Impact assessment of the supply chain based on the theory of fuzzy sets

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Abstract. The next questions were considered: creation of performance evaluation system as part of the automated software complex designed to improve the activities functioning of the business structures. These business structures are complex regarding their structure as well as liaison communications in a supply chain. Proposed model for the efficiency assessment was created while using the theory of fuzzy sets on the software basis in the MATLAB environment. Conducted investigations have shown that this developed model allows to create supply chains that are optimal in terms of its structure and efficiency; it equally formalizes the decision-making procedure and reduces the error probabilities when it comes to the supply chain management.

1. Introduction
Supply chains are regarded as the complex systems in the context of their structure and operation mode. Supply chain management - it is “the management of relationships with suppliers and customers that are “located” in the different parts of this system; this management is aimed at achieving of the higher customer value while having lower costs throughout the supply chain as a whole ring” (5). It is more expedient & appropriate to analyze and to evaluate this type of the complex control systems on the basis of methodology called as the methodology of general cybernetic theory of systems. Its essence narrows down to a comprehensive assessment of all interrelated elements of the system; these elements are bent on the single goal achievement. Performance is one of the indicators of overall comprehensive assessment of the structural elements activities within the supply chains. The effectiveness indicator of supply chain allows to assess “a degree of goals achievement, an expected state of the research object. It is determined by the value of output indicators of the research object .

Variety of the Russian and Foreign scientists’ works are dedicated to the problem of effectiveness assessment of the supply chains. V.I. Sergeev, James Stock, D. Waters and other authors – they highlight some different methods of assessment such as a comparison of the current indicators with absolute and past standards, with target functions and competitors data, usage of reengineering and benchmarking techniques, the best practices and the method of expert assessments (1-5). A common difficulty in impact assessment of the supply chains by various available methods is the quantification as well as formalization of value, since analysis of the supply chains functioning also includes some qualitative indicators.

2. Research objective
Supply chain is “a sequence of flows and processes that take a place among different counterparties (links) of this chain, and they are combined in order to meet the consumers requirements regarding goods and services” (11). Direct supply chain is characterized by presence of the next links : a first-tier supplier, a focus company, a first-tier consumer and a part (component) performing the transportation
process. Result evaluation of the direct supply chain activity includes both quantitative and qualitative performance indicators; it is possible to assess a result of the supply chain operation in the form of integral indicator of all parts / components performance only by combining these two types of parameters together.

3. Theory

Main requirements for the indicators of performance evaluation are compliances with the “SMART” concept, namely “indicators should be specific, measurable, achievable, relevant, tied to a certain period of time (time-certain)”. Indicators offered by the authors for effectiveness assessment of the direct supply chains are presented in Table 1.

**Table 1. Performance indicators for supply chain**

| Indicators                       | Value                                                                 | Formulas for calculation                                                                                                                                 |
|----------------------------------|-----------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------|
| Supply chain reaction \((T_0)\)  | It determines a duration of the cargo passage all along the supply chain. | \(T_0 = \sum T_p + \sum T_r + \sum T_t + \sum T_c\), whereabouts \(T_p\) – time spent for embarking, \(T_r\) – time spent for loading off cargo, \(T_t\) – time spent for reshipping / transport movement, \(T_c\) – time spent for the storage of goods in warehouses |
| Supply chain flexibility \((G_a)\) | Ability to maintain the stability of indicators regarding material, financial and information flows at the output, despite the unpredictability as well as changing environmental conditions. | \(G_a = \frac{n}{m}\), whereabouts \(n\) – number of changes made within a supply chain, \(m\) – total number of changes required all along a supply chain. |
| Supply chain reliability \((N)\)  | It is an object property to keep / to preserve values of the set operating parameters within certain limits corresponding to predetermined / standard mode & use conditions, maintenance, storage and transportation. | \(N = \frac{Z_v}{Z_o}\), whereabouts \(Z_v\) - number of orders / deliveries executed regarding all parameters of the completed order, \(Z_o\) - total number of completed deliveries. |
| Delivery Expediency \((S)\)      | Execution of orders within agreed, predetermined timescales.          | \(S = \frac{t}{p}\), whereabouts \(t\) – actual delivery period, \(p\) – prescheduled delivery period.                                                        |
| Number of claims \((P)\)         | It reflects the level of customer complaints towards the company / supply chain. | \(P = \frac{X}{C}\), whereabouts \(X\) – number of deliveries when the customers claims were received, \(C\) – total number of deliveries. |
| Supply chain costs               | Aggregate costs regarding the main logistics functions                | \(Z = C * W\), whereabouts \(W\) – purchase price per unit of product (including the costs of ordering and its transportation), RUB. \(R = T_1 * Z_{const}\), whereabouts \(T_1\) – tariff / rate for one delivery under given conditions, RUB.; \(Z_{const}\) – number of deliveries (delivery quantity). |
| Procurement cost \((Z)\)         |                                                                         | \(S_{const}\) – number of deliveries (delivery quantity). \(Sc = T_n * S\), whereabouts \(T_n\) – rental rate for 1 m2 of the warehouse area, including the cargo warehouse processing; \(S\) – size of the rentable area. |
| Shipping costs \((R)\)           |                                                                         |                                                                                                                                                    |
| Storage cost \((Sc)\)            |                                                                         |                                                                                                                                                    |
L. Zadeh (2) proposed an approach with an introduction of linguistic variables; this approach makes possible to lead qualitative expert assessments to quantitative ones, numerical (fuzzy). The feature of this approach is a rejection of the binary values concerning a regular set \( X \) \( (A \subseteq X) \) and an adoption of the intermediate degree of appurtenance on the segment \([0, 1]\).

As the rules for an objective function calculation, there is a matrix of fuzzy sets in the next form \( M_{\text{fin}} = a_{ij}(1), i,j = 1, 2 \ldots n. \)

Comprehensive assessment of the supply chains performance on the basis of fuzzy sets theory is performed while using the MATLAB software. Developed model for the objective function calculation on the basis of fuzzy sets theory in the MATLAB environment is shown in Figure 1.

![Figure 1. Model for the objective function calculation on the basis of the fuzzy sets theory in the MATLAB environment](image)

As concerns this model in Fig. 1, the input data are some performance indicators of a given chain; at the output we attain a comprehensive assessment of the chain in the form of performance indicator. Program solver consists of the expert rules set such as “if ... then …”, prescribed rules in a model of the order of hundred (Figure 2.).

![Figure 2. Expert rules for calculation of supply chain performance in the MATLAB environment](image)

Model for the performance calculation is based on a reference model of supply chain, that is a model whose performance is equal to one (unit). Thus, the closer the output indicator of supply chain performance to one, it means that an analyzed supply chain is as close as possible to the ideal. In case of ineffective operation of the chain, if there is a decrease of its effectiveness indicator, so, it is possible to enter into the system the performance indicators of other potential counterparties and to reassess the new supply chain effectiveness.

4. Experimental results

As an example and a test check of the developed model functioning and so that to calculate the performance indicator of supply chains, we had considered three chains of a company that specializes in stationery and office supplies and carries out transportation across the territory of Russia. The
analyzed supply chains are direct and they include the next links (parts / elements): supplier, carrier, consumer. Indicators for each of the chains are presented in Table 2.

Table 2. Supply chain performance indicators (presence of shipping Carrier A)

| Indicators                        | Supply chain № 1 | Supply chain № 2 | Supply chain № 3 |
|-----------------------------------|------------------|------------------|------------------|
| Supply chain reaction             | 3                | 7                | 6                |
| Supply chain flexibility          | 0.9              | 0.9              | 0.9              |
| Supply chain reliability          | 0.96             | 0.96             | 0.96             |
| Expediency                        | 0.87             | 0.87             | 0.87             |
| Claims                            | 0.98             | 0.98             | 0.98             |
| Purchase / Procurement costs      | 22 500           | 210 000          | 310 000          |
| Shipping costs                    | 6 800            | 77 321           | 70 700           |
| Costs for storage                 | 100              | 960              | 1 700            |
| Ancillary / Supplementary costs   | 1 950            | 5 500            | 9 900            |
| Total costs                       | 31 400           | 294 781          | 392 300          |

As a result of the made calculation within the MATLAB environment, we obtain the next performance indicators for the direct supply chains (Table 3).

Table 3. Supply chain performance / effectiveness (performance of shipping Carrier A)

| Performance / Effectiveness       | Supply chain № 1 | Supply chain № 2 | Supply chain № 3 |
|-----------------------------------|------------------|------------------|------------------|
|                                   | 0.79             | 0.92             | 0.87             |

It is essential to note that effectiveness of the first and the third supply chains is significantly lower than the second one. We would like to offer to make a replacement of the link (part / element) in chains in favor of another executor of the transport process.

The indicators values of supply chains functioning (first and third) after replacement of the counterparty are presented in Table 4.

Table 4. Supply chain performance indicators (presence of shipping Carrier B)

| Indicators                        | Supply chain № 1 | Supply chain № 3 |
|-----------------------------------|------------------|------------------|
| Supply chain reaction             | 2                | 5                |
| Supply chain flexibility          | 0.98             | 0.98             |
| Supply chain reliability          | 0.97             | 0.97             |
| Expediency                        | 0.93             | 0.93             |
| Claims                            | 0.98             | 0.98             |
| Purchase / Procurement costs      | 22 500           | 310 000          |
| Shipping costs                    | 6 900            | 82 000           |
| Costs for storage                 | 120              | 1750             |
| Ancillary / Supplementary costs   | 1350             | 10 700           |
| Total costs                       | 31948            | 404 650          |

Received performance indicators of the direct supply chains (first and third) after the replacement of carrier A by carrier B in chains 1 and 3 are presented in Table 5.

Table 5. Supply chain performance / effectiveness (performance of shipping Carrier B)

| Performance / Effectiveness       | Supply chain № 1 | Supply chain № 2 |
|-----------------------------------|------------------|------------------|
|                                   | 0.9              | 0.91             |
Taking into consideration the data in Table 5, we could see that replacement of the counterparty made it possible to increase the performance indicator of the first and third supply chains.

In a general way, algorithm for the effectiveness assessment of supply chains, that was developed by the authors, is presented in Figure 3.

![Figure 3. Block diagramm of the algorithm for effectiveness assessment of the supply chain](image)

Thus, the offered model for performance assessment of the supply chains allows to increase the chain effectiveness and to create the most beneficial and optimal connections between the links (parts / elements).

5. Discussion of results
Hybrid model for the effectiveness assessment of supply chains offered by the authors is made as a result of interfusion of such methods as expert assessment, benchmarking and fuzzy sets theory. In contrast to other well-known methods of the effectiveness assessing, the proposed model allows not only to formalize and to calculate complex indicator of the supply chain performance, but also to create optimal and effective structures as well as to manage them while choosing the "best" counterparties for a particular chain.

Application of this calculation method of the supply chain effectiveness will allow to reduce logistics costs in real terms, to increase a profit of the supply chain and to reduce a final cost of the material flow (goods or services) and also to facilitate the process of management decision making.

6. Summary and Conclusions
This article deals with complexity of a comprehensive assessment of the supply chains effectiveness, formalization of the performance indicators. The conducted studies allowed to combine several approaches to make the effectiveness assessing of direct supply chains possible, to develop the author's hybrid model for performance assessing in the MATLAB software environment.

The author's model allows to evaluate the effectiveness and the structure of supply chains, to manage this structure and to choose optimal, the “best” contractors. Based on a reference model of supply chains and on the prescribed expert rules in the model, it allows in real terms to make
profitable decisions in supply chain management within a short time, to formalize the decision-making procedure and to reduce the likelihood of errors in supply chain management.

References
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