. The study showed that in recent years there has been a proliferation of models based on fuzzy logic, the analytic hierarchy process, and linear and nonlinear programming. Today we can distinguish several directions of research in this area: fuzzy modeling, fuzzy programming, the fuzzy hierarchical approach, the fuzzy TOPSIS method, etc.

Based on the theory of fuzzy sets, we have developed a hierarchical model, a fuzzy conclusion for the assessment of suppliers of machine-building enterprises. Despite the fact that the proposed architecture is a hierarchical knowledge base and has a rather complex structure, it allows a rapid assessment of suppliers. To improve the clarity and transparency of the calculations, an intermediary assessment of performance indicators has been provided. This in turn increases the flexibility of its setting and the adequacy of the work. In addition, it enables procurement managers to assess their effectiveness and to take timely and appropriate management decisions on choosing the best supplier.

Bibliography

Amid A., Ghodspour S.H., O'Brien C. (2006), *Fuzzy Multi-Objective Linear Model for Supplier Selection in a Supply Chain*, "International Journal of Production Economics", No. 104.

Ageev A.V. (2007), *Ocenka Vybora Postavshhikov Produkcii v Logisticheskih Processah*, "Ekonomicheskij Analiz: Teorija i Praktika", No. 21.

Bulanov K.N. (2009), *Funkcional'nye Zony Logisticheskoj Strategii Snabzhenija Predprijatij Po Proizvodstvu Gruzovyh Avtomobilej*, "Izvestija Sankt-Peterburgskogo Universiteta Ekonomiki i Fnansov", No. 3.

Chan F.T.S., & Niraj K. (2008),*Global Supplier Development Considering Risk Factors Using Fuzzy Extended AHP-based Approach,*"Omega", No. 35.

Christopher M. (2004), *Logistics and Supply Chain Management*, St. Petersburg, Izdatelskij Dom Piter.

Dremov V.V. (2007), *Sovershenstvovanie Processa Vybora Postavshhika Na Metallurgicheskom Predprijatii*. "Uspehi Sovremennogo Estestvoznanija", No. 1.

Eremina E.A., Vedernikov D.N. (2013), *Informacionnaja Sistema Vybora Postavshhika Na Osnove Metoda Nechetkogo Logicheskogo Vyvoda*, "Sovremennye Problemy Nauki i Obrazovanija", No. 3.

Grishchenko O. (2012), *Opredelenie Uslovij Sotrudnichestva s Postavshhikom Po Lizingovoj Sdelke*, "Logistika", No. 4.

Hendfild R.B., Nichols E.L. (2003), *The Reorganization of the Supply Chain. Creation of Integrated Systems of Formation of Values*, Moscow, Publishing House "Williams".

Kostyuk I.V. (2010), *Avtomatizirovannyj Vybor Postavshhikov Instrumentoobespechenija s Ispol'zovaniem Bazy Znanija Na Primere Detali «krestovina»*,"*Social'no-ekonomicheskie i Tehnicheskie Sistemy: Issledovanie*, *Proektirovanie, Optimizacija*", No. 53.

Kozin M.N. (2006), *Integral'naja Mdel' Vybora Postavshhika Gosudarstvennogo Oboronnogo Zakaza s Uchetom Faktora Riska*, "Finansy i Kredit", No. 29.

Kozlova E.V., Volynsky V.Y. (2014), *Metody i Modeli Vybora Postavshhikov Material'nyh Resursov: Sovremennoe Sostojanie i Analiz*, "Logisticheskie Sistemy v Global'noj Ekonomike", Materialy Mezhdunarodnoj nauchno-prakticheskoj konferencii resursov: Sovremennoe sostojanie i analiz (Krasnojarsk 3–4.03.2014).

Kozlova E.V., Volynsky V.Y. (2014), *Obzor Matematicheskih Modelej Vybora Postavshhikov Material'nyh Resursov*, "Sbornik Nauchnyh Trudov Vuzov Rossii «Problemy Ekonomiki, Finansov i Upravlenija Proizvodstvom»", No. 35.

Kozlova E.V., Volynsky V.Y. (2015), *Sovershenstvovanie Processa Predvaritel'noj Ocenki Postavshhikov Material'nyh Resursov Na Mashinostroitel'nom Predprijatii*, "Ekonomicheskij Analiz: Teorija i Praktika", No. 415.

Kravets O.Y., Rudychev A.A., Borachuk V.V. (2013), *Formalizacija Upravlenija Otnoshenijami s Postavshhikom Telekommunikacionnyh Uslug*, "Ekonomicheskij Analiz: Teorija i Praktika", No. 40.

Kuznecova M.N. (2012), *Metodika Analiza i Ocenki Postavshhikov Resursov*, "Ekonomicheskij Analiz: Teorija i Praktika", No. 43.

Kulakov Y.N., Kulakov A.B. (2014), *Formirovanie Strategii Upravlenija Proizvodstvennymi Zapasami Predprijatija Na Osnove Analiza Matricy ABC*XYZ,* "Finansovaja Analitika: Problemy i Reshenija", No. 20.

Kutuzov D.V. Bykova E.P. (2008), *Kutuzov D.V., Bykova E.P. Prilozhenie Metoda Analiza Ierarhij k Vyboru Postavshhika*, "Prikaspijskij Zhurnal: Upravlenie i Vysokie Tehnologii", No. 2.

Kuimova E.I. (2013), Primenenie Teorii Nechetkih Mnozhestv Dlja Vybora Postavshhika, "Vostochno-Evropejskij Zhurnal Peredovyh Tehnologij", No. 4 (64).
Ku C.Y., Chang C.T. & Ho, H.P. (2010), Global Supplier Selection Using Fuzzy Analytical Hierarchy Process and Fuzzy Goal Programming. "Qual Quant", No. 44.
Leenders M.R., Fearon H.E. (2002), Supply and Inventory Management, "Logistics", St. Petersburg, „Victoria Plus".
Leszczynski B.S., Konkin U.A. (2008), Vybor Postavshhika s Ispol'zovaniem Metodov Teorii Nechetkih Mnozhestv, "Vestnik TGU. Ekonomika", No. 2.
Laysons K., Gillingham M. (2005), Management Procurement and Supply Chain, Moscow, INFRA-M.
Lipatova O.N. (2012), *Organizacionno-Ekonomicheskie Reshenija Pri Vybore Postavshhikov*, Vestnik AGTU, Ser.: "Ekonomika", No.2.
Lukinskiy V.S. (2007), Modeli i Metody Teorii Logistiki: uchebnoe posobie, St. Petersburg, Izdatelskij Dom Piter.
Luitzen de Boer (2001), *A Review of Methods Supporting Supplier,* "Selection. European Jornal of Purchasing & Supply Management", No.7.
Malochko V. (2003), Ocenka i Vybor Postavshhikov, Moscow.
Maizlish A.V., Volynsky V.Y. (2011), Sovershenstvovanie Analiza i Klassifikacii Material'nyh Zapasov na Promyshlennom Predprijatii, Izvestija Vysshih Uchebnyh Zavedenij. Serija "Ekonomika, finansy i upravlenie proizvodstvom", No. 4.
Maizlish A.V., Volynsky V.Y. (2014), Algoritm Operativnogo Upravlenija Zapasami Material'nyh Resursov Proizvodstvennyh Predprijatij Na Osnove Jacheechnoj Modeli, "Ekonomicheskij Analiz: Teorija i Praktika", No. 42.
Norwich A.M. (1986), *Construction Membership Functions*. Fuzzy Sets and Possibility Theory. Recent advances.ed. Yager R.R. Moscow, *Radio i Svjaz'*.
Olgin V.A. (2013), Algoritm Vybora Logisticheskogo Posrednika v Cepi Postavok Predprijatij Sfery Obshhestvennogo Pitanija, "Vestnik SGTU", No. 1.
Okolelova E.Y. (2012), Upravlenie Sistemoj MTO Predprijatija Na Osnove Teorii IGR, "Organizator Proizvodstva", No. 2.
Orlovsky S.A. (1981), Prinjatie Reshenij Pri Nechetkoj Ishodnoj Informacii, Moscow, Radio i Svjaz'.
Pleschenko V.I. (2011), *Zakupki Promyshlennyh Predprijatij: Tendencii i Zakonomernosti,* "Logistika i Upravlenie Cepjami Postavok", No. 2.
Pleschenko V.I. (2012), *Ocenka Sostojanija Konkurentnoj Sredy Postavshhikov Na Baze Cenovyh Pokazatelej v Ramkah Zakupochnoj Dejatel'nosti Promyshlennyh Predprijatij*, "Ekonomicheskij Analiz: Teorija i Praktika", No. 46.
Rudzki R.E. Rudzki R. (2008), Effektivnoe Snabzhenie: Prostye i Nadezhnye Sposoby Snizhenija Izderzhek i Povyshenija Pribyli, Minsk, Grevcov Pablisher.
Rotshteyn A.P. (2002),Vlijanie Metodov Defazzifikacii na Skorost' Nastrojki Nechetkoj Modeli, "Kibernetika i sistemnyj analiz", No. 5.

Rybalko M.A. (2011), Sovremennye Klassifikacii Postavshhikov Logisticheskih Uslug, “Perspektivy nauki”, No. 18.
Sagar M.K., Singh D. (2012), Suppier Selection Criteria: Study of Automobile Sector in India, “International Journal of Engineering Research and Development”, No. 4.
Salikov Y.U., Gorbaneva Y.Y. (2011), Mehanizm Formirovanija Strategii Priobretenija Resursov Dlja Promyshlennogo Predprijatija, Vestnik AGTU. Ser.: Ekonomika, No. 1.
Stoc J.R. Lambert D.M. (2005), *Strategic Logistics Management*, trans. from English, Moscow, INFRA-M.
Shtovba S.D. (2004), *Classification of Objects Based on Fuzzy Inference*. Exponenta Pro: Math applications, No. 1.
Shapiro J. (2006), *Modeling of Supply Chain*, St. Petersburg, Izdatelskij Dom Piter.
Tahriri F., Osman M.R. (2008), AHP approach for supplier evaluation and selection in a steel manufacturing company, “Journal of Industrial Engineering and Management”, No. 01(02).
Urazova N. (2009), Vybor i Ocenka Postavshhika. “ElektroInfo”, No. 1.
Valeyeva A.N. (2012), *Koncepcija Resursosberezhenija v Opredelenii effektivnogo Vzaimodejstvija Predprijatija s Postavshhikami Syr’ja*, “Vestnik KTU”, No. 8.
Volynsky V.Y., Kraev A.A. (2011), *Sovremennoe Sostojanie Voprosa Klassifikacii, Ocenki i Vybora Postavshhikov*, Sb. nauch. trudov vuzov Rossii „Problemy Ekonomiki, Finansov i Upravlenija Proizvodstvom”, No. 30.
Vostrikov A.V. (2009), Analiz Strategii Vakupok Avtomobilestroitel’nogo Predprijatija v Period Krizisa, “Vestnik SamGUPS”, No. 6.
Vostrikov A.V. (2009) *Ispol’zovanie Modeli «Transportnoj Zadachi» Pri Vybore Postavshhika, Sposoba Dostavki i Organizacii Skladirovanija Produkcii*, “Vestnik SamGUPS”, No. 5.
Waters D. (2003), *Logistics. Supply Chain Management. Trans. from English.* The series „Foreign textbook”, Moscow, UNITY-DANA.
Ware N.R., Singh S.P., Banwet D.K. (2012), *Supplier Selection Problem: A State-of-the-art Review*. “*Management Science Letters*”, No. 2.
Weber C.A., Current J.R. & Desai A. (1998), *Non-cooperative Negotiation Strategies for Vendor Selection* “European Journal of Operational Research”, No. 108.

Summary

The subject of our research is the process of selecting a supplier of material resources to machine-building enterprises. The aim of this work is to identify factors that improve the process of supplier selection of material resources to large enterprises. Testing this model is made on the example of the “KRANEKS” machine-building enterprise. The methodological basis of the scientific research is work in the fields of systems analysis, management accounting, and econometrics. As a result of the research, a methodology and estimation algorithm of suppliers was developed, as well as a hierarchical model of fuzzy inference to supplier evaluation. These developments are mainly aimed at supporting decision making in choosing the best provider for a machine-building enterprise. These developments mainly focused on decision support in choosing the best provider for an engineering enterprise whose list of material resources runs into the thousands. They are aimed at improving the efficiency of administrative decisions in the supplier selection process of machine-building enterprises and improving the work process of their purchasing departments.

Keywords: supplier selection, preliminary assessment of the supplier, purchase, procurement strategy, complexity of the procurement, priority supplier, selection criteria, mathematical models, fuzzy models, AHP-fuzzy model

Streszczenie

Model rozmyty oceny dostawców materiałów dla przedsiębiorstw sektora budowy maszyn

Przedmiotem badań jest proces wyboru dostawców materiałów w przedsiębiorstwach sektora budowy maszyn. Celem jest identyfikacja czynników ulepszających ten proces w dużych przedsiębiorstwach. Zbudowany model przetestowano na przedsiębiorstwie „KRANEKS". Podstawy teoretyczno-metodologiczne pracy zawierają się w obrębie analizy systemów, rachunkowości zarządczej i ekonometrii. W rezultacie stworzone metodologię oraz algorytm wyboru dostawcy oraz hierarchiczny model wnioskowania rozmytego dla oceny dostawców. Narzędzia te dobrze nadają się do wspierania decyzji o wyborze dostawców w przedsiębiorstwie sektora budowy maszyn. W istocie mogą one wspierać decyzje w każdym przedsiębiorstwie produkcyjnym, które zgłasza zapotrzebowanie na dostawy licznych materiałów. Narzędzia te mają poprawiać efektywność decyzji administracyjnych oraz wspierać działy zakupów tego rodzaju przedsiębiorstw.

Słowa kluczowe: wybór dostawcy, wstępna ocena dostawcy, zakup, strategie zaopatrzenia, złożoność zaopatrzenia, dostawca priorytetowy, kryteria wyboru, model matematyczny, model rozmyty, model rozmyty AHP

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