doi:10.22306/al.v8i3.253 Received: 06 Sep. 2021; Revised: 23 Sep. 2021; Accepted: 29 Sep. 2021

DESCRIPTION OF A NOVEL SUPPLIER SELECTION METHOD FOR COMPANIES MANUFACTURING FOOD SUPPLEMENTS

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Keywords: supplier selection, supply chain design, logistics, process development
Abstract: The publication presents a novel supplier selection method that can be of significant help in the optimal design of the supply chains of so-called commissioned food supplement companies. As a prelude to this, the article also explores the literature on existing supplier selection methods using the method of systematic literature search. A key characteristic of the newly developed method is that it incorporates such aspects into the supplier selection process as the environmental impact of logistics processes or the modernity of the supplier's logistics system, both becoming highly important criteria in recent years. The method also supports one and multi actor decision making following state of the art principles in modern data driven supply chain management. As a result, it can be stated that the newly introduced method provides a state of the art approach to supplier selection, while it also takes into account all the traditional aspects related to the field.

1 Introduction

The development and operation of the supply chain of small and medium-sized enterprises producing and selling food supplements has a major impact on competitiveness, as it has a significant impact on the way in which individual customer needs (quality, deadline, cost) are met [1].

In recent decades, customer demand for dietary supplements has increased significantly, further reinforced by the pandemic situation from 2020 [2]. It can be concluded that the dietary supplement product structure is changing extremely rapidly and dynamically [3]. The increasing competitive situation has increased the quality and quantity of the logistics services related to food supplements companies (e.g. shorter lead times, increased flexibility, etc.). It can be said that with the expansion of the product range manufactured and sold by companies, the complexity of manufacturing and logistics processes is constantly increasing, which generates new logistical challenges for today's logistics professionals [4]. The sale of food supplements takes place in a specific case of supply chains, as the products are not the property of the seller as a result of commission sales [5]. In commissioned sales surveys of several companies producing and distributing dietary supplements, it was found that on average 20% of commissioned products were sold in devaluation and 15% were scrapped due to maturity, and there have been many cases where no sales of the products have been made due to a shortage of products in respect of warehouses selling on a 'scheduled' commission [6]. The increasing demand and the complexity of the logistics process, the problems in practice described above, and the possibilities of applying new technological achievements of Industry 4.0 (for example IoT, Big Data, cyberphysical systems, etc.) in the field create new efficiency gains in the field.

Based on the practical experience of the authors, it can be concluded that there are significant shortcomings in the selection of suppliers, the development of processes and their scheduling. This experience served as the primary motivation to develop a novel supplier selection method for the field, based on a practice oriented scientific approach. The development of the method was proceeded by a systematic literature research, in which the existing supplier selection methods were explored. This is covered in section 2 of the publication. Section 3 contains the detailed description of the proposed supplier selection method itself. Finally, section 4 serves as the Conclusion for the publication. Overall, the authors believe that the developed novel supplier selection method could be successfully applied to increase the operational efficiency of the examined systems, thereby supporting the competitiveness of the field.

2 Literature research

The literature research was carried out using the Systematic Literature Review (SLR) method. Systematic literature research consists of the following steps:

1. Identifying research questions (Who's done what so far? Who did or published the research first? Where are the scientific gaps?).
2. Mapping related literature, primarily through online databases.
3. Reducing results, selecting relevant literature and reading them to determine the main direction of research (definition of extra keywords, based on authors, by date, etc.).
4. Develop a method of processing and analyzing literature.
5. Formulation of major scientific breakthroughs and results.
6. Definition of scientific gap or bottleneck.

On this basis, the first step is to define keywords that cover the topic of research work [7].

Table 1 Keyword hits in Scopus, Web of Science and ScienceDirect [Source: Own Edit]

	Scopus						Web of Science						ScienceDirect					
search keywords	supplier selection	supplier selection AND medicine/pharma	supplier selection AND medicine/pharma AND method	supplier selection AND method	supplier selection AND weight	supplier selection AND method AND weight	supplier selection	supplier selection AND medicine/pharma	supplier selection AND medicine/pharma AND method	supplier selection AND method	supplier selection AND weight	supplier selection AND method AND weight	supplier selection	supplier selection AND medicine/pharma	supplier selection AND medicine/pharma AND method	supplier selection AND method	supplier selection AND weight	supplier selection AND method AND weight
search range	title, abstract, keywords	title, abstract, keywords	title, abstract, keywords	title, abstract, keywords	title, abstract, keywords	title, abstract, keywords	title, abstract, keywords	title, abstract, keywords	title, abstract, keywords	title, abstract, keywords	title, abstract, keywords	title, abstract, keywords	title, abstract, keywords	title, abstract, keywords	title, abstract, keywords	title, abstract, keywords	title, abstract, keywords	title, abstract, keywords
2000-2020 in total	7550	50	24	3086	1811	725	4616	22	11	2140	1086	831	1282	3	0	510	186	134
2000	88	0	0	21	5	3	30	0	0	6	3	1	13	0	0	2	1	0
2001	93	2	0	20	0	0	35	0	0	6	0	0	14	0	0	4	0	0
2002	75	0	0	14	2	0	25	0	0	6	3	1	8	0	0	2	0	0
2003	138	0	0	26	5	2	43	0	0	9	0	0	20	0	0	3	1	1
2004	142	2	0	29	4	0	42	1	0	7	5	3	17	0	0	2	0	0
2005	198	1	0	49	10	5	62	1	0	15	2	1	18	0	0	5	2	1
2006	240	3	1	62	8	4	60	0	0	18	4	2	24	0	0	7	4	3
2007	261	7	0	87	24	16	76	0	0	15	4	3	34	0	0	9	2	1
2008	343	1	1	142	35	25	113	0	0	41	12	8	35	0	0	11	2	1
2009	378	1	0	137	51	34	160	0	0	54	20	10	70	0	0	21	6	4
2010	407	1	1	137	48	28	157	1	1	52	26	16	55	0	0	15	5	2
2011	453	0	0	174	58	40	189	0	0	74	41	25	80	0	0	35	15	10
2012	401	2	1	166	57	40	183	0	0	59	29	18	80	0	0	33	14	9
2013	445	2	2	184	65	46	205	1	1	88	44	29	86	0	0	37	14	11
2014	500	2	1	227	72	58	259	1	0	127	59	46	93	0	0	36	11	7
2015	459	5	3	176	72	41	350	2	2	138	77	46	102	0	0	46	21	13
2016	484	4	1	215	58	45	374	3	0	185	89	65	81	1	0	33	9	7
2017	510	3	1	227	875	57	412	2	1	204	98	76	100	1	0	43	19	18
2018	596	3	2	286	100	71	511	4	2	281	144	115	113	0	0	53	19	11
2019	663	7	7	357	123	101	665	3	2	363	200	174	131	0	0	66	20	18
2020	676	4	3	350	139	109	665	3	2	392	226	192	108	1	0	47	21	17

In general, the process of supplier selection is based on several aspects of decision making. The decision-making process is complicated by the need to take into account the characteristics of the material to be scored, the participants in decision making and its role in the organization when analysing the criteria [8]. The literature on supplier selection is extremely rich, many publications analyse different aspects of decision-making methods. The literature analysis focuses on the examination of decision making methods and the analysis of the criteria used

As shown in Figure 1, systematic literary research was carried out first in the chapter using the following keywords when analysing the literature in the field:

- selection supplier / supplier selection,
- medicine or pharma / medicine,
- method / method,
- weight / weight

In the databases, a simple search was also used for this literary research section, where only two search words were given first, then several search words, the combinations and results of which are given in Figure 1.

The table shows that searches for original keywords have been narrowed down to "supplier selection AND method AND weight" to create a more limited search result. After that, the search results for each keyword resulted in sufficiently relevant results, so a total of 1690 works were selected and analysed in detail. It can be said that the words medicine/pharma have greatly reduced the result of the hit.

The chronological distribution of the selected publications is illustrated in Figure 2, where it can be observed that the number of publications with an increasing trend towards the research directions examined is displayed year after year.

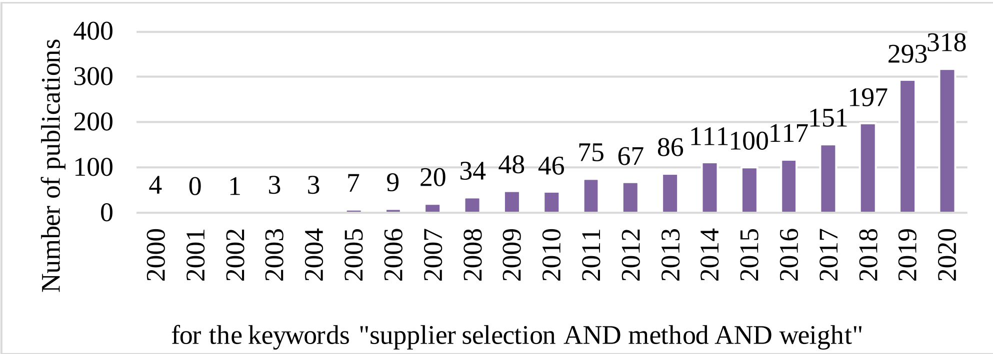

Figure 1 Number of publications related to the topic by year of publication [Source: Own Edit]

Figure 3 illustrates the importance of different disciplines in the publication list of the Scopus scientific database based on data from the past 20 years. It can be observed that the delimited field of research clearly shows a multidisciplinary character. Research related to engineering also plays a prominent role here, but there are also publications approaching pharmaceuticals and social aspects. Figure 7 shows that there are few publications on this subject in the pharmaceutical sector.

Figure 4 is based on data from the Scopus database for the last 5 years, which is based on the search for the keywords "supplier selection AND method AND weight", which together contains 424 publications. The search results then searched the search results for keywords that appear in scientific works outside of the keywords you specify. It can be observed that decision support and supply chains play a major role in the majority of publications related to the subject area.

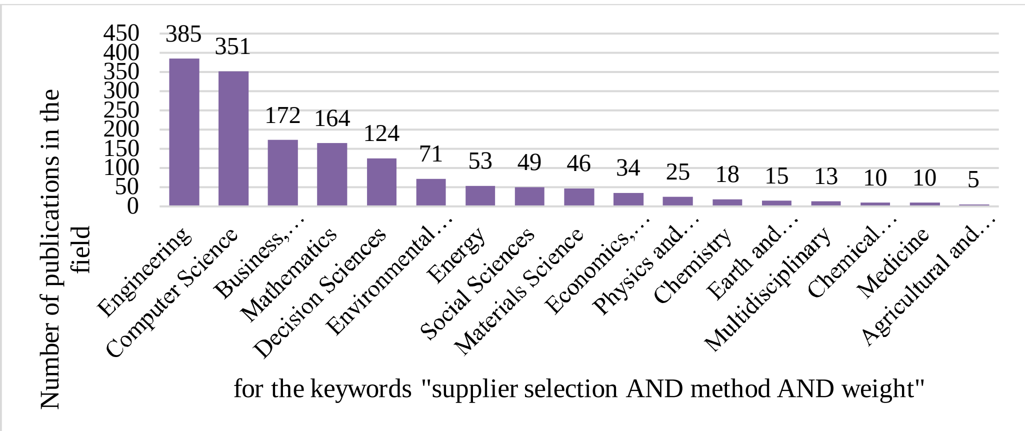

Figure 2 The emergence of disciplines in publications [Source: Own Edit]

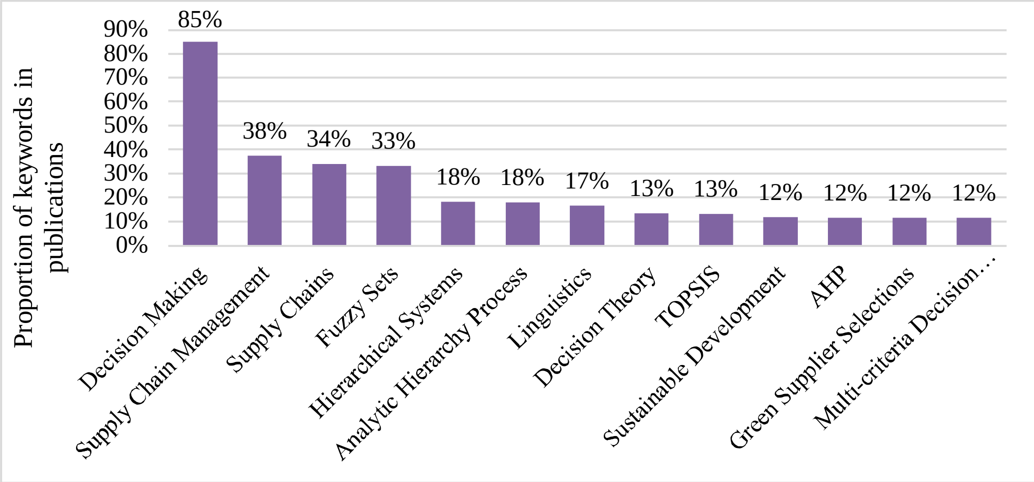

Figure 3 Distribution of keywords other than search keywords in publications [Source: Own Edit]

As a further analysis, the 10 most published persons on the subject were selected (Table 1). It can be said that the total number of authors involved in the publication of four or more articles is estimated at 39.

Table 2 The authors who published 10 most published authors for "supplier selection AND method AND weight" in the Scopus scientific library between 2015 and 2020 [Source: Self-edit]

Author	published articles	Author	published articles
Wei, G.	15	Wu, J.	9
Liao, H.	11	Zavadskas, E.K.	9
Kar, S.	10	Wei, C.	8
Krishankumar, R.	9	Wan, S.P.	8
Ravichandran, K.S.	9	Chen, T.Y.	7

The following summary literary review was prepared, focusing on outstanding authors and most cited publications, by processing 1690 works (Scopus, Wos, ScienceDirect in total) delimited in systematic literature research.

Jenoui and Abouavdellah published about supplier selection for pharmaceutical products in 2015. They note that one of the most important logistical challenges in this sector is the choice of supplier, but there are few methods for decision-makers to choose the optimal supplier. A new heuristic model will be created that takes into account only costs and deadlines [9].

Voeng and Kritchanchai will use VMI technology to supply medicines between distributors and hospitals in 2019. In the study, a multi-aspect decision-making method based on the AHP method is used to determine weight factors for the selection of suppliers, illustrating the critical factors of the use of VMI in different types of hospitals [10].

In a case study in 2019, Bakhtiar et al. also analyzed the selection of a hospital supplier for pharmaceuticals. Supplier selection is treated by one of the methods of the MCDM “Multi Criteria Decision Making” model, which takes into account several criteria, the “gray-based major set method”, which involves several decision-makers who play an important role in the hospital [11].

Pourghahreman and Rajabzadeh discussed the selection of pharmaceutical supplier agents in 2015, listing the criteria that have been defined from various publications, thus selecting 10 qualitative and 10 quantitative criteria from 38 factors. From these supplier assessments, a ranking is established using the TOPSIS and PROMETHEE methods. According to the results of the survey, quality criteria are one of the most important factors in the choice of supplier [12].

In 2006, Chen and his co-authors published a paper on fuzzy-based decision-making to address the problem of supply chain supplier selection. In their research, they propose an MCDM model for supplier selection. According to the TOPSIS method, a proximity co-efficient is determined to determine the ranking order of all suppliers [13].

Hossein and his team discussed supplier selection in 2011. In their publication, they describe that the process of purchasing raw materials is influenced by a number of parameters. The most important of these parameters are the product arrival time (order lead time), purchase and delivery costs and raw material quality from the date of order [14].

In 2017, Gupta and Barua discussed the selection of suppliers for SMEs based on their green innovation capacity. The aim of their study is to examine supplier selection among SMEs on the basis of their green innovation capacity. A three-phase methodology is used, the first phase of which is the green innovation criterion, the second phase is the ranking of selection criteria, and the third phase uses the TOPSIS method to prioritize suppliers based on the weight of the criteria obtained in the second phase [15].

Sarkis and Dhavale conducted a supplier selection in 2015 with sustainable operations in mind. In the sustainable approach, a three-prone set of criteria is set up and a new methodological approach based on the Bayes framework and the Monte Carlo Markov Chain (MCMC) simulation will be developed using specific selection targets for supplier ranking and selection [16].

In the supply chain, it can be seen that in the last five years, environmental protection and the development of new methods have become one of the important aspects of supplier selection. A number of new methods have been developed or further developed on the basis of their own criteria, which can take into account several aspects [15-20].

Based on the literature analysis, it can be concluded that there are a huge number of supplier selection methods in a wide variety of areas, but there is little literature on medicinal products or dietary supplements. There is no elaborated method in the referred literature to provide a general solution for selecting suppliers for all companies producing dietary supplements. Some of the methods do not take into account quality parameters (e.g., concentration, proportion of transport errors, etc.), while others do not consider environmental aspects, the importance of which is increasingly appreciated nowadays.

3 Development of a supplier selection method for companies producing dietary supplements that sell commissioned

A significant part of supplier selection methods focusses on the automotive industry [21-23], but a number of methods have also been developed for food supplements and pharmaceutical companies [24-27]. It can be concluded that some of these selection methods focus strictly on costs, other methods focus on quality or environmental protection, but the approach that takes into account logistical aspects has not been elaborated in detail so far. One of the literatures with the most diverse criteria [27], which produces a summary analysis of several publications in the field of supplier selection [28-40], also does not take sufficient account of logistical aspects.

With regard to companies producing food supplements, this aspect is particularly important as delayed deliveries, long delivery lead times or insufficiently defined logistical costs can significantly impair the competitiveness of companies.

As a result of the foregoing, the objective was to develop a general supplier selection method for companies producing commissioned dietary supplements that are suitable for taking into account relevant aspects as well as for single and multi-stakeholder decision-making. The chapter also describes the process of supplier selection, the criteria to be examined and the method of deciding on supplier selection.

3.1 Supplier selection process

The task of selecting a supplier is to provide the company with raw materials according to the need and cost saving in the range, quantity, quality, and time required by the company's operations or production program [37]. The following is the process of selecting a supplier based on practical experience and analysis of the literature [41-42].

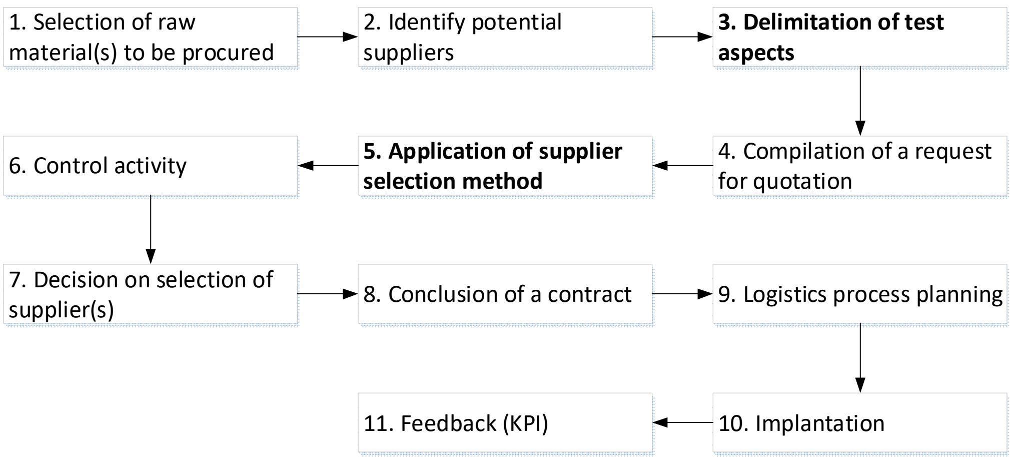

Figure 4 Supplier selection process [Source: Own Edit]

Process steps (Figure 5):

Step 1. The inventory policy of the central manufacturer and the commissioning company determines the range of raw materials to be procured.

Step 2. Based on the raw materials to be procured, the suppliers involved in the study will be selected. Relevant sources of information collection:

- corporate relationship system (former suppliers, etc.),

- information from a consulting firm,
- internet search.

Step 3. Central manufacturing and commissioning companies determine the test criteria that are important to them based on the raw material(s) to be procured.

Step 4. When compiling a request for proposals, particular attention should be paid to the objective and easy evaluation of tenders relating to the selected test criteria.

Step 5. Suppliers that are the best alternative based on the test criteria set out in Step 3 will be selected using the supplier selection method.

Step 6. Control activities should ensure the establishment of controls to reduce risks to the achievement of organizational objectives, including the soundness of the offer from selected suppliers. The control activity should also cover the economical, efficiency and efficiency adequacy of suppliers.

Step 7. Following the steps described in the previous steps, optimal suppliers will be selected.

Step 8. The selected supplier is contacted by the central logistics and production company, and the supplier contract is concluded on the basis of the above given quotation. In relation to the service contract, it is necessary to clearly define the powers, the possibilities for sanctioning and premeditation, and the indicators attached to them.

Step 9. After the conclusion of the contract, the procurement logistics process (activities, tools used, scheduling, etc.) must be planned.

Step 10. The implementation and testing of the specified purchasing system will be carried out.

Step 11. In order to enforce the sanctions and premeditation options set out in the service contract, the indicators of the operating system will be monitored.

3.2 *Definition of the test criteria*

Supplier selection criteria can take into account qualitative and quantitative aspects, which can be interpreted as a minimizing or maximizing objective function component. The logistic indicators described up to (1) ... (5) describe the quantitative aspects to be taken into account, and the logistic indicators described up to (6)… (8) describe the definition of the values of the qualitative aspects. These relevant indicators are defined below.

3.2.1 Order lead time

The lead time can be interpreted between two arbitrary points in the logistics chain. One of the basic principles of its calculation when purchasing is that parallel events should be considered the longest. The expected lead time (average time) and its standard deviation are taken into account.

When calculating the order lead time, we calculate the general case that the raw materials, regardless of whether they are supplied directly or indirectly, are ordered at the previous stage, i.e., the distribution warehouse of an indirect supplier, and from there the raw material demand can be directly met. The order lead time can be calculated in the same way for direct and indirect supply [41].

In the case of raw material r, v. the supplier may be given the order lead time (1) on the basis of the relationship:

$$t_{r,v}^{B} = t_{r,v}^{BE} + t_{r,v}^{BCS} + t_{r,v}^{BS} + t_{r,v}^{BW}, [\text{hour}] \qquad (1)$$

where:

- $t_{r,v}^{B}$: the total order lead time for r. raw material at the v. supplier,
- $t_{r,v}^{BE}$: the preparation time after ordering at the v. supplier in the case of r. raw material (purchase and manufacture of components for raw materials),
- $t_{r,v}^{BCS}$: post-order packing time and ERKE training time at the v. supplier in the case of r. raw material,
- $t_{r,v}^{BS}$: delivery time after order in the case of r. raw material at the v. supplier,
- $t_{r,v}^{BW}$: waiting time (storage) time after ordering at the v. supplier in the case of r. raw material.

The main factors influencing the order lead time in the case of dietary supplemental raw materials, the supplier's distance from the central production plant, the flexibility of the supplier's production equipment, production programming, the mode of transport, the characteristics of the means of transport, the purchase of raw materials, the flexibility of the purchase of packaging material, the possibility of delivery from stock, the size of the available stocks and the customs procedure time.

The values determined on the basis of the (1) shall be recorded in matrix form:

$$\mathrm{T}^{\mathrm{B}} = \left[\mathrm{t}_{\mathrm{r,v}}^{\mathrm{B}}\right], [\text{hour}] \qquad (2)$$

where the matrix contains the total order lead time for the v. supplier for r. raw material

3.2.2 Total acquisition cost

The purchase price of the raw material for the dietary supplements to be sold significantly affects the available margin weight. It directly affects expenditure since the purchase value of goods sold is a significant cost factor for commercial enterprises. However, it also affects turnover indirectly, as the purchase price affects the sales price, including the quantity that can be sold. The components of the actual purchase price for a product are the price invoiced by the vendor, the separate cost of the purchase, and the preferences or preferences associated with the purchase of the product.

The price at which companies producing food supplements that sell them commissioned manages to obtain their raw materials from their supplier partners depends on several factors. The validated purchase price of the product is influenced by its quality and earned value, the long term business relationship, the quantity of the goods purchased, and the use of ancillary services related to the purchase. However, behind this apparent diversity lies essentially two factors affecting the invoiced price established by the supplier. These are the inputs related to the production and distribution of the product and the market position of the product. In addition to the invoiced price less discounts plus surcharges, all expenses are included in the purchase price, which are individually linked to the raw material until it is delivered to the warehouse. These factors include freight costs, loading fees, product purchase costs, and customs clearance fees.

For r. raw material, the cost of the total purchase at the "v." supplier can be determined as follow:

$$k_{r,\mathrm{v}}^{B} = k_{r,\mathrm{v}}^{BF} + k_{r,\mathrm{v}}^{BR} + k_{r,\mathrm{v}}^{BB} + k_{r,\mathrm{v}}^{BV}, [\mathrm{EUR}] \quad (3)$$

where:

- $k_{r,\mathrm{v}}^{B}$: the total cost of purchase for r. raw material at the v. supplier,
- $k_{r,\mathrm{v}}^{BF}$: total freight costs up to arrival at the v. supplier in the case of r. raw material,
- $k_{r,\mathrm{v}}^{BR}$: all loading costs up to arrival at the v. delivery point in the case of r. raw material,
- $k_{r,\mathrm{v}}^{BB}$: the cost of purchase in the case of r. raw material at the v. supplier,
- $k_{r,\mathrm{v}}^{BV}$: customs clearance costs for r. raw material at the v. supplier.

Based on (3), the previous ones can be given in matrix form:

$$K^{B} = \left[k_{r,\mathrm{v}}^{B}\right], [\mathrm{EUR}] \quad (4)$$
$$(\, r = 1,2 \dots n\,), \quad (\, \mathrm{v} = 1,2 \dots m\,)$$

where the matrix contains the total acquisition cost for the "v." supplier for r. raw material.

3.2.3 Raw material quality

One of the most important factors in the creation of the product is the quality of the purchased raw material. By increasing the quality of the ordered raw material, the concentration of the active substance in it, the purchase price increases, and the production time of the ordered raw material increase, but the quantity of raw material ordered decreases, since the quantity of active ingredient prescribed in the formula can be satisfied with fewer raw materials. It can be said that the quality of the raw material can be related to the cost of purchasing the ordered raw material and its order lead time. This is not typical, but there may be cases where a raw material contains several components, in which case it is necessary to prepare and manage several quality matrices. The developed method is presented on a basic ingredient, which can be easily extended to several components.

On this basis, the matrix N^{B} can be determined, which for each supplier contains the value of the raw material concentration for each product purchased:

$$N^{B} = \left[n_{r,\mathrm{v}}^{B}\right], [\%] \quad (5)$$
$$(\, r = 1,2 \dots n\,),\ (\, \mathrm{v} = 1,2 \dots m\,).$$

3.2.4 Environmental impact of logistics process

The environment, which is becoming increasingly important in all areas of social and economic life today, also has high expectations of logistics. It has a significant impact, for example, on procurement, the use of environmentally friendly recyclable materials, the use of so-called 'green' technologies, the collection and handling of hazardous substances and the environmental impact values of vehicles for transport [43].

An increasingly important aspect of the development of supply chains is to reduce emissions in the logistical process of deliveries. To take this into account, the environmental load matrix (6) of logistics processes is defined, where the subjective, individual competence of the company is entrusted to evaluate each supplier on a scale of 1 to 10 (1=worst, 10=best).

$$E^{B} = \left[e_{r,\mathrm{v}}^{B}\right], [\mathrm{point}] \quad (6)$$

3.2.5 Modernity of the supplier's logistics system

A key issue in the selection process may be the modernity of the logistics system of suppliers. This aspect affects both the cost and quality of the procurement process. To take this into account, a matrix (7) determining the modernity of the supplier's logistics system is defined, where the company subjectively evaluates suppliers on a scale of 1 to 10 (1=worst, 10=best).

$$P^{B} = \left[p_{r,\mathrm{v}}^{B}\right], [\mathrm{point}] \quad (7)$$
$$(\, r = 1,2 \dots n\,), \quad (\, \mathrm{v} = 1,2 \dots m\,).$$

3.2.6 Reliability

On the basis of financial and supplier reference data, account should be taken of the reliability of a particular supplier, as the supply of raw materials may result in risks if an unstable supplier is selected. The reliability matrix (8) is defined to validate this aspect, where the company scores its suppliers between 1.10 as described in the previous criterion (1=worst, 10=best).

$$M^{B} = \left[m_{r,\mathrm{v}}^{B}\right], [\mathrm{point}] \quad (8)$$
$$(\, r = 1,2 \dots n\,),\ (\, \mathrm{v} = 1,2 \dots m\,).$$

3.3 *Description of the supplier selection decision method*

With regard to the supplier selection method, a multi-faceted decision-making method has been developed, the important element of which is the definition and normalization of the limitation of the selected logistical indicators and the application of the Churchman-Ackoff weighting method.

Steps to apply the method:

Step 1: Define logistical indicators to be minimized and maximized, grouped as follows.

Components to minimize:
- total costs related to delivery,
- total lead time of purchase,
- environmental impact of the logistics process,

Components to maximize:
- quality of raw material,
- the modernity of the supplier's logistics system,
- supplier's reliability.

Step 2: Define supplier selection criteria. In this step, the criteria for supplier selection are defined in paragraph 1. (8) by specifying restrictive conditions for relationships.

Total lead time: In order to meet customer needs in a timely manner, it is important to set the maximum expected lead time:

$$t_r^B \leq t_{r,max}^B \tag{9}$$

Total cost of procurement: In order to ensure the competitiveness of the company, it is important to fix the maximum possible acquisition cost for the selection of suppliers:

$$k_r^B \leq k_{r,max}^B \tag{10}$$

Environmental impact of the logistics process: Using the "green" technologies used by the supplier, it is important to record the maximum environmental load on the basis of the collection and handling of hazardous substances and the environmental load values of the vehicles during transport:

$$e_r^B \leq e_{r,max}^B \tag{11}$$

Raw material quality: In order to comply with the formula prescribed for the production, a minimum or upper raw material concentration may be set in order to comply with the formula prescribed for the supply of raw materials:

$$n_{r,min}^B \leq n_r^B \leq n_{r,max}^B \tag{12}$$

In terms of the modernity and reliability of the supply supplier's logistics system, lower limits may be laid down, for which there is a:

$$p_{r,min}^B \leq p_r^B \tag{13}$$
$$m_{r,min}^B \leq m_r^B \tag{14}$$

Step 3: Define reduced matrices. In this step, the values of matrix (1) to (8) are modified based on the conditionality described in Step 2. Formally, this means that all reduced matrices are marked with one override.

Step 4: Normalize logistical indicators. In this respect, the value of each target function component is transformed from 0 to 1. It can be seen that there are two types of target function components in the optimization task, there are three minimization functions (15), (18), (25) and three maximizing target functions (21), (28), (32). They should be managed together during optimization. Co-treatment requires that all target functions be either maximized or minimized. In the developed method, the minimizing target function components have been left unchanged, the maximizing target functions have been converted into minimizing target function components.

Normalization of logistical indicators:

Normalization of purchase cost matrix values: The relationship (15) is given for r. raw material in terms of the optimal v. supplier for all transport costs. Then, for all values, formula (16) can be used to determine the normalized target function components.

$$K_r^{B\prime} = \min_{\mathrm{v}}\{k_{r,\mathrm{v}}^{B\prime}\};\ (v = 1,2,\dots,m;\ r = 1,2,\dots,n) \tag{15}$$
$$(r \text{ belongs to a } \mathrm{v}_{opt})$$
$$\gamma_{r,\mathrm{v}}^1 = \frac{K_r^{B\prime}}{k_{r,\mathrm{v}}^{B\prime}};\ (v = 1,2,\dots,m;\ r = 1,2,\dots,n) \tag{16}$$
$$0 < \gamma_{r,\mathrm{v}}^1 \leq 1 \tag{17}$$

Normalization of the procurement lead time matrix: Based on the relationship (18), the optimal v. supplier for r. raw material is the total lead time related to the supply. The normalized target function components can then be determined using formula (19) for all values:

$$T_r^{B\prime} = \min_{\mathrm{v}}\{t_{r,\mathrm{v}}^{B\prime}\};\ (v = 1,2,\dots,m;\ r = 1,2,\dots,n) \tag{18}$$
$$(r \text{ belongs to a } \mathrm{v}_{opt})$$
$$\gamma_{r,\mathrm{v}}^2 = \frac{T_r^{B\prime}}{t_{r,\mathrm{v}}^{B\prime}};\ (v = 1,2,\dots,m;\ r = 1,2,\dots,n) \tag{19}$$
$$0 < \gamma_{r,\mathrm{v}}^2 \leq 1 \tag{20}$$

Normalization of quality matrix values: Based on the relationship (21), the optimal v. supplier for r. raw material is the quality (concentration) of the raw material related to the supply. Quality components are normalized using the relationship (22).

$$N_r^{B\prime} = \max_{\mathrm{v}}\{n_{r,\mathrm{v}}^{B\prime}\};\ (v = 1,2,\dots,m;\ r = 1,2,\dots,n) \tag{21}$$
$$(r \text{ belongs to a } \mathrm{v}_{opt})$$
$$\gamma_{r,\mathrm{v}}^3 = 1 - \frac{n_{r,v}^{B\prime}}{N_r^{B\prime}};\ (v = 1,2,\dots,m;\ r = 1,2,\dots,n) \tag{22}$$
$$0 < \gamma_{r,\mathrm{v}}^3 \leq 1 \tag{23}$$

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Normalization of the environmental load of the procurement logistics process: Based on the relationship (24), the optimal v. supplier for r. raw material is the environmental burden of the supply related procurement logistics process. Quality components are normalized using the relationship (25):

$$E_r^{B\prime} = \min_{\mathrm{v}} \{e_{r,\mathrm{v}}^{B}{}'\};\ (v = 1,2,\dots,m;\ r = 1,2,\dots,n) \quad (24)$$

$(r$ belongs to a $\mathrm{v}_{opt})$

$$\gamma_{r,\mathrm{v}}^4 = \frac{E_r^{B}{}'}{e_{r,\mathrm{v}}^{\mathrm{B}}{}'}\ ;\ (v = 1,2,\dots,m;\ r = 1,2,\dots,n) \quad (25)$$

$$0 < \gamma_{r,\mathrm{v}}^4 \le 1 \quad (26)$$

Normalization of the logistics system of suppliers: Based on the relationship (27), the optimal v. supplier for r. raw material is the modernity of the supplier logistics system related to the supply. Quality components are normalized using the relationship (28):

$$P_r^{B\prime} = \max_{\mathrm{v}} \{p_{r,\mathrm{v}}^{B}{}'\};\ (v = 1,2,\dots,m;\ r = 1,2,\dots,n) \quad (27)$$

$(r$ belongs to a $\mathrm{v}_{opt})$

$$\gamma_{r,\mathrm{v}}^5 = 1 - \frac{p_{r,\mathrm{v}}^{B}{}'}{P_{\mathrm{v}}^{\mathrm{B}}{}'};\ (v = 1,2,\dots,m;\ r = 1,2,\dots,n) \quad (28)$$

$$0 < \gamma_{r,\mathrm{v}}^5 \le 1 \quad (29)$$

Normalisation of supplier reliability: Based on the relationship (30), the optimal v. supplier for r. raw material is the supplier's reliability in relation to supply. Then, for all values, formula (31) can be used to determine the normalized target function components:

$$M_r^{B\prime} = \max_{\mathrm{v}} \{m_{r,\mathrm{v}}^{B}{}'\};\ (v = 1,2,\dots,m;\ r = 1,2,\dots,n) \quad (30)$$

$(r$ belongs to a $\mathrm{v}_{opt})$

$$\gamma_{r,\mathrm{v}}^6 = 1 - \frac{M_r^{B}{}'}{m_{r,\mathrm{v}}^{\mathrm{B}}{}'};\ (v = 1,2,\dots,m;\ r = 1,2,\dots,n) \quad (31)$$

$$0 < \gamma_{r,\mathrm{v}}^6 \le 1 \quad (32)$$

Step 5: Weighting normalized target function components. As the importance of target functions is generally different, target function values should be weighted according to their importance [44]. The weighting factors for the target functions are set to η_1; η_2; η_3; η_4; η_5; η_6 which the Churchman-Ackoff weighting method was used to determine. The method basically relies on the values of a single professional person but can be easily extended to the assessment of several persons if necessary [45].

Steps of Churchman-Ackoff's weighting method [46]:

Step 1. Sorting logistics indicators according to their importance (C_1 most important, then $C_2, \dots, C_6$).
Step 2. The weight of aspect C_1 is taken as 1, and then the weight of the other aspects relative to C_1 must be given ($W_1, W_2, \dots, W_6$). In order to increase the reliability of the estimate, each aspect should be compared with groups that can be formed from all aspects. For example C_1 $with$ $\{C_2, \dots, C_6\}, \{C_2, \dots, C_{n-1}\}, \dots, \{C_2, \dots, C_3\}$. If C_1 is more important, but the inequality given by the initial weights does not prove this, the value of W_1 must be adjusted so that the inequality is satisfied (if less, if equal is the same principle.
Step 3. Compare C_2 with $\{C_3, C_4, \dots, C_6\}$ as in step 2.
Step 4. Continue the comparisons until a comparison of C_{6-2} and $\{C_{6-1}, C_p\}$ is obtained.
Step 5. Divide the weight of each aspect by $\sum_{l=1}^{p} W_l$, thereby gaining the weights described in the relationship (33), the sum of which will be 1.

Factors $\eta_1 - \eta_6$ are subject to the relationships (33):

$$\begin{array}{lll} 0 < \eta_1 \le 1, & 0 < \eta_2 \le 1, & 0 \le \eta_3 < 1 \\ 0 < \eta_4 \le 1, & 0 < \eta_5 \le 1, & 0 \le \eta_6 < 1 \end{array} \quad (33)$$
$$\sum_{i=1}^{6} \eta_i = 1$$

Step 6: Define a target function. Weighted target function values are defined as follows:

$$E_{r,\mathrm{v}} = \gamma_{r,\mathrm{v}}^1 \cdot \eta_1 + \gamma_{r,\mathrm{v}}^2 \cdot \eta_2 + \gamma_{r,\mathrm{v}}^3 \cdot \eta_3 + \gamma_{r,\mathrm{v}}^4 \cdot \eta_4 + \gamma_{r,\mathrm{v}}^5 \cdot \eta_5 + \gamma_{r,\mathrm{v}}^6 \cdot \eta_6 \quad (34)$$

where the matrix $E_{r,\mathrm{v}}$ contains the weighted target function values by r. raw material and v. supplier.

The optimal supplier for r. raw material can be defined as follows:

$$U_r = \min_{\mathrm{v}}\{E_{r,\mathrm{v}}\} \quad (35)$$
$$(r = 1,2 \dots n)$$

where U_r the minimum value of the target function for r. raw material to which the proposed supplier (v_{opt}).

4 Conclusions

The publication presented a novel supplier selection method for companies producing commissioned dietary supplements, which could enable the supply chains of those companies to be developed more efficiently. Furthermore, prior to this, the literature on existing supplier selection methods was explored using the method of systematic literature research.

The results described can be used for the practice primarily for companies engaged in the placement of commission and commission stocks. A test method can be presented for a specific example, and with minimal correction it can be applied to all supply chain types.

However, in order to properly explore all possible application cases, a rigorous testing phase would be further required, during which all the possible combinations of the utilized parameters could be examined and a detailed sensitivity analysis could be implemented. This would be especially important in relation to the environmental impact, the modernity and the reliability indicators, which are used to quantify complex and qualitative aspects of the supplier selection criteria. Similarly, it would be also useful for validating the determined weights of the indicators in a given application. Therefore, the next forthcoming step in the research will be the realization of such a testing program, which can significantly contribute to the wider scale applicability of the developed method.

A main objective of the research was also to explore and implement the longer term possibilities for further development of the introduced test method. A number of further development options can be described, among which the extension of the test model to the operation of commissioned sales companies with several central warehouses and production plants, as well as the development of a computerized web application for the application of test methods at the enterprise level. By implementing these further development ideas, it may be possible to create a decision support tool that can be used in a way that can be used extensively and easily by any commission sales company during the supplier selection process.

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Review process

Single-blind peer review process.