Study of the Structural Significance of Supply Chain Elements with Variable Order Rate

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Abstract

One of the most significant stages of building a supply chain is the analysis of the criticality of the elements that make up it. When assessing the criticality of functional elements of adaptive supply chains, it is proposed to use the corresponding integral indicators. The introduced indicators, in addition, allow calculating the structural significance taking into account fluctuations in demand, based on the idea of a parametric genome of the structure of complex systems. This article presents the results of evaluating the significance of the functional elements of a certain supply chain with varying intensities of customer orders.

Keywords

Criticality of failure of elements, integral indicator, parametric genome, complex multi-mode object, joint and separate receipt of customer orders

1. Introduction

[1] The present and future of modernization of the economy, new relationships between transport organizations and cargo owners in Russia are developing in the direction of using innovative systems [1, 2]. Time, quality, safety, costs have become almost the most critical factors in the management of transport and logistics systems. According to the authors, it is necessary to move from existing, predominantly functional, management methods to process ones, which are based on risk management systems [3]. Solving this complex problem requires not only process analysis, but also reliability management mechanisms.

Ensuring security and control over transport and logistics processes in supply chains is based on integrated risk, which is a new management tool for the transport sector. New approaches to improving the efficiency of processes are based on modeling, labeling and identification of goods, management of acceptable risks in the transport and logistics system, which contributes to ensuring the integrated safety of the transportation process in supply chains [4-7].

Under these conditions, the question of studying the structural and functional properties of supply chains (SC) from the standpoint of considering them as complex systems becomes relevant [8-10]. The constant increase in the complexity of the structural and functional features of the SC leads to the spread of methods that take into account not only the numerical values of the reliability indicators of the functional elements (FE) of the supply chains (warehouses, manufacturing plants, suppliers, distributors, etc.), but also more general assessments of the impact of failures elements on the functioning of the entire SC under consideration, namely, assessing the criticality of FE failures [11].

Revealing the level (degree) of criticality of failure for each element of the SC allows you to focus on improving the most important nodes in terms of SC functioning [12]. The criticality of FE failures must be considered as a complex property, which includes several particular indicators: the degree of redundancy of the element; the likelihood of failure; resistance of functional elements to external influences; structural significance, etc. [13].

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Another important condition in solving problems of evaluating, analyzing and synthesizing the appearance of a SC is the need to take into account various options for the receipt of customer orders, which significantly affect the survivability and structural and functional reliability of both individual elements and the entire SC as a whole [11, 14-16].

The presented article presents the results of a study of the structural significance of the functional elements of supply chains, depending on the nature and intensity of the receipt of dynamic customer orders.

2. Method for studying the structural significance of elements of the supply chain

To assess the structural significance of the SC elements, it is advisable to use the capabilities of the general logical-probabilistic method and the program complex of logical-probabilistic modeling "Arbiter" [17], which is a universal graphical tool for the structural representation of the studied properties of complex objects.

As a rule, the analysis of structurally complex objects begins with the construction of a functional integrity diagram (FID) of the object [3]. The structure of the constructed circuit includes functional elements (FE), which are various technological operations, subsystems, blocks, nodes, connections of various physical nature, elements, etc.

Based on the FID, we will calculate the probabilistic polynomial of the successful functioning of the SC [12,13,17], taking into account the conditions of joint and separate receipt of dynamic customer orders.

Let the probabilistic polynomial of the successful functioning of the SC (customer service) have the form (1)

$$\Re(P_1,...,P_n,P_{n+1},...,P_{n+m},Q_1,...,Q_n,Q_{n+1},...,Q_{n+m}) \quad (1)$$

где $P_i(Q_i = 1 - P_i), i = 1,...,n$ - the probability of failure-free operation (failure) of the FE SC, and $P_{n+i}(Q_{n+i} = 1 - P_{n+i}), i = 1,...,m$ - will be understood as the intensity of receipt (absence) of a customer order on the considered time interval, varying from 0 to 1, and denote them by $\alpha_i = P_{n+i}, i = 1,...,m$.

Based on **the concept of the parametric genome of the structure** of SC [18] introduced earlier by the authors $\vec{\chi}(\alpha_1,\alpha_2,...,\alpha_m) = (\chi_0(\alpha_1,\alpha_2,...,\alpha_m), \chi_1(\alpha_1,\alpha_2,...,\alpha_m),...,\chi_n(\alpha_1,\alpha_2,...,\alpha_m))^T$, –vector, the elements of which are the coefficients of the probabilistic polynomial (2) of the successful functioning of the SC for the case of a homogeneous structure (equal probability of failure-free operation of the FE $P_1 = P_2 = ... = P_n = P$),

$$\Re(P,\alpha_1,\alpha_2,...,\alpha_m) = \chi_0(\alpha_1,\alpha_2,...,\alpha_m) + \\ +\chi_1(\alpha_1,\alpha_2,...,\alpha_m)P + ... + \chi_n(\alpha_1,\alpha_2,...,\alpha_m)P^n, \quad (2)$$

we calculate the indicators of structural and functional reliability for a homogeneous and inhomogeneous SC structure according to the formulas (3) [18,19]

$$F_{homog}(\vec{\chi}(\alpha_1,...,\alpha_m)) = \int_0^1 \Re(P,\alpha_1,...,\alpha_m)dP = \vec{\chi}(\alpha_1,...,\alpha_m)\cdot(1,\frac{1}{2},\frac{1}{3},...,\frac{1}{n+1})^T,$$

$$(3)$$

$$F_{heterog}(\vec{\chi}(\alpha_1,...,\alpha_m)) = \vec{\chi}(\alpha_1,...,\alpha_m)\cdot(1,\frac{1}{2},\frac{1}{2^2},...,\frac{1}{2^n})^T,$$

$$F_{homog\ poss}(\vec{\chi}(\alpha_1,...,\alpha_m)) = \sup_{\gamma\in[0,1]} \min\{\gamma, G(\{\mu | \Re(\mu,\alpha_1,...,\alpha_m) \geq \gamma\})\}.$$

To assess the structural significance of the FE, we calculate the polynomial (4) taking into account the dynamically changing intensities of customer orders and call it the significance polynomial. The resulting polynomial is calculated by differentiating the probabilistic polynomial of the successful functioning of the SC by the availability factor (probability of no-failure operation) of the i-th element [17].

$$\xi_i(P_1,...,P_n,\alpha_1,...,\alpha_m) = \frac{\partial\Re(P_1,...,P_n,\alpha_1,...,\alpha_m)}{\partial P_i} = \\ = \Re(P_1,...,P_n,\alpha_1,...,\alpha_m)\Big|_{P_i=1} - \Re(P_1,...,P_n,\alpha_1,...,\alpha_m)\Big|_{P_i=0}. \quad (4)$$

Then each polynomial of significance $\xi_i(P_1,...,P_n,\alpha_1,...,\alpha_m)$ $(\forall i = 1,...,n)$ can be associated with a parametric genome $\vec{\chi}^i(\alpha_1,\alpha_2,...,\alpha_m)$, the substitution of which in formulas (3) allows calculating the significance of functional elements of homogeneous and heterogeneous supply chains.

It is easy to see that the structural significance of the FE of SC depends on the nature and intensity of the receipt of dynamic customer orders [20,21]. We get that in addition to separate or joint receipt of orders, the intensity of receipt can be equal $\alpha_1 = \alpha_2 = ... = \alpha_m = \alpha$ or unequal. For the four options for the receipt of dynamic customer orders considered in the example, using the approach proposed in [11,17], to assess the structural significance of the FE of SC, we introduce the following integral indicators (5) - (8)

$$J_{se} = m \cdot \int_0^{1/m} F_*(\vec{\chi}_p(\alpha))d\alpha, \qquad (5)$$

$$J_{je} = \int_0^1 F_*(\vec{\chi}_c(\alpha))d\alpha, \qquad (6)$$

$$J_{su} = m! \cdot \iiint\limits_{\substack{\alpha_1+...+\alpha_m \le 1 \\ 0 \le \alpha_i \le 1, i=1,...,m}} F_*(\vec{\chi}_p(\alpha_1,...,\alpha_m))d\alpha_1 d\alpha_2 ... d\alpha_m, \qquad (7)$$

$$J_{ju} = \int_0^1 \int_0^1 ... \int_0^1 F_*(\vec{\chi}_c(\alpha_1,...,\alpha_m))d\alpha_1 d\alpha_2 ... d\alpha_m, \qquad (8)$$

Integral indicators (5) and (6) are intended to assess the structural significance of the FE of homogeneous and heterogeneous SC with respectively separate and joint receipt of customers of equal intensity orders, and indicators (7) and (8) - with respectively separate and joint receipt of unequal in intensity orders. It is easy to understand that $F_{\hom og}$, $F_{heterog}$ or $F_{\hom og \text{ poss}}$ can be used as the integrand F_* in formulas (5) - (8) for the corresponding parametric genomes $\vec{\chi}_s(\alpha), \vec{\chi}_j(\alpha), \vec{\chi}_s(\alpha_1,...,\alpha_m), \vec{\chi}_j(\alpha_1,...,\alpha_m)$.

Here

$$\vec{\chi}_s(\alpha) = \vec{\chi}_s^i(\alpha), \vec{\chi}_j(\alpha) = \vec{\chi}_j^i(\alpha), \vec{\chi}_s(\alpha_1,...,\alpha_m) =$$
$$= \vec{\chi}_s^i(\alpha_1,...,\alpha_m), \vec{\chi}_j(\alpha_1,...,\alpha_m) = \vec{\chi}_j^i(\alpha_1,...,\alpha_m)$$

$(\forall i = 1,...,n)$ respectively, the parametric genomes of the structural significance of the functional elements of the adaptive supply chain with an incompatible (separate) receipt of customers of equal intensity, with a joint receipt of orders of equal intensity, with a separate receipt of orders of unequal intensity, with a joint receipt of customers with unequal intensity of orders.

3. Conversion of expressions in integrated indicators for simplified estimation of the structural significance of elements of SC

To calculate the values of integral indicators of the structural significance of functional elements, taking into account the nature and intensity of the receipt of dynamic customer orders, we will use formulas (5) - (8). Let us denote the parametric genome of the significance polynomial of the element under consideration for the case of equivalent (unequal) in intensity of incoming customer orders by $\vec{\chi}(\alpha)$ $(\vec{\chi}(\alpha_1,...,\alpha_m))$. In this case, for a homogeneous or inhomogeneous structure, as in formulas (5) - (8), we use either

$$F_*(\vec{\chi}(\alpha_1,...,\alpha_m)) = \vec{\chi}(\alpha_1,...,\alpha_m) \cdot (1, \frac{1}{2}, \frac{1}{3}, ..., \frac{1}{n+1})^T,$$

$$F_*(\vec{\chi}(\alpha)) = \vec{\chi}(\alpha) \cdot (1, \frac{1}{2}, \frac{1}{3}, ..., \frac{1}{n+1})^T,$$

or

$$F_*(\vec{\chi}(\alpha_1,...,\alpha_m)) = \vec{\chi}(\alpha_1,...,\alpha_m) \cdot (1, \frac{1}{2}, \frac{1}{2^2}, ..., \frac{1}{2^n})^T,$$

$$F_*(\vec{\chi}(\alpha)) = \vec{\chi}(\alpha) \cdot (1, \frac{1}{2}, \frac{1}{2^2}, ..., \frac{1}{2^n})^T.$$

The use of the polynomial for the successful functioning of the supply chain (1) allows one to obtain parametric genomes of both the entire SC and the values of its FE. It should be noted that expression (1) has the form of a polynomial [17], the monomials of which include variables with degrees either 1 or 0. In this case, the integrand can be represented in its most general form as follows (9)

$$F_*(\vec{\chi}(\alpha_1,...,\alpha_m)) = \beta_0 + \sum_{i=1}^m \beta_i \alpha_i + \sum_{i=1}^m \sum_{j=i+1}^m \beta_{ij} \alpha_i \alpha_j +$$
$$+ \sum_{i=1}^m \sum_{j=i+1}^m \sum_{k=j+1}^m \beta_{ijk} \alpha_i \alpha_j \alpha_l + ... + \beta_{12...m} \alpha_1 \alpha_2 ... \alpha_m. \qquad (9)$$

Using the obtained equality (9), we obtain simplified expressions for the integral indicators of the structural significance of the FE of a homogeneous or inhomogeneous SC.

Then, as can be seen from the reasoning, formulas (5), (6) and (8) take the following form

$$J_{se} = m \cdot \int_0^{1/m} F_*(\vec{\chi}(\alpha))d\alpha =$$
$$= m \cdot \int_0^{1/m} (\beta_0 + \sum_{i=1}^m \beta_i \alpha + \sum_{i=1}^m \sum_{j=i+1}^m \beta_{ij} \alpha^2 + ... + \beta_{12...m} \alpha^m) d\alpha =$$
$$= \frac{\beta_0}{m^0 \cdot 1} + \frac{\sum_{i=1}^m \beta_i}{m \cdot 2} + \frac{\sum_{i=1}^m \sum_{j=i+1}^m \beta_{ij}}{m^2 \cdot 3} + ... + \frac{\beta_{12...m}}{m^m \cdot (m+1)},$$

$$J_{je} = \int_0^1 F_*(\vec{\chi}(\alpha))d\alpha =$$

$$= \int_0^1 (\beta_0 + \sum_{i=1}^m \beta_i \alpha + \sum_{i=1}^m \sum_{j=i+1}^m \beta_{ij} \alpha^2 + ... + \beta_{12...m} \alpha^m) d\alpha =$$

$$= \frac{\beta_0}{1} + \frac{\sum_{i=1}^m \beta_i}{2} + \frac{\sum_{i=1}^m \sum_{j=i+1}^m \beta_{ij}}{3} + ... + \frac{\beta_{12...m}}{(m+1)},$$

$$J_{ju} = \int_0^1 \int_0^1 ... \int_0^1 F_*(\vec{\chi}(\alpha_1, ..., \alpha_m)) d\alpha_1 d\alpha_2 ... d\alpha_m =$$

$$= \int_0^1 \int_0^1 ... \int_0^1 (\beta_0 + \sum_{i=1}^m \beta_i \alpha_i + \sum_{i=1}^m \sum_{j=i+1}^m \beta_{ij} \alpha_i \alpha_j + ... +$$

$$+ \beta_{12...m} \alpha_1 \alpha_2 ... \alpha_m) d\alpha_1 d\alpha_2 ... d\alpha_m =$$

$$= \frac{\beta_0}{2^0} + \frac{\sum_{i=1}^m \beta_i}{2^1} + \frac{\sum_{i=1}^m \sum_{j=i+1}^m \beta_{ij}}{2^2} + ... + \frac{\beta_{12...m}}{2^m}.$$

Simplifying expression (7), we obtain

$$J_{su} = m! \cdot \iiint\limits_{\substack{\alpha_1 + ... + \alpha_m \le 1 \\ 0 \le \alpha_i \le 1, i=1,...,m}} F_*(\vec{\chi}_p(\alpha_1, ..., \alpha_m)) d\alpha_1 d\alpha_2 ... d\alpha_m =$$

$$= m! \cdot \iiint\limits_{\substack{\alpha_1 + ... + \alpha_m \le 1 \\ 0 \le \alpha_i \le 1, i=1,...,m}} (\beta_0 + \sum_{i=1}^m \beta_i \alpha_i + \sum_{i=1}^m \sum_{j=i+1}^m \beta_{ij} \alpha_i \alpha_j + ... +$$

$$+ \beta_{12...m} \alpha_1 \alpha_2 ... \alpha_m) d\alpha_1 d\alpha_2 ... d\alpha_m = \frac{\beta_0}{1} + \frac{\sum_{i=1}^m \beta_i}{m+1} +$$

$$+ \frac{\sum_{i=1}^m \sum_{j=i+1}^m \beta_{ij}}{(m+1)\cdot(m+2)} + ... + \frac{\beta_{12...m}}{(m+1)\cdot(m+2)\cdot ... \cdot(m+m)}.$$

In this m-fold integral, the value of the integral of any monomial consisting of $k \le m$ different variables and included in polynomial (9) is a constant value equal to

$$m! \cdot \iiint\limits_{\substack{\alpha_1 + ... + \alpha_m \le 1 \\ 0 \le \alpha_i \le 1, i=1,...,m}} \alpha_{i_1} \cdot \alpha_{i_2} \cdot ... \cdot \alpha_{i_k} d\alpha_1 d\alpha_2 ... d\alpha_m =$$

$$= m! \cdot \int_0^1 \alpha_1 d\alpha_1 \int_0^{1-\alpha_1} \alpha_2 d\alpha_2 ...$$

$$... \int_0^{1-\alpha_1-\alpha_2-...-\alpha_{k-1}} \alpha_k d\alpha_k \int_0^{1-\alpha_1-\alpha_2-...-\alpha_k} d\alpha_{k+1} ... \int_0^{1-\alpha_1-\alpha_2-...-\alpha_{m-1}} d\alpha_m.$$

If we integrate this monomial over the variables $\alpha_{k+1}, \alpha_{k+2}, ..., \alpha_m$, we get the following expression

$$\frac{m!}{1\cdot 2 \cdot ... \cdot (m-k)} \cdot \int_0^1 \alpha_1 d\alpha_1 \int_0^{1-\alpha_1} \alpha_2 d\alpha_2 ...$$

$$... \int_0^{1-\alpha_1-\alpha_2-...-\alpha_{k-1}} (1-\alpha_1-\alpha_2-...-\alpha_k)^{m-k} \cdot \alpha_k d\alpha_k.$$

It is easy to see that the last integral of this expression is equal to

$$\int_0^{1-\alpha_1-\alpha_2-...-\alpha_{k-1}} (1-\alpha_1-\alpha_2-...-\alpha_k)^{m-k} \cdot \alpha_k d\alpha_k =$$

$$= \frac{(1-\alpha_1-\alpha_2-...-\alpha_{k-1})^{m-k+2}}{(m-k+1)\cdot(m-k+2)}.$$

As a result, we get

$$m! \cdot \iiint\limits_{\substack{\alpha_1 + ... + \alpha_m \le 1 \\ 0 \le \alpha_i \le 1, i=1,...,m}} \alpha_{i_1} \cdot \alpha_{i_2} \cdot ... \cdot \alpha_{i_k} d\alpha_1 d\alpha_2 ... d\alpha_m =$$

$$= \frac{m!}{m! \cdot (m+1)\cdot(m+2)\cdot ... \cdot(m+k-2)} \cdot$$

$$\cdot \int_0^1 (1-\alpha_1)^{m+k-2} \cdot \alpha_1 d\alpha_1 = \frac{1}{(m+1)\cdot(m+2)\cdot ... \cdot(m+k)}.$$

4. Results of calculating the structural significance of elements of SC with variable intensities of customer orders

Let's calculate the structural significance of the elements of some adaptive supply chain in the context of dynamically changing customer orders. In this article, we will use the results obtained in [11], namely: as functional elements, as already mentioned above, in supply chains can be distributors, warehouses, manufacturing plants, providers, suppliers, etc. Scheme of functional integrity of some. The SC, taking into account various options for the receipt of dynamic customer orders, is shown in Figure 1.

It should be noted that in the presented FID, vertices 1-10 reflect the operability (probability of no-failure operation) of the elements of the SC under consideration, vertices 11-14 reflect the intensity of incoming dynamic customer orders (or can be interpreted as probabilities of incoming customer orders), and vertices 15-33 are fictitious and describe the logical relationships between the elements of the supply chain.

Using the program complex "Arbiter" [17], for the FID of the SC we obtain two polynomials reflecting the probability of its successful functioning (10)

$$\Re_j(P_1,...,P_{10},P_{11},...,P_{14},Q_1,...,Q_{10},Q_{11},...,Q_{14}),$$
$$\Re_s(P_1,...,P_{10},P_{11},...,P_{14},Q_1,...,Q_{10},Q_{11},...,Q_{14}), \quad (10)$$

where

$\Re_s(P_1,...,P_{10},P_{11},...,P_{14},Q_1,...,Q_{10},Q_{11},...,Q_{14})$ - is a function of the probability of satisfying customer orders, which is a group of incompatible events (GIE); and $\Re_j(P_1,...,P_{10},P_{11},...,P_{14},Q_1,...,Q_{10},Q_{11},...,Q_{14})$ - is a function of the probability of satisfying orders from non-GIE customers; $P_i(Q_i), i=\overline{1,10}$ - probability of uptime (failure) of supply chain elements, and $P_{10+i}(Q_{10+i}), i=\overline{1,4}$ - is the rate of receipt of dynamic customer orders.

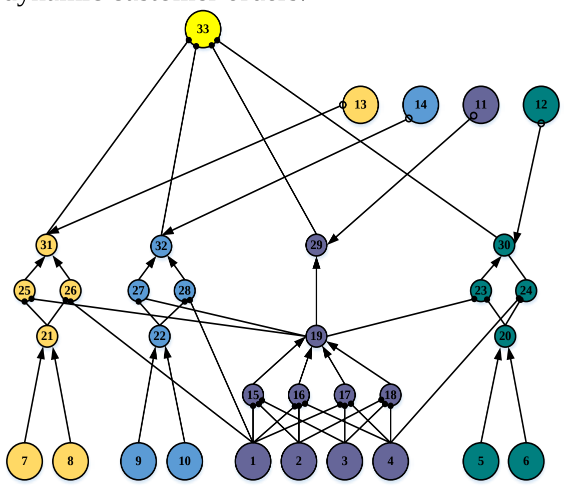

Figure 1: Example figure

Let us calculate the polynomials (9) for the heterogeneous $(F_{heterog}(\vec{\chi}_j^i(\alpha_1,...,\alpha_4)), F_{heterog}(\vec{\chi}_s^i(\alpha_1,...,\alpha_4)))$ and homogeneous $(F_{homog}(\vec{\chi}_j^i(\alpha_1,...,\alpha_4)), F_{homog}(\vec{\chi}_s^i(\alpha_1,...,\alpha_4)))$ structure of the SC, having determined for each i-th functional element the significance polynomial according to formula (4) for the cases of the presence and absence of GNS among the incoming customer orders and the corresponding parametric genomes $\vec{\chi}_j^i(\alpha_1,\alpha_2,\alpha_3,\alpha_4), \vec{\chi}_s^i(\alpha_1,\alpha_2,\alpha_3,\alpha_4)$.

Then, for example, for an element represented on the FID by vertex 1, the required polynomials (9) will have the following form

$$F_{homog}(\vec{\chi}_j^1(\alpha_1,...,\alpha_4)=0,25\alpha_1+0,066667\alpha_2+0,433333\alpha_3+$$
$$+0,433333\alpha_4-0,11667\alpha_1\alpha_2-0,48333\alpha_1\alpha_3-0,48333\alpha_1\alpha_4-$$
$$-0,46429\alpha_2\alpha_3-0,13095\alpha_2\alpha_4-0,55357\alpha_3\alpha_4+$$
$$+0,482143\alpha_1\alpha_2\alpha_3+0,14881\alpha_1\alpha_2\alpha_4+$$
$$+0,577381\alpha_1\alpha_3\alpha_4+0,386508\alpha_2\alpha_3\alpha_4-0,40079\alpha_1\alpha_2\alpha_3\alpha_4,$$
$$F_{heterog}(\vec{\chi}_j^1(\alpha_1,...,\alpha_4)=0,375\alpha_1+0,09375\alpha_2+0,65625\alpha_3+$$
$$+0,65625\alpha_4-0,1875\alpha_1\alpha_2-0,75\alpha_1\alpha_3-0,75\alpha_1\alpha_4-0,5\alpha_2\alpha_3-$$
$$-0,4375\alpha_2\alpha_4-0,82031\alpha_3\alpha_4+0,523438\alpha_1\alpha_2\alpha_3+$$
$$+0,460938\alpha_1\alpha_2\alpha_4+0,851563\alpha_1\alpha_3\alpha_4+0,5625\alpha_2\alpha_3\alpha_4-$$
$$-0,57617\alpha_1\alpha_2\alpha_3\alpha_4,$$

$$F_{homog}(\vec{\chi}_s^1(\alpha_1,...,\alpha_4)=0,25\alpha_1+0,066667\alpha_2+$$
$$+0,433333\alpha_3+0,433333\alpha_4\ ,$$
$$F_{heterog}(\vec{\chi}_j^1(\alpha_1,...,\alpha_4)=0,375\alpha_1+$$
$$+0,09375\alpha_2+0,65625\alpha_3+0,65625\alpha_4\ .$$

The results of the study of the structural significance of elements of the SC with separate (taking into account GIE) and joint (excluding GIE) receipt of equal or unequal in intensity orders from customers of a homogeneous or inhomogeneous structure of SC are given in Table 1 and Figure 2.

Table 1

Values of structural significance of SC elements

Number of elements	Joint receipt of orders				Separate receipt of orders			
	Unequal		Equal		Unequal		Equal	
	Homog	Heterog	Homog	Heterog	Homog	Heterog	Homog	Heterog
1	0,20794	0,29309	0,16617	0,22656	0,23667	0,35625	0,14792	0,22266
2	0,13008	0,17224	0,11119	0,14160	0,09000	0,13125	0,05625	0,08203
3	0,12860	0,17126	0,11000	0,14082	0,09000	0,13125	0,05625	0,08203
4	0,16895	0,23157	0,13927	0,18438	0,16333	0,24375	0,10208	0,15234
5	0,04878	0,07166	0,04474	0,06322	0,03667	0,05625	0,02292	0,03516
6	0,04878	0,07166	0,04474	0,06322	0,03667	0,05625	0,02292	0,03516
7	0,04998	0,07556	0,04508	0,06517	0,03667	0,05625	0,02292	0,03516
8	0,05146	0,07654	0,04627	0,06595	0,03667	0,05625	0,02292	0,03516
9	0,04998	0,07556	0,04508	0,06517	0,03667	0,05625	0,02292	0,03516
10	0,05146	0,07654	0,04627	0,06595	0,03667	0,05625	0,02292	0,03516

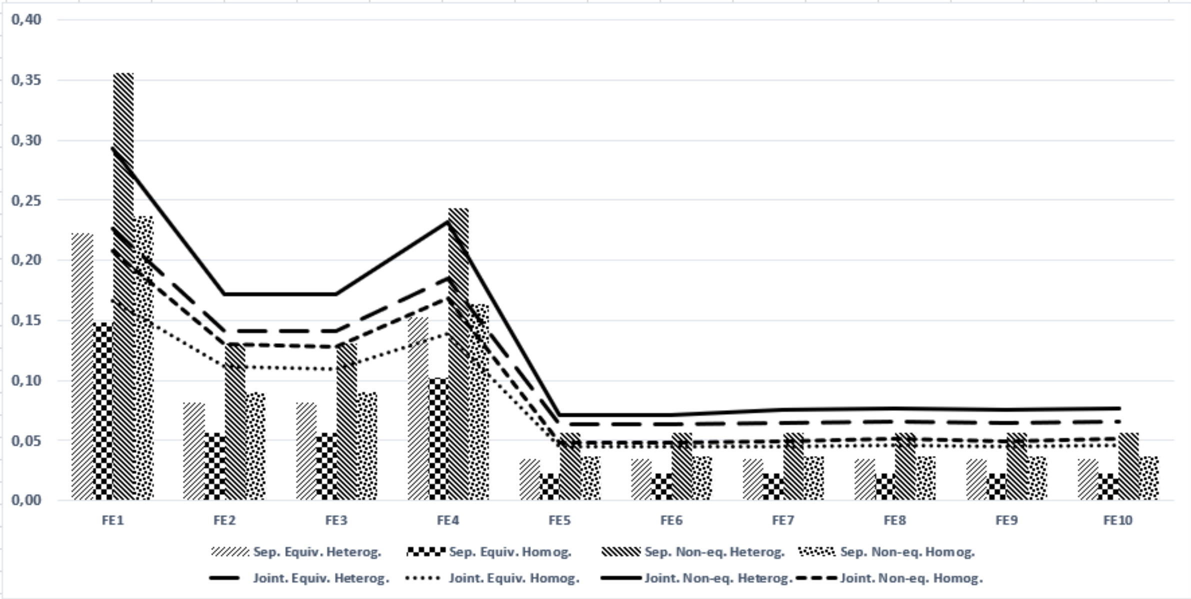

Figure 2: Structural Significance of SC elements in conditions of demand fluctuations

Analysis of the results of calculating the structural significance of the SC elements makes it possible to draw the following conclusions.

Regardless of the nature and intensity of orders, the first four elements have the greatest structural significance, and the maximum value of the indicators of their significance is achieved with a separate arrival of orders of unequal intensity, when the supply chain under consideration consists of elements that are heterogeneous in terms of the probability of failure-free operation. The rest of the SC elements have approximately equal significance, significantly different from the significance of elements 1-4.

In addition, taking the value of the indicator of the structural significance of FE1 as 1, with the joint receipt of customer orders, regardless of the equivalence of the receipt of orders and the homogeneity of the SC structure, the structural significance of the remaining FE will have the following shares of this value: for FE4 0.79-0.84, for FE2 and FE3 - 0.59-0.67, for others it will be approximately 0.23-0.29. And in the case of receipt of orders from customers that are GIE: for FE4 it is 0.68-0.69, for FE2 and FE3 - 0.37-0.38, for others - about 0.15. This suggests that with the joint receipt of dynamic customer orders while achieving the goal of the supply chain - satisfying customer orders, the structural significance of the first four functional elements becomes more homogeneous, while for others it doubles in contrast to the option of receiving orders clients representing GIE.

5. Conclusion

To calculate the structural significance of the functional elements of a certain supply chain, the significance polynomial was determined for each individual element as a result of differentiating the probabilistic polynomial of the successful functioning of the SC with respect to the variable characterizing the probability of failure-free operation of this element. Based on the concept of the parametric genome and using the derived formulas for calculating the structural and functional reliability of the SC, expressions were obtained for the indicators of the structural significance of elements of the SC, which reflect the contributions to the structural and functional reliability of the SC when transferring elements from an inoperative state to an operable one, taking into account fluctuations in demand. Finally, an example of a study of the structural significance of functional elements of an adaptive supply chain in the context of dynamic customer orders is considered.

The analysis of the results obtained in this article allows us to conclude that the change in the intensity and nature of the receipt of customer orders has a significant effect on the values of integral indicators of the structural significance of the SC elements, which predetermines the need to take into account such changes in further studies of the structural and functional properties of the SC.

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