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METHOD OF SELECTION OF SUPPLIERS OF DIETARY SUPPLEMENT MANUFACTURING COMPANIES

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Abstract: Literature analyzes show that there are a huge number of supplier selection methods in a wide variety of fields, however, there is little literature on medicine or dietary supplements. Among these publications, there is no developed method that would provide a general solution for the selection of a supplier of all food supplement companies. Some of the methods do not take into account quality parameters (eg. concentration, transport error rate, etc.) and others do not take into account aspects related to environmental protection, which is becoming more and more important nowadays. In the dissertation, a general decision-making method for the selection of suppliers of food supplement manufacturing companies is presented, which takes into account the logistical and environmental parameters in both qualitative and quantitative terms. The method presented in the dissertation is described through an example.
Keywords: supplier selection, dietary supplements, logistics

1. INTRODUCTION

A significant portion of supplier selection methods focus on the automotive industry [1, 2, 3], however, a number of methods have also been developed for dietary supplement manufacturing and pharmaceutical companies [4, 5, 6, 7]. It can be seen that some of these selection methods focus strictly on costs, while other methods focus on quality or environmental protection, however, a logistical approach has not been developed in detail so far. One of the most diverse literature [7], which provides a summary analysis of several publications in the field of supplier selection [8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20], also does not take sufficient account of logistical considerations.
For companies producing food supplements, this aspect is particularly important, as late deliveries, long lead times or improperly defined logistics costs can significantly impair companies' competitiveness.

In the dissertation, I aimed to develop a general supplier selection method for consignment selling dietary supplements manufacturing companies that is suitable for taking into account the shortcomings identified in the literature, as well as for taking into account relevant aspects, as well as for single- and multiplayer decision-making. The chapter also describes the supplier selection process, the aspects to be examined, and the supplier selection decision method [21, 22, 23, 24, 25, 26]. The dimension of the quantitative values may differ depending on the company under study, so the presented method does not include the dimensions. The example described in the dissertation provides an easier understanding of the method.

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2. THE IMPACT OF THE FOURTH INDUSTRIAL REVOLUTION

The task of selecting a supplier is to provide the company with the raw materials in the range, quantity, quality and time required by the company's operation or production program, as required and cost-effectively [17]. In the following, the process of supplier selection determined on the basis of my practical experience and the analysis of the literature [26, 27, 28] is presented.

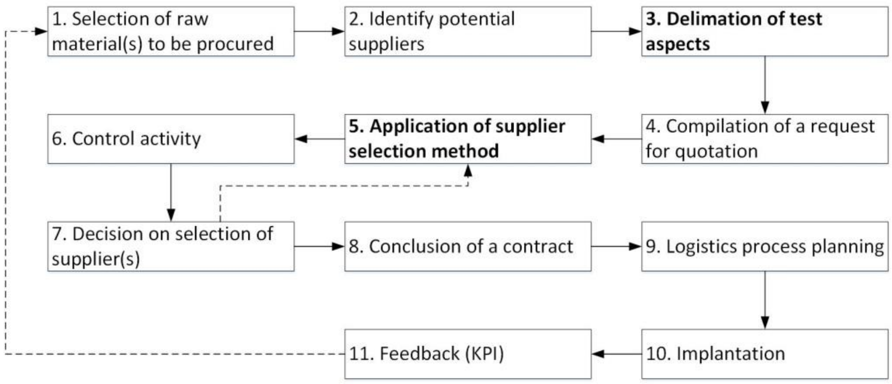

Figure 1. Supplier selection process [Source: Own edit]

Process steps [26] (Figure 1.):

1. step: Based on the inventory policy of the central manufacturer and the consignor company, the range of raw materials to be procured is determined.
2. step: Based on the raw materials, the suppliers to be included in the study are selected. Relevant sources of information collection:
    - corporate relationship system (former suppliers, etc.),
    - information from a consulting firm,
    - internet search.
3. step: The central manufacturing and consignor company determines the test criteria that are important to them based on the raw material(s) to be procured.
4. step: When compiling the call for tenders, special attention should be paid to ensuring that tenders related to the selected test criteria can be evaluated objectively and easily.
5. step: Using the supplier selection method, the suppliers that are the best alternative based on the test criteria outlined in Step 3 are selected.
6. step: In the case of control activities, it is necessary to ensure the establishment of controls aimed at reducing the risks endangering the achievement of organizational goals, and thus the validity of the offer of the selected suppliers. The control activity should also cover the adequacy of suppliers in terms of economy, efficiency and effectiveness.
7. step: Following the steps described in the previous steps, the optimal suppliers are selected. If the selection process fails due to the lack of suitable supplier(s), it may be necessary to modify the decision method parameters in step 5.

8. step: The selected supplier is contacted by the central logistics and manufacturing company and then the supplier contract is concluded based on the price offer given above. In connection with the service contract, the powers, the possibilities of sanctions and bonuses, as well as the indicators attached to them must be clearly defined.
9. step: After concluding the contract, the procurement logistics process (activities, tools used, schedule, etc.) should be planned.
10. step: The implementation and testing of the defined procurement system will be performed.
11. step: In order to enforce the sanctioning and premissing options set out in the service contract, the indicators of the operating system will be monitored. If the KPIs determined on the basis of the activity performed by the logistics service provider do not meet the expectations set in the service contract, a new supplier selection process may be initiated.

3. DEFINING 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 in *relation (3.1.)…(3.5.)* describe the definition of the quantitative aspects to be taken into account, and the logistic indicators described in *relation (3.6.)…(3.8.)* describe the definition of the values of the qualitative aspects. These relevant indicators are defined below [26].

3.1. Order lead time

The leadtime can be interpreted between any two points in the logistics chain. One of the principle sused in the calculation of the procurement is that thelongest should be taken into account in parallel events. The expected value of the leadtime (meantime) and its standard deviation are only taken into account.

When calculating the order leadtime, we take into account the general case that the rawmaterials, regardless of whether they are supplied directly or indirectly, are ordered at the previous stage, ie at the indirect supplier's distribution warehouse, and the raw material demand can be met directly from there. The order leadtime can be calculated in the same way for direct and indirect supply [26, 27].

In the case of the *r*-th rawmaterial, the order leadtime at the *v*-th supplier can be specified on the basis of the *relation* (*3.1.)*:

$$t_{r,v}^{B} = t_{r,v}^{BE} + t_{r,v}^{BCS} + t_{r,v}^{BS} + t_{r,v}^{BW}, \tag{3.1}$$

where:

- $t_{r,v}^{B}$: the total order lead time for *r*-th rawmaterial, at the *v*-th supplier,
- $t_{r,v}^{BE}$: preparation time after order for *r*-th raw material, at the *v*-th supplier (procurement and production of components required for raw materials),
- $t_{r,v}^{BCS}$: packing time after order and unit cargo formation time for *r*-th raw material, at the *v*-th supplier,
- $t_{r,v}^{BS}$: delivery time after order for *r*-th raw material, at the *v*-th supplier,

- $t_{r,\mathrm{v}}^{BW}$: waiting time (storage) time after order for *r*-th raw material, at the *v*-th supplier.

The main factors influencing the order lead time for dietary supplementary raw materials: the distance of the supplier from the central production plant, the flexibility of the supplier's production equipment, production programming, mode of transport, means of transport equipment, raw material procurement, packaging procurement flexibility, the amount of stocks available, and the time of the customs procedure [26].

The values determined on the basis of *relation (3.1.)* must be recorded in the form of a matrix:

$$T^B = \left[t_{r,\mathrm{v}}^B\right], \quad (r = 1,2 \ldots n), \quad (\mathrm{v} = 1,2 \ldots m), \tag{3.2.}$$

where the matrix contains the total order lead time forr-th raw material, at the *v*-th supplier.

3.2. Total purchase cost

The raw material purchase price of the sold dietary supplements has a significant impact on the available margin weight. It has a direct effect on expenditure, as a significant cost factor for commercial enterprises is the purchase value of the goods sold. However, it also indirectly affects sales revenue, as the purchase price also affects the sales price, and thus the quantity that can be sold. The components of the actual purchase price of a product are the price invoiced by the supplier, the specific cost of the purchase, and the preferences or disparities associated with the purchase of the product.

The price at which consignment seller dietary supplements manufacturing companiescan 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 demand, the long-term business relationship, the quantity of the purchased goods, and the use of additional services related to the purchase. However, there are basically two factors behind this apparent diversity that affect the price charged by the supplier. These are the costs associated with the production and distribution of the product and the market position of the product. In addition to the invoiced price reduced by discounts and increased by surcharges, all expenses are individually related to the purchase price until the delivery of the given raw material to the warehouse. Such factors include freight costs, loading charges, the cost of purchasing the product, and the customs clearance fee [26].

The total purchase cost in the case of *r*-thraw materials, at the *v*-th supplier can be given on the basis of *relation (3.3)*:

$$k_{r,\mathrm{v}}^B = k_{r,\mathrm{v}}^{BF} + k_{r,\mathrm{v}}^{BR} + k_{r,\mathrm{v}}^{BB} + k_{r,\mathrm{v}}^{BV}, \tag{3.3.}$$

where:

- $k_{r,\mathrm{v}}^B$: the total purchase cost for *r*-th rawmaterial, at the *v*-th supplier,
- $k_{r,\mathrm{v}}^{BF}$: the total freight cost for *r*-th rawmaterial, at the *v*-th supplier,
- $k_{r,\mathrm{v}}^{BR}$: the total loading cost for *r*-th rawmaterial, at the *v*-th supplier,
- $k_{r,\mathrm{v}}^{BB}$: the purchase cost for *r*-th rawmaterial, at the *v*-th supplier,

- $k_{r,v}^{BV}$: the customs clearance fee for *r*-th rawmaterial, at the *v*-th supplier.

Based on the *relation (3.3.)* I also give the previous ones in matrix form:

$$K^B = \left[k_{r,v}^B\right], \quad (r = 1,2 \dots n), \quad (v = 1,2 \dots m), \tag{3.4.}$$

where the matrix contains the total purchase cost for *r*-th raw material, at the *v*-th supplier.

3.3. Raw material quality

One of the most important factors in the production 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 ingredient in it increases, at the same time the purchase price increases, the production time of the ordered raw material increases, but the amount of the ordered raw material decreases. It can be said that the quality of the raw material can be related to the purchase cost of the ordered raw material as well as the order lead time. It is not typical, but there may be cases when a raw material contains several components, in which case it is necessary to prepare and handle several quality matrices. In the dissertation, the developed method is presented for one raw material component, which can be easily extended to several components.

Based on these, I determined the N^B *matrix (3.5.)*, which for each supplier contains the value of the raw material concentration for each procured product [26]:

$$N^B = \left[n_{r,v}^B\right], \quad (r = 1,2 \dots n), \quad (v = 1,2 \dots m). \tag{3.5.}$$

3.4. Environmental impact of the logistics process

Environmental protection, which is playing an increasingly important role in all areas of social and economic life today, also places serious demands on logistics. For example, it has a significant impact on procurement, requiring production to use environmentally friendly and recyclable materials, using so-called "green" technologies, collecting and handling hazardous materials, and setting transport vehicle’s environmental load value [26, 29].

Reducing emissions in terms of the logistics process of supplies is becoming increasingly important in the design of supply chains. To take this into account, I defined the matrix of environmental impact of logistics processes *(3.6.)*, In which the subjective, individual competence of the company is to evaluate each supplier on a scale of 1-10 (1 = worst, 10 = best).

$$E^B = \left[e_{r,v}^B\right], \quad (r = 1,2 \dots n), \quad (v = 1,2 \dots m). \tag{3.6.}$$

3.5. Modernity of the supplier's logistics system

A key issue in the selection process can be the modernity of the suppliers' logistics system. This aspect affects both the cost and the quality of the procurement process. To take this aspect into account, I defined the matrix determining the modernity of the supplier's logistics system *(3.7.)*, in which the company subjectively evaluates suppliers on a scale of 1-10 (1 = worst, 10 = best).

$$P^B = \left[p^B_{r,\mathrm{v}}\right], \quad (r = 1,2 \dots n), \quad (\mathrm{v} = 1,2 \dots m). \tag{3.7.}$$

3.6. Reliability

Based on financial and supplier reference data, the reliability of a given supplier should be taken into account, as the selection of a supplier with unstable situation can lead to risks in the transport of raw materials. To validate this aspect, I defined the reliability matrix *(3.8.)*, in which the company scores its suppliers between 1-10 (1 = worst, 10 = best) as described in the previous aspect.

$$M^B = \left[m^B_{r,\mathrm{v}}\right], \quad (r = 1,2 \dots n), \quad (\mathrm{v} = 1,2 \dots m). \tag{3.8.}$$

4. DESCRIPTION OF THE SUPPLIER SELECTION DECISION METHOD

With regard to the supplier selection method, a multi-criteria decision method has been developed, an important element of which is the determination and normalization of the limitation of the selected logistics indicators and the application of the Churchman-Ackoff weighting method.

Method application steps [26]:

Step 1: Identify the logistics indicators to be minimized and maximized, which are grouped as follows.

Components to be minimized:

- all costs related to delivery,
- the total lead time of the procurement,
- the environmental impact of the logistics process,

Components to maximize:

- the quality of the raw material,
- the modernity of the supplier's logistics system,
- supplier reliability.

Step 2: Define the supplier selection criteria system. In this step, the system of supplier selection conditions is defined by specifying restrictive conditions *(3.1.)…(3.8.)*.

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

$$t_r^B \leq t_{r,max}^B \quad (3.9.)$$

Total procurement cost: In order to ensure the competitiveness of the company, it is important to set a maximum possible procurement cost for the selection of suppliers, for which it is necessary to:

$$k_r^B \leq k_{r,max}^B \quad (3.10.)$$

Environmental impact of the logistics process : Using the "green" technologies used by the supplier, the collection and treatment of hazardous materials, as well as the maximum environmental impact of the vehicles generated during delivery, it is important to limit the maximum environmental impact, for which*:*

$$e_r^B \leq e_{r,max}^B \quad (3.11.)$$

Raw material quality: With regard to the quality of the supplied raw material, in order to comply with the recipe prescribed in the production, a lower or upper raw material concentration limit may be specified, for which there is:

$$n_{r,min}^B \leq n_r^B \leq n_{r,max}^B \quad (3.12.)$$

In terms of the modernity and reliability of the supplier's logistics system for supply, the following limits can be set, for which:

$$p_{r,min}^B \leq p_r^B \quad (3.13.)$$
$$m_{r,min}^B \leq m_r^B \quad (3.14.)$$

Step 3: Determination of reduced matrices. Within the framework of this step, the values of the matrix *(3.1.)…(3.8.)* are modified based on the system of conditions described in step 2. Formally, this means that all reduced matrices are marked with an overbar ($'$).

Step 4: Normalize logistics indicators. In this regard, the values of all components of the objective function are transformed between 0 and 1. It can be seen that there are two types of objective function components in the optimization problem, there are three minimizing *(3.15., 3.18., 3.25.)* And three maximizing objective functions *(3.21., 3.28., 3.32.)*. These should be handled together during optimization. The condition for co-treatment is that all components of the objective function are brought to either a maximizing only or a minimizing only form. In the developed method I leave the minimizing objective function components unchanged, I transform the maximizing objective functions into minimizing objective function components.

Normalization of logistics indicators:

- Normalization of purchase cost matrix values: The *relation (3.15)* gives the optimal *v*-th supplier for *r*-th raw materialsin terms of total delivery costs. Then, for all values, the components of the normalized objective function can be determined using *formula (3.16)*.

$$K_r^{B\prime} = \min_{\mathrm{v}}\{k_{r,\mathrm{v}}^{B}{}'\}; \text{ (v =1,2,…m; r=1,2,….n),} \tag{3.15.}$$

(r has an assiciated$v$ *opt*),

$$\gamma_{r,\mathrm{v}}^{1} = \frac{K_r^{B}\prime}{k_{r,\mathrm{v}}^{B}\prime}, \text{ (v =1,2,…m; r=1,2,….n),} \tag{3.16.}$$

$$0 < \gamma_{r,\mathrm{v}}^{1} \leq 1 \; . \tag{3.17.}$$

- Normalization of the procurement lead time matrix: The *relation (3.18)* gives the optimal *v*-th supplier for *r*-th raw materials in terms of total lead time for delivery. The normalized objective function components can then be determined for each value using *formula (3.19)*:

$$T_r^{B\prime} = \min_{\mathrm{v}}\{t_{r,\mathrm{v}}^{B}{}'\}; \text{ (v =1,2,….m; r=1,2,….n),} \tag{3.18.}$$

(r has an assiciated$v$ *opt*),

$$\gamma_{r,\mathrm{v}}^{2} = \frac{T_r^{B}\prime}{t_{r,\mathrm{v}}^{\mathrm{B}}\prime}, \text{ (v =1,2,…m; r=1,2,….n),} \tag{3.19.}$$

$$0 < \gamma_{r,\mathrm{v}}^{2} \leq 1 \; . \tag{3.20.}$$

- Normalization of quality matrix values: The *relation (3.21)* gives the optimal *v*-th supplier for *r*-th raw materials in terms of the quality (concentration) of the raw material related to the supply. The normalization of the quality components is done using the *relation (3.22)*.

$$N_r^{B\prime} = \max_{\mathrm{v}}\{n_{r,\mathrm{v}}^{B}{}'\}; \text{ (v =1,2,….m; r =1,2,….n),} \tag{3.21.}$$

(r has an assiciated$v$ *opt*),

$$\gamma_{r,\mathrm{v}}^{3} = 1 - \frac{n_{r,v}^{B}\prime}{N_r^{\mathrm{B}}\prime}, \text{ (v =1,2,…m; r=1,2,….n),} \tag{3.22.}$$

$$0 \leq \gamma_{r,\mathrm{v}}^{3} < 1 \; . \tag{3.23.}$$

- Normalization of the environmental load of the procurement logistics process: The *relation (3.24)* gives the optimal *v*-th supplier for *r*-th raw materials in terms of the environmental impact of the procurement logistics process related to delivery. The normalization of the quality components is done using the *relation (3.25)*.

$$E_r^{B\prime} = \min_{\mathrm{v}}\{e_{,\mathrm{v}}^{B\prime}\}; \text{ (v =1,2,….m; r=1,2,….n),} \tag{3.24.}$$

(r has an assiciated$v$ *opt*),

$$\gamma_{r,\mathrm{v}}^{4} = \frac{E_r^{B}\prime}{e_{r,\mathrm{v}}^{\mathrm{B}}\prime}, \text{ (v =1,2,…m; r=1,2,….n),} \tag{3.25.}$$

$$0 < \gamma_{r,\mathrm{v}}^{4} \leq 1 \; . \tag{3.26.}$$

- Normalization of the modernity of the logistics system of suppliers: The *relation (3.27)* gives the optimal *v*-th supplier for *r*-th raw materials in terms ofthe modernity of the supplier logistics system related to delivery. The normalization of the quality components is done using the *relation (3.28)*.

$$P_r^{B\prime} = \max_{\mathrm{v}}\{p_{r,\mathrm{v}}^{B}{}'\};\ (\mathrm{v} = 1,2,\ldots.\mathrm{m};\ \ r=1,2,\ldots.\mathrm{n}\ ), \tag{3.27.}$$

(*r* has an assiciated*v opt*),

$$\gamma_{r,\mathrm{v}}^{5} = 1 - \frac{p_{r,v\prime}^{B}}{P_{\mathrm{v}}^{\mathrm{B}}{}\prime},\ (\mathrm{v} = 1,2,\ldots\mathrm{m};\ r=1,2,\ldots.\mathrm{n}\ ), \tag{3.28.}$$

$$0 \le \gamma_{r,\mathrm{v}}^{5} < 1\ . \tag{3.29.}$$

- Normalization of supplier reliability: The *relation (3.30)* gives the optimal *v*-th supplier for *r*-th raw materials in terms of delivery-related supplier reliability. Then, for all values, the normalized objective function components can be determined using *formula (3.31)*.

$$M_r^{B\prime} = \max_{\mathrm{v}}\{m_{r,\mathrm{v}}^{B}{}'\};\ (\mathrm{v} = 1,2,\ldots.\mathrm{m};\ r=1,2,\ldots.\mathrm{n}), \tag{3.30.}$$

(*r* has an assiciated*v opt*),

$$\gamma_{r,\mathrm{v}}^{6} = 1 - \frac{M_r^{B}{}\prime}{m_{r,v\prime}^{\mathrm{B}}},\ (\mathrm{v} = 1,2,\ldots\mathrm{m};\ r=1,2,\ldots.\mathrm{n}\ ), \tag{3.31.}$$

$$0 \le \gamma_{r,\mathrm{v}}^{6} < 1\ . \tag{3.32.}$$

Step 5: Weighting of normalized objective function components. Since the importance of objective functions generally varies, objective function values should be weighted according to their importance [24]. The weighting factors of the objective functions aremarked η_1; η_2; η_3; η_4; η_5; η_6, for which I used the Churchman-Ackoff weighting method. The method basically relies on the values of a single professional, but can easily be extended to the evaluation of several individuals if necessary [30].

Steps of Churchman-Ackoff's weighting method [31]:

- Step 1: Sort logistics indicators by their importance (C1 most important, then C2,…, Cp).
- Step 2: Take the weight of aspect C1 as 1 and then give the weight of the other aspects relative to C1 (W1, W2,…, Wp). To increase the reliability of the estimate, each aspect should be compared with groups that can be formed from all aspects. Eg .: C1 with {C2,…., Cp}, {C2,…., Cn-1},…, with {C2… C3}. If C1 is more important, but the inequality given by the initial weights does not prove this, the value of W1 must be modified so that the inequality is satisfied (if less, if equal the same principle must be followed).
- Step 3: Compare C2 with {C3, C4,…, Cp} as in step 2.
- Step 4: Continue the comparisons until a comparison of Cp-2 and {Cp-1, Cp} is obtained.
- Step 5: Divide the weight of each aspect by $\sum_{l=1}^{p} W_l$ to obtain the weights described in *equation (3.33)*, the sum of which will be 1.

The *relationships (3.33)* apply to the $\eta_1 - \eta_6$ factors:

$$0 < \eta_1 \leq 1\,; \quad 0 < \eta_2 \leq 1\,; \quad 0 \leq \eta_3 < 1\,;$$
$$0 < \eta_4 \leq 1\,; \quad 0 \leq \eta_5 < 1\,; \quad 0 \leq \eta_6 < 1\,; \qquad (3.33.)$$
$$\sum_{i=1}^{6} \eta_i = 1$$

- Step 6: Define the objective function. The weighted objective function values are determined as follows:

$$E_{r,\mathrm{v}} = \gamma_{r,\mathrm{v}}^{1} \cdot \eta_1 + \gamma_{r,\mathrm{v}}^{2} \cdot \eta_2 + \gamma_{r,\mathrm{v}}^{3} \cdot \eta_3 + \gamma_{r,\mathrm{v}}^{4} \cdot \eta_4 + \qquad (3.34.)$$

where the $E_{r,\mathrm{v}}$matrix contains the weighted objective function values according to *r*-th raw material and *v*-th supplier.

The optimal supplier of a *r*-th raw material can be determined as follows:

$$U_r = \min_{\mathrm{v}}\{E_{r,\mathrm{v}}\} \qquad (3.35.)$$
$$(r = 1,2 \dots n)$$

where U_r is the minimum value of the target function for *r*-th raw material, to which the proposed supplier (v_{opt}) belongs.

5. Demonstration of the practical applicability of the developed method

The practical applicability of the developed method presented in the dissertation and the verification of the correctness of the explained relations are presented through fictitious examples.

I. Selection of raw materials to be procured:

Based on the inventory policy of the central consignor and manufacturing company, it determines 5 types of raw materials to be procured, which are the following:

r1, r2, r3, r4, r5.

II. Identify potential suppliers:

Based on the raw materials to be procured, the suppliers to be included in the study are selected, which are as follows:

v1, v2, v3, v4, v5.

III. Delimitation of test criteria:

The examined company can obtain the raw materials (r1,…, r5) from the supplier (v1,…, v5), the order lead time, the total procurement cost, the quality of the raw material, the environmental impact of the logistics process, the modernity of the supplier's logistics system and the reliability of the contained in the following *matrices (4.1-4.6)*:

Order lead time:

$$T^B = \begin{array}{c} \\ r_1 \\ r_2 \\ r_3 \\ r_4 \\ r_5 \end{array} \begin{array}{c} \begin{array}{ccccc} v_1 & v_2 & v_3 & v_4 & v_5 \end{array} \\ \begin{bmatrix} 100 & 400 & 550 & 600 & 350 \\ 100 & 600 & 900 & 250 & 500 \\ 100 & 600 & 950 & 700 & 700 \\ 100 & 550 & 400 & 800 & 650 \\ 100 & 550 & 800 & 1000 & 600 \end{bmatrix} \end{array} \quad \text{[hour]} \qquad (4.1)$$

Total purchase cost:

$$K^B = \begin{array}{c} \\ r_1 \\ r_2 \\ r_3 \\ r_4 \\ r_5 \end{array} \begin{array}{c} \begin{array}{ccccc} v_1 & v_2 & v_3 & v_4 & v_5 \end{array} \\ \begin{bmatrix} 1200 & 120 & 110 & 110 & 170 \\ 650 & 290 & 120 & 220 & 300 \\ 500 & 280 & 250 & 200 & 180 \\ 900 & 620 & 700 & 450 & 750 \\ 750 & 420 & 320 & 250 & 390 \end{bmatrix} \end{array} \quad \text{[EUR/kg]} \qquad (4.2)$$

Raw material quality (concentration)

$$N^B = \begin{array}{c} \\ r_1 \\ r_2 \\ r_3 \\ r_4 \\ r_5 \end{array} \begin{array}{c} \begin{array}{ccccc} v_1 & v_2 & v_3 & v_4 & v_5 \end{array} \\ \begin{bmatrix} 75 & 75 & 65 & 80 & 80 \\ 80 & 75 & 70 & 85 & 80 \\ 90 & 95 & 90 & 85 & 70 \\ 58 & 59 & 70 & 75 & 60 \\ 85 & 90 & 87 & 78 & 90 \end{bmatrix} \end{array} \quad \text{[\%]} \qquad (4.3)$$

Environmental impact of the logistics process:

$$E^B = \begin{array}{c} \\ r_1 \\ r_2 \\ r_3 \\ r_4 \\ r_5 \end{array} \begin{array}{c} \begin{array}{ccccc} v_1 & v_2 & v_3 & v_4 & v_5 \end{array} \\ \begin{bmatrix} 5 & 5 & 10 & 6 & 2 \\ 8 & 7 & 1 & 8 & 3 \\ 9 & 9 & 5 & 5 & 4 \\ 6 & 2 & 8 & 9 & 6 \\ 5 & 9 & 7 & 8 & 9 \end{bmatrix} \end{array} \quad \text{[point]} \qquad (4.4)$$

Modernity of the supplier's logistics system:

$$P^B = \begin{array}{c} \\ r_1 \\ r_2 \\ r_3 \\ r_4 \\ r_5 \end{array} \begin{array}{c} \begin{array}{ccccc} v_1 & v_2 & v_3 & v_4 & v_5 \end{array} \\ \begin{bmatrix} 8 & 5 & 4 & 6 & 8 \\ 7 & 7 & 3 & 8 & 8 \\ 6 & 9 & 5 & 8 & 7 \\ 5 & 10 & 8 & 9 & 6 \\ 4 & 10 & 9 & 7 & 9 \end{bmatrix} \end{array} \quad \text{[point]} \qquad (4.5)$$

Reliability

$$M^B = \begin{array}{c} \\ r_1 \\ r_2 \\ r_3 \\ r_4 \\ r_5 \end{array} \begin{array}{c} \begin{array}{ccccc} v_1 & v_2 & v_3 & v_4 & v_5 \end{array} \\ \begin{bmatrix} 2 & 7 & 6 & 8 & 8 \\ 4 & 8 & 8 & 10 & 4 \\ 9 & 10 & 9 & 7 & 5 \\ 7 & 2 & 6 & 7 & 6 \\ 8 & 1 & 7 & 8 & 7 \end{bmatrix} \end{array} \quad \text{[point]} \qquad (4.6)$$

IV. Application of supplier selection method:

Step 1: Define the objective function components to be minimized and maximized

Components to be minimized:

- all costs related to delivery,
- the total lead time of the procurement,
- the environmental impact of the logistics process.

Components to maximize:

- the quality of the raw material,
- the modernity of the supplier's logistics system,
- supplier reliability.

Step 2: Define a set of conditions

Total lead time:

$$t_r^B \leq 950 \text{ hours} \tag{4.7.}$$

Total purchase cost:

$$k_r^B \leq .850 \text{ EUR/kg} \tag{4.8.}$$

Environmental impact of the logistics process:

$$e_r^B \leq 9\ points\ . \tag{4.9.}$$

Raw material quality:

$$60\% \leq n_r^B \leq 90\% \tag{4.10.}$$

Modernity of the supplier's logistics system related to delivery:

$$5\ points \leq p_r^B\ , \tag{4.11.}$$

Reliability:

$$4\ points \leq m_r^B\ . \tag{4.12.}$$

Step 3: Determination of reduced matrices. In the framework of this step, based on the system of conditions described in step 2, the values of the *matrix (4.1.)…(4.6.)* are modified to the *reduced matrices (4.13.)…(4.18.)*. Formally, this means that all reduced matrices are marked with an override (′).

$$T^{B'} = \begin{matrix} & v_1 & v_2 & v_3 & v_4 & v_5 \\ r_1 & 100 & 400 & 550 & 600 & 350 \\ r_2 & 100 & 600 & 900 & 250 & 500 \\ r_3 & 100 & 600 & 950 & 700 & 700 \\ r_4 & 100 & 550 & 400 & 800 & 650 \\ r_5 & 100 & 550 & 800 & - & 600 \end{matrix}\ . \tag{4.13.}$$

$$K^{B'} = \begin{matrix} & v_1 & v_2 & v_3 & v_4 & v_5 \\ r_1 & - & 120 & 110 & 110 & 170 \\ r_2 & 650 & 290 & 120 & 220 & 300 \\ r_3 & 500 & 280 & 250 & 200 & 180 \\ r_4 & - & 620 & 700 & 450 & 750 \\ r_5 & 750 & 420 & 320 & 250 & 390 \end{matrix} \tag{4.14.}$$

$$N^{B'} = \begin{matrix} & v_1 & v_2 & v_3 & v_4 & v_5 \\ r_1 & 75 & 75 & 65 & 80 & 80 \\ r_2 & 80 & 75 & 70 & 85 & 80 \\ r_3 & 90 & 95 & 90 & 85 & 70 \\ r_4 & - & - & 70 & 75 & 60 \\ r_5 & 85 & 90 & 87 & 78 & 90 \end{matrix}. \tag{4.15.}$$

$$E^{B'} = \begin{matrix} & v_1 & v_2 & v_3 & v_4 & v_5 \\ r_1 & 5 & 5 & - & 6 & 2 \\ r_2 & 8 & 7 & 1 & 8 & 3 \\ r_3 & 9 & 9 & 5 & 5 & 4 \\ r_4 & 6 & 2 & 8 & 9 & 6 \\ r_5 & 5 & 9 & 7 & 8 & 9 \end{matrix}. \tag{4.16.}$$

$$P^{B'} = \begin{matrix} & v_1 & v_2 & v_3 & v_4 & v_5 \\ r_1 & 8 & 5 & - & 6 & 8 \\ r_2 & 7 & 7 & - & 8 & 8 \\ r_3 & 6 & 9 & 5 & 8 & 7 \\ r_4 & 5 & 10 & 8 & 9 & 6 \\ r_5 & - & 10 & 9 & 7 & 9 \end{matrix}. \tag{4.17.}$$

$$M^{B'} = \begin{matrix} & v_1 & v_2 & v_3 & v_4 & v_5 \\ r_1 & - & 7 & 6 & 8 & 8 \\ r_2 & 4 & 8 & 8 & 10 & 4 \\ r_3 & 9 & 10 & 9 & 7 & 5 \\ r_4 & 7 & - & 6 & 7 & 6 \\ r_5 & 8 & - & 7 & 8 & 7 \end{matrix}. \tag{4.18.}$$

If the conditions are not met, the *v*-th supplier's *r*-th raw material to be excluded is contained in the following matrix (1 value to be excluded, otherwise 0):

$$\text{Exclusion matrix} = \begin{matrix} & v_1 & v_2 & v_3 & v_4 & v_5 \\ r_1 & 1 & 0 & 1 & 0 & 0 \\ r_2 & 0 & 0 & 1 & 0 & 0 \\ r_3 & 0 & 0 & 1 & 0 & 0 \\ r_4 & 1 & 1 & 0 & 1 & 0 \\ r_5 & 1 & 1 & 0 & 1 & 0 \end{matrix}. \tag{4.19.}$$

Step 4: Normalization of order lead time values, total purchase cost values, raw material quality values, logistics process environmental loads values, modernity of supplier logistics system values and of reliability values *(4.13)…(4.24)*:

$$T_{max}^{B'} = \begin{matrix} r_1 & r_2 & r_3 & r_4 & r_5 \\ [600 & 600 & 950 & 800 & 800] \end{matrix} . \quad (4.20.)$$

$$\gamma^1 = \begin{matrix} \\ r_1 \\ r_2 \\ r_3 \\ r_4 \\ r_5 \end{matrix} \begin{matrix} v_1 & v_2 & v_3 & v_4 & v_5 \\ \end{matrix} \begin{bmatrix} - & 0{,}66 & - & 1 & 0{,}58 \\ 0{,}16 & 1 & - & 0{,}41 & 0{,}83 \\ 0{,}18 & 0{,}63 & 1 & 0{,}74 & 0{,}74 \\ - & - & 0{,}5 & 1 & 0{,}81 \\ - & - & 1 & - & 0{,}75 \end{bmatrix} . \quad (4.21.)$$

$$K_{max}^{B'} = \begin{matrix} r_1 & r_2 & r_3 & r_4 & r_5 \\ [170 & 650 & 500 & 750 & 390] \end{matrix} . \quad (4.22.)$$

$$\gamma^2 = \begin{matrix} r_1 \\ r_2 \\ r_3 \\ r_4 \\ r_5 \end{matrix} \overset{\begin{matrix} v_1 & v_2 & v_3 & v_4 & v_5 \end{matrix}}{\begin{bmatrix} - & 0{,}7 & - & 0{,}64 & 1 \\ 1 & 0{,}44 & - & 0{,}33 & 0{,}46 \\ 1 & 0{,}56 & 0{,}5 & 0{,}4 & 0{,}36 \\ - & - & 0{,}93 & 0{,}6 & 1 \\ - & - & 0{,}82 & - & 1 \end{bmatrix}} . \quad (4.23.)$$

$$N_{max}^{B'} = \begin{matrix} r_1 & r_2 & r_3 & r_4 & r_5 \\ [80 & 85 & 95 & 75 & 90] \end{matrix} . \quad (4.24.)$$

$$\gamma^3 = 1 - \begin{matrix} r_1 \\ r_2 \\ r_3 \\ r_4 \\ r_5 \end{matrix} \overset{\begin{matrix} v_1 & v_2 & v_3 & v_4 & v_5 \end{matrix}}{\begin{bmatrix} - & 0{,}93 & - & 0{,}75 & 1 \\ 0{,}94 & 0{,}88 & - & 1 & 0{,}94 \\ 0{,}94 & 1 & 0{,}95 & 0{,}89 & 0{,}73 \\ - & - & 0{,}93 & 1 & 0{,}8 \\ - & - & 0{,}96 & - & 1 \end{bmatrix}} . \quad (4.25.)$$

$$E_{max}^{B'} = \begin{matrix} r_1 & r_2 & r_3 & r_4 & r_5 \\ [6 & 8 & 9 & 9 & 9] \end{matrix} . \quad (4.26.)$$

$$\gamma^4 = \begin{matrix} r_1 \\ r_2 \\ r_3 \\ r_4 \\ r_5 \end{matrix} \overset{\begin{matrix} v_1 & v_2 & v_3 & v_4 & v_5 \end{matrix}}{\begin{bmatrix} - & 0{,}83 & - & 1 & 0{,}33 \\ 1 & 0{,}87 & - & 1 & 0{,}37 \\ 1 & 1 & 0{,}55 & 0{,}55 & 0{,}44 \\ - & - & 0{,}88 & 1 & 0{,}66 \\ - & - & 1 & - & 0{,}77 \end{bmatrix}} . \quad (4.27.)$$

$$P_{max}^{B'} = \begin{matrix} r_1 & r_2 & r_3 & r_4 & r_5 \\ [8 & 8 & 9 & 9 & 9] \end{matrix} . \quad (4.28.)$$

$$\gamma^5 = 1 - \begin{matrix} r_1 \\ r_2 \\ r_3 \\ r_4 \\ r_5 \end{matrix} \overset{\begin{matrix} v_1 & v_2 & v_3 & v_4 & v_5 \end{matrix}}{\begin{bmatrix} - & 0{,}83 & - & 1 & 0{,}33 \\ 1 & 0{,}87 & - & 1 & 0{,}37 \\ 1 & 1 & 0{,}55 & 0{,}55 & 0{,}44 \\ - & - & 0{,}88 & 1 & 0{,}66 \\ - & - & 1 & - & 1 \end{bmatrix}} . \quad (4.29.)$$

$$M^{B'}_{max} = \begin{matrix} r_1 & r_2 & r_3 & r_4 & r_5 \\ [8 & 10 & 10 & 7 & 7] \end{matrix} . \quad (4.30.)$$

$$\gamma^6 = 1 - \begin{matrix} \\ r_1 \\ r_2 \\ r_3 \\ r_4 \\ r_5 \end{matrix} \begin{matrix} v_1 & v_2 & v_3 & v_4 & v_5 \\ - & 0,85 & - & 1 & 1 \\ 0,4 & 0,8 & - & 1 & 0,4 \\ 0,9 & 1 & 0,1 & 0,7 & 0,5 \\ - & - & 0,85 & 1 & 0,85 \\ - & - & 1 & - & 1 \end{matrix} . \quad (4.31.)$$

Step 5: Weighting of normalized objective function components. Determination of weighting factors by the Churchman-Ackoff weighting method.

The weighting factors determined by the weighting method are included in the *data (4.32.)…(4.36)*:

$$C_1 = K^{B'} ;\ C_2 = T^{B'} ;\ C_3 = N^{B'} ; C_4 = E^{B'} ;\ C_5 = P^{B'} ;\ C_6 = M^{B'} \quad (4.32.)$$

$$W_1 = 1 ;\ W_2 = 0,8 ;\ W_3 = 0,6 ; \quad (4.34.)$$

$$W_4 = 0,4 ;\ W_5 = 0,3 ;\ W_6 = 0,2 \quad (4.35)$$

$$\eta_1 = 0,243\ \ \eta_2 = 0,303\ \eta_3 = 0,181\ \eta_4 = 0,121\ \ \eta_5 = 0,091\ \eta_6 = 0,061 \quad (4.36.)$$

Application of selection method *(4.37)*:

$$E = \begin{matrix} \\ r_1 \\ r_2 \\ r_3 \\ r_4 \\ r_5 \end{matrix} \begin{matrix} v_1 & v_2 & v_3 & v_4 & v_5 \\ - & 0,510 & - & 0,603 & 0,544 \\ 0,510 & 0,527 & - & 0,320 & 0,490 \\ 0,484 & 0,443 & 0,565 & 0,044 & 0,472 \\ - & - & 0,542 & 0,545 & 0,655 \\ - & - & 0,619 & - & 0,578 \end{matrix} \quad (4.37.)$$

The lowest value must be selected in each row to determine from which supplier each raw material should be obtained:

$r_1 \rightarrow v_2$
$r_2 \rightarrow v_4$
$r_3 \rightarrow v_2$
$r_4 \rightarrow v_3$
$r_5 \rightarrow v_5$

6. SUMMARY

The choice of the topic of the dissertation was induced by the experience gained in corporate practice and the development opportunities discovered in connection with the companies distributing dietary supplements. In the case of the type of company selling dietary supplements, a method has been developed for the efficient operation of the optimal selection of suppliers, which takes into account the logistical and environmental parameters in terms of both quality and quantity. In order to illustrate the method and to ensure its practical applicability, the verification of the correctness of the explained correlations was presented through fictitious examples. The results presented can be used for practice primarily in the case of companies dealing with food supplements and pharmaceuticals.

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