Engineering of logistics flows

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Abstract. The article is devoted to the engineering of logistics flows. Logistics flow engineering aims to apply methods of fuzzy modeling of logistics processes according to indicators-criteria of fuzzy relationships, search for the most optimal counterparties that will allow achieving the best level of supply quality, taking into account all possible potential uncertainties. The author considers the algorithm of fuzzy modeling processes, which will improve the quality of development and the level of applied solutions to the problem of choosing a counterparty. It is advisable to use the fuzzy modeling algorithm in logistics flow engineering to obtain operational information, but taking into account the aggregation of input information data on the criteria of the fuzzy relationship system. The considered algorithm makes it possible to represent the relationships of criteria of various attributes, on the basis of which decisions can be made on aggregated indicators. This algorithm allows you to integrate the material and financial properties of logistics flows to increase the level of decisions based on the data system of information flows. Keywords: logistics, flows, system, model, resources, quality, sets, criteria.

1 Introduction

Due to the processing and analysis of a large amount of information in the construction of logistics links, the relevance of such a field of activity as logistics flow engineering is also growing. Unlike conventional logistics flow management, whose tasks are to monitor compliance with the operational plan for the supply of resources, logistics flow engineering is engineering support at all stages of the supply chain, including the optimal choice of the counterparty of the supplied resources, reducing the time for the development of analytical documentation by promptly obtaining information that allows organising the control of logistics activities.

2 Materials and Methods

The introduction of digital technologies ensures the quality of processed documentation and reduces labour costs for logistics operations. Currently, logistics activities have a high rate of information technology development, but at the same time a low level of implementation of modern, original engineering solutions in the field of optimising the selection of contractors of resource suppliers [1,2]. As a result, the developed logistics solutions reveal
deviations in the organisation of the supply chain of resources. The quality of the prepared documentation regarding the development of original logistics solutions leads to a reduction in delivery costs, an increase in the level of logistics activities and is reflected in the profits of participants in the supply chain of resources.

This has led to the need and expediency of developing a methodology for assessing and forecasting logistics flows of resources.

When developing and testing the methodology for assessing and forecasting logistics flows of resources, the following defining provisions are distinguished:

First, as the basis of the algorithm, the concept of a fair counterparty-resource-property optimisation system is chosen;

Secondly, the level of the designed solutions in a single information and digital space is taken into account;

Thirdly, to control the quality of logistics decisions, a systematic approach is introduced using fuzzy logic algorithms.

Based on these positions, the author has developed and tested a methodology for assessing and forecasting logistics flows of resources.

The introduction of information and innovative technologies can improve the reliability of the design of logistics flows, reducing logistics costs based on the allocation of cost points in the supply chain when moving material flows [3].

The development of artificial intelligence systems in supply logistics management is appropriate for processing an array of information data and building optimal supply chains of resources, including the search for new contractors for resources with specified properties [4].

A feature of the unified information and digital space of logistics flows is the property of complanarity, which is characterised by informative identification in the digital environment, cleared from the use of data on material and financial information [5].

It is advisable to develop data analysis methods that are focused on building logistic models that take into account the incompleteness and inaccuracy of incoming information. The methodology and algorithms of fuzzy sets and fuzzy logic are focused on a wide range of practical tasks in the logistics chain of resources. Digital tools make it possible to implement the principles of fuzzy modeling tasks with a reliable level. Fuzzy logic mechanisms serve as the basis for intellectual conclusions that take into account aspects of information uncertainty, unlike traditional formal logic systems. Modeling of the system determines the identification of significant patterns, structures, and accumulation of data. When identifying in the context of the methodology of system modeling, the problem of informal methods of analysis is solved [6, 7]:

- building scenarios to analyse alternative solutions to the problem;
- non-standard approaches for generating new solutions;
- conceptual analysis to achieve the required level of quality of consideration of the problem;
- building a goal tree to identify bottlenecks in the solution under study.

Modeling helps to generate some new information about the indicators and attributes of the system. The algorithm of the system modeling methodology includes the following iterations:

- identification of input variables that are characterised by the criteria of the system;
- performing calculations with a simulated digital model to obtain output variables;
- assessment of the quality level of the results obtained based on checking the consistency of individual components of the indicators of the aggregated model;
- determination of the level of reliability of the decisions made, modeled in the form of control actions of the original problem;
- assessment of the possibility of practical implementation of the results obtained.
As a result of assessing the quality level of the results obtained and the reliability of the decisions made, problem-oriented changes are made to the system in the composition of additional components of the model structure in order to ensure the optimality of the problem being solved.

The process of the behavior of the counterparties of the resource supply chain, to a certain extent, is characterized by the uncertainty of the state of its elements. The process of functioning of information operating systems is characterized by the complexity of behavior, since their reliability and security does not always meet the requirements of various categories of users. In fuzzy modeling of the system, uncertainty factors are taken into account in the process of constructing information-logical models. System analysis helps to optimally take into account the uncertainty factor in problem decision-making.

A fuzzy set combines attributes of an arbitrary shape with a relative relation of belonging to a given set. A finite set is characterized by a finite power, which is equal to the number of elements of the set.

In order to manage logistics flows, using fuzzy modeling mechanisms, the author set the following tasks:

- analyze the methodology of fuzzy modeling;
- to study the possibility of using fuzzy modeling methods for logistics supply management when choosing a resource counterparty;
- to substantiate the expediency of using the fuzzy modeling method for operational planning of the logistics parameters of the system.

For the information and digital space using complanar flows, it is necessary to model an algorithm using fuzzy logic mechanisms.

Fuzzy logic mechanisms make it possible to make decisions based on logistic data, which increase the reliability of the information obtained, compared with traditional mathematical methods.

The main assumptions that arise when modeling processes at the design stage of development are related to the semantic uncertainty of identical parameters, incomplete formalisation of processes, inconsistency of the input data array, uncertainty of the output data.

Fuzzy modeling provides a reliable level of information quality with an inaccurate description of input data [6, 8].

The decision-making process is carried out using the membership function of the theory of fuzzy sets, in a direct way, according to which each position of the studied indicator is evaluated by an expert survey or as a result of applying machine learning algorithms and determining the probability of the set of properties under consideration [9-11].

The construction of a model of complex systems is designed on the basis of the theory of fuzzy relations, which form a set of fuzzy connections. An odd relation is defined by a set or list of ordered elements. A fuzzy relation between elements from two sets is called binary, in which no restrictions are imposed on the membership functions.

The unified information space presents and records data in the form of an information and logistics model. When designing, the model should not be overloaded with attribute criteria of indicators, but at the same time it should cover a sufficient level of identification of quality indicators.

The process of choosing a counterparty can be divided into several main stages [12-14].

1. Identification of representatives of the necessary nomenclature of resources
2. Determination of selection criteria
3. Determination of the weight of each criterion
4. Plotting and choosing the optimal option

The attributes of the criteria system are defined as follows:
- algorithm of price and terms agreement on contracts;
- reputation and operational experience;
- compliance of the counterparty's portfolio with the request data (territorial remoteness, absence of lawsuits, absence of unfulfilled contracts, availability of material and production base);
- review of work regulations under special conditions and response in unforeseen circumstances;
- provision of additional services and bonuses.

The values of the membership functions of the selected indicators can be obtained by expert analysis or as a result of machine learning.

For this study, a triangular membership function was chosen, which is described by the numbers \((a, b, c)\) ordered by the ratio, \(a \leq b \leq c\), and is calculated by the formula of properties [12, 15]:

\[
\mu_A(x) = \begin{cases} 
1 - \frac{b-x}{b-a}, & a \leq x \leq b \\
1 - \frac{x-b}{c-b}, & b \leq x \leq c \\
0, & x \leq a, c \leq x 
\end{cases}
\]  

(1)

For the example under consideration, the intervals of values of fuzzy variables were determined by an expert survey for selected indicators of the fuzzy set \(Y\).

Formulas were used to determine the vertices of the membership function:

\[
a = \min(a_i) \tag{2}
\]

\[
b = \max\{\max(a_i) \mid \min(b_j)\} \tag{3}
\]

\[
c = \max(b_j) \tag{4}
\]

The results of the calculations are presented in Table 1.

\[
\begin{array}{|l|c|c|c|}
\hline
\text{Indicators} & \text{Range of values} & a & b & c \\
\hline
\text{The algorithm of price and terms agreement on contracts} & \[0.65:0.85\] & 0.65 & 0.80 & 0.85 \\
\text{Reputation and operational experience} & \[0.75:0.95\] & 0.75 & 0.85 & 0.95 \\
\text{Compliance of the supplier's portfolio with the request data} & \[0.70:0.95\] & 0.70 & 0.85 & 0.95 \\
\text{Review of work regulations under special conditions and response in unforeseen circumstances} & \[0.40:0.75\] & 0.40 & 0.65 & 0.75 \\
\text{Provision of additional services and bonuses} & \[0.40:0.60\] & 0.40 & 0.55 & 0.60 \\
\hline
\end{array}
\]

The parameters of membership functions are necessary for calculating membership levels by fuzzy sets from the set of variable values.

Based on the selected attributes, we will build a model of binary fuzzy relations \(Z\) “Resource – selection criteria” and the relation \(R\) “Counterparty – selection criteria”. To construct the first relation, two basic sets \(X\) and \(Y\) are introduced. For the second relation \(N\) and \(Y\). Finite set of resources is described by the set \(X\). The set \(Y\) describes the selection criteria. The set \(Z\) defines a finite set of counterparties.
As a result of machine learning, the values of an aggregated indicator were obtained that takes into account changes in the properties of resource supplies, such as timing, delivery cost, shelf life, batch volume, quality control criteria (Tables 2 and 3).

Table 2. Relation Z “Resource – selection criteria”.

<table>
<thead>
<tr>
<th>Resources</th>
<th>Range of values</th>
<th>X1</th>
<th>X2</th>
<th>X3</th>
<th>X4</th>
<th>X5</th>
</tr>
</thead>
<tbody>
<tr>
<td>The algorithm of price and terms agreement on contracts</td>
<td>[0.65:0.85]</td>
<td>0.85</td>
<td>0.8</td>
<td>0.7</td>
<td>0.6</td>
<td>0.75</td>
</tr>
<tr>
<td>Reputation and operational experience</td>
<td>[0.75:0.95]</td>
<td>0.75</td>
<td>0.7</td>
<td>0.65</td>
<td>0.8</td>
<td>0.85</td>
</tr>
<tr>
<td>Compliance of the supplier's portfolio with the request data</td>
<td>[0.70:0.95]</td>
<td>0.7</td>
<td>0.9</td>
<td>0.75</td>
<td>0.85</td>
<td>0.95</td>
</tr>
<tr>
<td>Review of work regulations under special conditions and response in unforeseen circumstances</td>
<td>[0.40:0.75]</td>
<td>0.4</td>
<td>0.65</td>
<td>0.6</td>
<td>0.45</td>
<td>0.55</td>
</tr>
<tr>
<td>Provision of additional services and bonuses</td>
<td>[0.40:0.60]</td>
<td>0.4</td>
<td>0.4</td>
<td>0.5</td>
<td>0.45</td>
<td>0.6</td>
</tr>
</tbody>
</table>

Table 3. Relation R “Counterparty – selection criteria”.

<table>
<thead>
<tr>
<th>Counterparty</th>
<th>Resource counterparty</th>
<th>Resource counterparty</th>
<th>Resource counterparty</th>
<th>Resource counterparty</th>
<th>Resource counterparty</th>
</tr>
</thead>
<tbody>
<tr>
<td>The algorithm of price and terms agreement on contracts</td>
<td>0.48</td>
<td>0.35</td>
<td>0.45</td>
<td>0.60</td>
<td>0.65</td>
</tr>
<tr>
<td>Reputation and operational experience</td>
<td>0.62</td>
<td>0.50</td>
<td>0.35</td>
<td>0.48</td>
<td>0.70</td>
</tr>
<tr>
<td>Compliance of the supplier's portfolio with the request data</td>
<td>0.65</td>
<td>0.60</td>
<td>0.40</td>
<td>0.35</td>
<td>0.80</td>
</tr>
<tr>
<td>Review of work regulations under special conditions and response in unforeseen circumstances</td>
<td>0.40</td>
<td>0.32</td>
<td>0.30</td>
<td>0.45</td>
<td>0.42</td>
</tr>
<tr>
<td>Provision of additional services and bonuses</td>
<td>0.40</td>
<td>0.40</td>
<td>0.40</td>
<td>0.45</td>
<td>0.45</td>
</tr>
</tbody>
</table>

The results of determining the correlating dependencies of the obtained values of the aggregated indicator of the ratio Z “Resource – selection criteria”, taking into account changes in the properties of resource supplies, at the minimum and maximum values in the studied interval, are presented in Tables 4 and 5.

Table 4. Correlating dependencies of resource supplies for the minimum value in the range.

<table>
<thead>
<tr>
<th>Resources</th>
<th>Z</th>
<th>X1</th>
<th>X2</th>
<th>X3</th>
<th>X4</th>
<th>X5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z</td>
<td>1.00</td>
<td>0.74</td>
<td>0.79</td>
<td>0.71</td>
<td>0.76</td>
<td>0.57</td>
</tr>
<tr>
<td>X1</td>
<td>0.74</td>
<td>1.00</td>
<td>0.99</td>
<td>0.73</td>
<td>0.75</td>
<td>0.68</td>
</tr>
<tr>
<td>X2</td>
<td>0.79</td>
<td>0.99</td>
<td>1.00</td>
<td>0.78</td>
<td>0.81</td>
<td>0.69</td>
</tr>
<tr>
<td>X3</td>
<td>0.71</td>
<td>0.73</td>
<td>0.78</td>
<td>1.00</td>
<td>0.98</td>
<td>0.94</td>
</tr>
<tr>
<td>X4</td>
<td>0.76</td>
<td>0.75</td>
<td>0.81</td>
<td>0.98</td>
<td>1.00</td>
<td>0.85</td>
</tr>
<tr>
<td>X5</td>
<td>0.57</td>
<td>0.68</td>
<td>0.69</td>
<td>0.94</td>
<td>0.85</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Table 5. Correlating dependencies of resource supplies for the maximum value in the range.

<table>
<thead>
<tr>
<th>Resources</th>
<th>Z</th>
<th>X1</th>
<th>X2</th>
<th>X3</th>
<th>X4</th>
<th>X5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z</td>
<td>1.00</td>
<td>0.74</td>
<td>0.80</td>
<td>0.93</td>
<td>0.92</td>
<td>0.85</td>
</tr>
</tbody>
</table>
In the dependence study, the resources with the greatest dependence $X_1$, $X_2$, and $X_4$ were selected for the minimum value in the range (Table 4). For the maximum value in the range – $X_3$, $X_4$, and $X_5$ (Table 5).

As a result of the regression analysis of these indicators, threshold values of the aggregated indicator for the studied resources were obtained (Table 6).

The membership function for binary relations $Z$ and $R$ is described by the formula [6]:

$$\mu_{(R,Z)}((x_i,x_k)) = \max_{x_j \in X_2} \min \{ \mu_Z((x_i,x_j)), \mu_R((x_i,x_j)) \}$$  \hspace{1cm} (5)

The data of the fuzzy set, according to formula 5, are compiled in the following order: determination of the minimum values of the membership function of all positions according to Tables 2 and 3 for each selection criterion, then selection of the maximum value from the values obtained:

As a result of data analysis using machine learning, aggregated indicators for counterparties participating in the resource selection were obtained.

**Table 6. Relation г “Counterparty – resource”.

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Counterparty N1</th>
<th>Counterparty N2</th>
<th>Counterparty N3</th>
<th>Counterparty N4</th>
<th>Counterparty N5</th>
<th>Min value</th>
<th>Max value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resource X1</td>
<td>0.48</td>
<td>0.35</td>
<td>0.45</td>
<td>0.7</td>
<td>0.65</td>
<td>0.62</td>
<td>0.69</td>
</tr>
<tr>
<td>Resource X2</td>
<td>0.62</td>
<td>0.5</td>
<td>0.35</td>
<td>0.48</td>
<td>0.7</td>
<td>0.66</td>
<td>0.78</td>
</tr>
<tr>
<td>Resource X3</td>
<td>0.65</td>
<td>0.6</td>
<td>0.4</td>
<td>0.35</td>
<td>0.8</td>
<td>0.77</td>
<td>0.85</td>
</tr>
<tr>
<td>Resource X4</td>
<td>0.47</td>
<td>0.32</td>
<td>0.3</td>
<td>0.55</td>
<td>0.42</td>
<td>0.40</td>
<td>0.45</td>
</tr>
<tr>
<td>Resource X5</td>
<td>0.57</td>
<td>0.45</td>
<td>0.4</td>
<td>0.46</td>
<td>0.45</td>
<td>0.44</td>
<td>0.46</td>
</tr>
</tbody>
</table>

Based on the data obtained, we construct a diagram of indicators г “Counterparty – resource” (Figure 1).
Results of the Research

According to the results of the study, it was determined that the threshold indicators, according to the aggregate values of regression data analysis, are satisfied by “Counterparty N5” for all resources in the sample; “Counterparty N4” meets the threshold values for resources X1, X4 and X5; “Counterparty N1” fell into the range of threshold values for resources X4 and X5. Thus, the “Counterparty N5” is optimal for the supply of resources.

The considered algorithm of resource flow engineering allows organising logistics activities qualitatively. The algorithm makes it possible to present in tables fuzzy relationships of relationships of criteria of various attributes, based on which decisions can be made on aggregated indicators. This algorithm allows integrating the material and financial properties of logistics flows to increase the level of decisions based on the data system of information flows.

Conclusion

As a result of the introduction of engineering by logistics flows of resources, the time frame for the preparation of operational documentation is reduced, and the reliability of the work performed is increased due to the use of digitalisation of management tools in logistics activities. The article concludes that it is advisable to use the fuzzy modeling algorithm in logistics flow engineering to obtain operational information, but taking into account the aggregation of input information data on the criteria of the fuzzy relationship system. The fuzzy modeling algorithm allows predicting the threshold indicators of criteria that need to be analysed for each counterparty of resources based on aggregated data indicators.
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