EVALUATION OF SUPPLY CHAINS EFFECTIVENESS AND RELIABILITY BASED ON MODELLING LOGISTICS OPERATIONS

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ABSTRACT
Apart from the total logistics costs (TLC) nowadays to evaluate the integrated supply chains (SC) effective functioning some new criteria are used more often. These criteria characterise the quality and reliability of accomplishing logistics operations and functions. It is obvious that these metrics are connected and their separate representation is a consequence of not enough developed supply chains theoretic model. The paper presents the critical analysis of existing approaches to the TLC evaluation and SC reliability, the methodical approach which allows to evaluate the total costs indexes and supply chains reliability. Taking into consideration that most indicators which describe the chain functioning are the random values, to obtain the required evaluations there is a developed algorithm based on simulation.

Keywords: supply chains, reliability, total logistics costs, simulation

INTRODUCTION
Modern period of logistics and SCM development is characterized by a heightened interest not only for the total logistic costs, but for the row of new concepts such as «sustainability», «flexibility», «adaptability», «response time» and, of course, «reliability».
As for the total logistic costs, there two main directions of research have been set: at a micro and macro levels. Thus, at the macro level collection and analysis of statistical data of TLC let us state that in different countries these costs make up from 8-10 % (the USA, for example) till 20 % GDP (Singapur, Russia) (Ballou 1999; Bowersox and Closs 1996; Jonsson 2008).
These rates are average; they characterize the flow of global economic processes and can subsequently be used for long-term forecasts at the macro level and for the development of strategies, etc.
Another field of research is connected to the collection, systematization and analysis of costs in SC at the micro level (Christopher 2011; Stock and Lambert 2001; Waters 2003). An empirical approach of estimating logistics business operations costs in SC has undoubted advantages, but it also has some significant shortcomings.
It is important to point out that traditionally, the analysis of logistics and transportation (L&T) scenarios within a supply chain considers the overall costs as the most important performance measure (Cohen and Lee 1988). Wherein it is essential to take into consideration different stochastic variables and uncertainties: late deliveries, machine breakdowns, order cancellations, increased inventories, additional capacities or unnecessary slack time, etc. (Van der Vorst et al. 2000). Thus, according to (Bruzzone and Longo 2014), analytical models rarely succeed in indentifying proper and optimal solutions for L&T problems.
As for the supply chains reliability, we have to point out that most experts, for example (Klimov and Merkuryev 2008), think that the reliability is defined as a probability that a system will not fail before predicted time moment. From a known probability distribution (exponential distribution is the most commonly used life distribution for technical system reliability analysis (Ventsel and Ovcharov 1983; Andrew and Moss 2002; Rausand and Hoyland 2004) it is possible to define a mean time to failure.
For our purpose the studies, that contain the quantitative methods of assessing the reliability of supply chains, can be divided into two groups.
In the first group of studies the assessment of the reliability of supply chains is carried out on the basis of the so-called circuit reliability (serial, parallel and mixed compound of elements with different types of redundancy - «active/hot», «standby/cold») (Blanchard 2004). All estimates are based on the probability of faultless operation of the elements of chain.
The second group of studies contains failure models, which, by analogy with technical systems (Gertsbakh and Kordonsky 1966), can be presented by the following types:

- the model of the «perfect» or «ideal» order (Ballou 1999; Christopher 2011);
- the model of «supply and demand» (Kersten and Blecker 2006);
- the «just-in-time» model (Lukinskiy et al. 2014b).

The search for real supply chain efficiency and reliability formulas is difficult and it increases with the development of the theory. Therefore, quantitative methods and supply chains modelling are actively developing on modern information systems and information technologies (Bruzzone et al. 2004; Ivanov et al. 2011; Langevin and Riopel 2005).

Exactly мodelling and simulation is one of the most important available methodologies to investigate systems behavior where traditional approaches are unable to deal with their complexity and the high number of interacting phenomena or interoperable components (Longo 2011).

Thorough analysis and synthesis of scientific publications, monographs, textbooks on logistics and supply chain management enabled us to arrive at the following conclusions:

1. There has been a stable tendency of the development of analytic tools, which can be used to manage and improve SC business processes efficiency.
2. The process of the TLC model forming which appeared one hundred years ago in a first variant (Harris 1913) nowadays is a multileveled model and is continuing to develop.
3. To evaluate the supply chains reliability according to (Ballou 1999; Blanchard 2004; Christopher 2011), there is a most often used model which is a product of the probability of no-failure of Pi for each i-th logistics operation or function.
4. Models for the total logistics costs and evaluation of reliability are examined separately which contradicts the actual functioning supply chains.
5. Fundamentally new approach (from accessible sources to the authors) is presented in works (Lukinskiy et al. 2014a; Lukinskiy V.S. and Lukinskiy V.V. 2015) where the supply chain is considered as a recoverable system mainly due to the insurance stocks on the different levels of the logistic system.

1. METHODOLOGICAL APPROACH

The executed analysis of works of logistics and SCM (Bowersox and Closs 1996; Christopher 2011; Stock and Lambert 2001) lets us state that logictic approach is, in fact, is a system approach towards the research of social-economic and human-machinery systems.

For the calculation costs and the reliability indicators of logistics system let's use the idea of a simple supply chain (SSC). By «simple supply chain» we shall mean the following:

- a part of the logistics chain (channel), which include at least two major links of logistics system such as «supplier» and «consumer» that are connected to each other by logistics operations: purchase, order processing, transportation and storage, etc.
- SSC extension is possible due to main intermediaries («the third party» in logistics): carriers, freight forwarders, warehouses, etc.
- any supply chain can be represented as a set of individual SSC.

A supply chain is characterised by self-organization. Essentially supply chains are considered restorable, which is why when assessing reliability one should take into account this most important quality.

In accordance with described approach the supply chain can be presented as a discrete-continuous model and described as a graph, which is based on the Gantt chart.

In this case we have the supply chain in which the delivery of finished goods is made from the plant of manufacturer to warehouse or distribution center The chain includes 6 basic operations that must be made to fulfill the order: agreement of supply; order picking at warehouse; processing of documents for cargo dispatch; transportation (vehicle loading, cargo transportation, unloading); processing of documents when receiving cargo; placing of cargo at warehouse.

2. MODELS DEVELOPMENT FOR THE COSTS EVALUATIONS AND THE SC RELIABILITY INDEXES

The considered methodical approach allows pronouncing a hypothesis that the specification of the educed features of supply chains can be realized if there are three constituents presented: firstly, the dependences for the supply chains TLC; secondly, the equation for the supply chain reliability indexes evaluation; thirdly, a models complex which allows to figure out logistics operations reliability indexes using the parameters included in the TLC. Thus, the interconnection between the total costs and the supply chains reliability shows itself out in that way that the reliability indexes are calculated taking into account the TLC parameters and the expenses (fines) of the supply chains reliability support and renewal are taken into consideration at the TLC calculating process.

We consider it advisable to describe the models complex in three stages.

The first stage. Analysis of numerous researches has allowed us to create a TLC model as follows (for the normal distribution laws of random variables):

$$\begin{aligned} C_{\Sigma} &= C_{ps}\cdot A + \frac{A\cdot C_0}{Q} + \frac{A\cdot C_t}{Q} + \frac{Q}{2}\cdot C_{ps}\cdot f + \\ &+ C_{ps}\cdot f^{*}\cdot \sigma_s \cdot x_p + \frac{A}{Q}\cdot\sum_{j=1}^{n} C_{pl\_j}\cdot\sigma_s\cdot I(x_p)_j \end{aligned}, \qquad (1)$$

where, C_{ps} is the price from the supplier per unit in conventional units (c.u.), A represents the consumption (products) in units, C_o is ordering costs (where the expenses of order process and goods picking at the warehouse are included) in c.u., Q is order stock in units, C_t is transportation costs in c.u., f is storage costs of the current stock, in total price of products (share), f* is storage costs of an insurance stock, in total price of products (share), σ_s is general root-mean-square deviation of stock in units, x_p is the ratio of the normal law of distribution (Math), j – the type of violation (e.g. delay, lack of documents, wrong order picking and so on.), n – the violations types amount, $I(x_p)_i$ is the integral of losses which characterises the mean size of the violation; C_{pl_j} is the penalty in c.u. (fine size for the j-th violation kind).

The registration of the j-th expenses (fines) kind connected with the failures in supply chains or shortage, or delay at the order picking at the warehouse or transportation is done using the so-called integral of losses (Axsäter 2006) and that is the peculiarity of the equation (1)

$$I(x)=\int_x^\infty (t-x)\varphi(t)dt=\varphi(x)-x(1-\Phi(x)), \quad (2)$$

where $\varphi(x),\Phi(x)$ are accordingly the density and function of random variables distribution of x.

The second stage. To evaluate the reliability indexes let us assume that SSC includes six logistics operations (Figure 1) and every one of them is characterised by the reliable work probability of P_i. In the picture 1 the following indications are used:

1. Purchase, ordering is P_1;
2. Order picking at the warehouse (transportation) is P_2;
3. Supply control at the supplier warehouse is P_3 (the quantity evaluation is P_{31}, the quality evaluation is P_{32} and the documents authenticity is P_{33});
4. Transportation (from the supplier to the consumer) is P_4;
5. Order reception and control at the consumer's warehouse is P_5;
6. Placement at the warehouse is P_6.

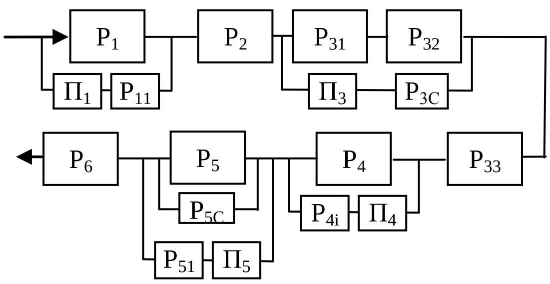

Figure 1: Calculation Chart For The Simple Supply Chain Reliability Evaluation

Along with the main modules in the chart there are logical switches Π_i for some logistic operations which allow us to choose different management solutions.

While calculating or modelling a logical switch allows us to consider various renewal variants if there is a failure at carrying out the i-th operation. If we speak about the circuit reliability calculation, then the i-th switch plays its main role and is taken into account at calculating as a component with a reliable work probability of $P_{\text{п}i}$. If we consider an alternative renewal variant, then the switch allows us to make a decision to use the insurance stocks (in the chart they are components P_{3C} and P_{5C}) or some other variants to restore the reliability of this operation implementation (e.g. using the goods substitute is P_{51}, changing the driving itinerary is P_{4i} and so on) that is $P_{\text{п}i}=1$. If the reservation is not used, the switch reliable work probability is equal to 0.

The general equation for the reliable work probability of the SSC as a system with a serial components uniting is written as following:

$$P_\Sigma=\prod_{i=1}^{n} P_i^* \quad (3)$$

where P_i^* is the reliable work probability of the i-th operation with the renewal taken into account.

It is obvious that the corresponding dependences considering the serial and parallel connection of components are formed for P_i^*. For example, for the third operation (the supply formation at the consumer's warehouse) the equation to calculate P_3^* is written like that:

$$P_3^*=P_{33}\cdot\left[1-(1-P_{31}\cdot P_{32})(1-P_{\Pi 3}\cdot P_{3C})\right], \quad (4)$$

where P_{33} is the reliable (correct) documents fulfilment probability; P_{31}, P_{32} respectively is reliable order processing probability according to the quantity and quality; $P_{\Pi 3}$ is a logical switch, $P_{\Pi 3}=1$; P_{3C} is supply reliability probability (the presence of the insurance stocks) at the supplier's warehouse.

The third stage. In Table 1 there are the failure models to evaluate the reliable work probability of the SSC components and there are short characteristics how to use them, as well that have been taken from the work (Lukinskiy V.S. and Lukinskiy V.V. 2015). The presented models are based on the general theory of reliability of complex systems and the disciplines that are included in the operations research (probability theory, the theory of stochastic processes, queuing theory, the theory of recovery, etc.), in particular, on the theorem on numerical characteristics, repeated experiments, the compositions of distributions, the transformation of random variables, etc.

In Table 1 there are main components for every logistic operation. With the help of these components the supply chains reservation is carried out.

Thus, not only does the calculations implementation with the use of the worked out models (see table 1) allow us to evaluate the reliability indexes of some certain operations and the whole SSC, but it also allows us to evaluate changing of the total logistic costs by taking the expenses (fines) into account and possible parameters variations of some certain logistic operations, as well.

Table 1: The Models For Calculation Of The Logistic Operations Reliable Implementation Probability In A Simple Supply Chain

Logistic operation	The model to evaluate P_i of the logistic operation	The model characteristic	Reservation components in SC
1.Purchase, order	«Demand X – Supply Y»	The random variables difference of Z=Y-X is considered	1. Choosing several suppliers. 2. Changing the parameters of demand and supply
2.Order picking at the supplier's warehouse	'Just in time' model	The sum (composition) of random variables $T=\sum\tau_i$, where τ_i is the implementation time of the i-th operation during the order picking	Combinatorial methods to minimise the picking time T
3.Formed order control	Probability model based on the total event probability formula	The use of the general theorem about repeated experiments; special cases: binomial distribution and Poisson's distribution	Insurance stocks at the warehouse; the use of goods substitute; delivery time postponement and others
4.Transportation (supplier-consumer)	'Just in time' model considering restrictions and delays while moving along the route.	See point 2	Choosing alternative variants (changing the route and kind of transportation, toll road sections, changing the crew and so on)
5.Supply control at the consumer's warehouse	See point 3 and inventory management strategy models, as well.	See point 3 in the view of the theorem about the numerical characteristics of sum of random number of random variables	See point 3
6.Place-ment at warehouse	Linear programming, heuristic methods	Nomenclature analysis of ABC, XYZ and others	The application of 'chaotic cells', RFID sensors and others

3. EVALUATION OF EFFICIENCY INDEXES AND SUPPLY CHAINS RELIABILITY

Having analyzed the first table models lets us conclude that most parameters included in them are random variables that are subjected to various distribution laws. So, the quantitative evaluation must be done with the use of probabilistic descriptions. It is known that analytical and numeral methods can be applied to figure out the sought-for parameters in a general case.

Since analytical methods application for the models from the table 1 is limited, there is a necessity to use other tools, for example, the Monte Carlo method (Ventsel and Ovcharov 1983; Taha 2011; Longo 2011).

In this work we are intending to create the modelling of every logistic operation as corresponding 'realisation' and 'experiment' in two variants. The first variant implies the use of basic values of random parameters. The second one is carried out in the view of external and internal reservation.

Subsequent statistical treatment will allow us to define the distribution parameters and laws which are necessary to calculate the reliability and costs (expenses) indexes included in TLC. Figure 2 shows us the principle block diagram for modelling the logistic operations for the simple supply chain.

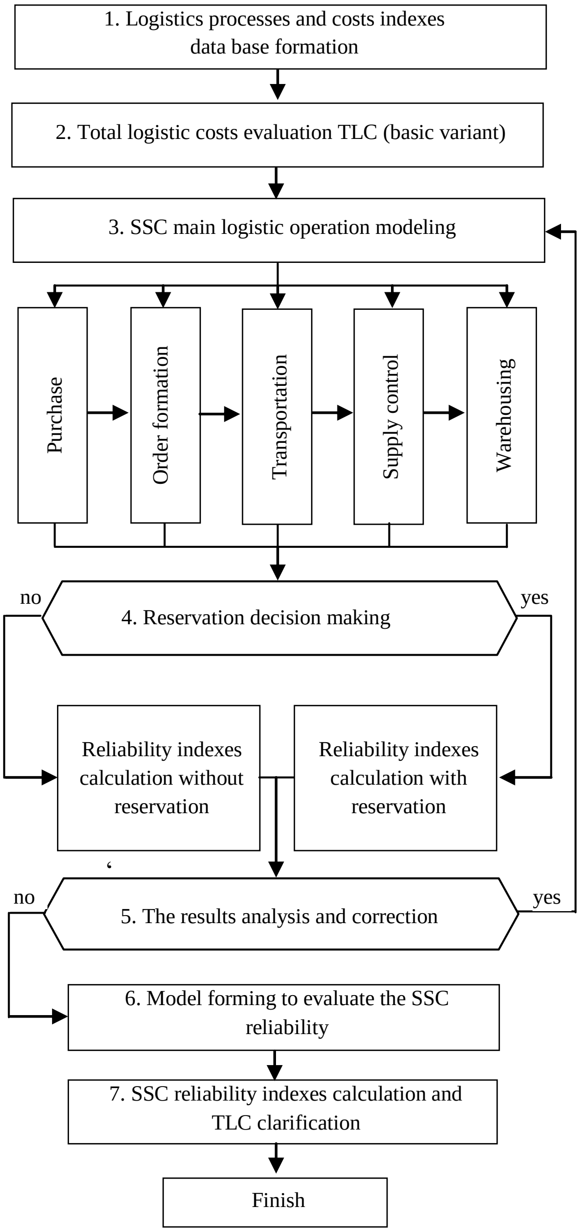

Figure 2: The Principle Block Diagram For Modelling The Logistic Operations For The Simple Supply Chain

The reliability indexes calculations results for the whole chain can be shown as a set of combinations with two extreme variants: either the reservation lack in all the operations, or in the view of maximum quantity of the reserve components in every logistic operation. It is obvious that when the analysis and correction have been carried out, we can choose the optimal variant with the minimal TLC and maximum reliability.

4. APPROBATION

The experimental verification of the developed methodics approach has been carried out using the published in different sources data and also gathered information about the reliability indexes of various logistic operations and functions at the warehouses (terminals) of transport companies and others.

Let us examine some logistic operations to illustrate the calculations implementation sequence based on the developed methodics approach.

We have taken the following parameters as initial figures (see formula 1): A= 1000 units, C_o=100 c.u., C_{ps}=50 c. u., f=0,2 (that is, the costs for the products unit storage a year are 10 c. u.).

If we use the well-known formulas (Stock and Lambert 2001), we will find the optimal order size Q_o = 141 units, the supply quantity a year N=7, costs minimum $C_{\sum min}$=1410 c. u.

Let us examine the logistic operation 'purchase' without reservation. Let us assume that the demand mean value $\overline{A}$ = 1000 units and the root-mean-square deviation σ_A=200 units; respectively, supplier abilities $\overline{A}_n = 1200$ units, σ_n=50 units.

According to the 'demand-supply' failure model the probability shortage absence (for the normal distribution laws) is calculated with the formula:

$$P = 1 - F\left(x_p = -\frac{\overline{A}_n - \overline{A}}{\sqrt{\sigma_n^2 + \sigma^2}} \right), \qquad (5)$$

where x_p is the ratio of the normal law of distribution. On the basis of x_p (according to the table from the Appendix A (Ballou 1999) we find

$$P = 1 - F\left(x_p = -\frac{1200 - 1000}{\sqrt{200^2 + 50^2}} \right) = 1 - F(-0{,}97) = 0{,}834$$

Let us use the integral of losses (according to the table from the Appendix B (Ballou 1999) to figure out the average deficit

$$\overline{A}_{sos} = \sqrt{\sigma_n^2 + \sigma^2} \cdot I(x_p = -0{,}97) =$$
$$= 206 \cdot 0{,}0882 = 18\, units$$

Let us assume that the fine for the products unit deficit C_{pl}=50 c. u. Then, the products short supply expenses are

$$C_{pl}^* = C_{pl} \cdot \overline{A}_{sos} = 900\ \text{c.u.}$$

These expenses must be considered in the formula (1) at the TLC calculation. It should be emphasized that in this example the purchase is carried out once a year.

Let us examine the variant with reservation when the second supplier takes part in the purchase tender and the faultless supply implementation probability is the same as the first supplier's one, that is, $P_{11}=P_1$ (see figure 1). For the parallel components connection we find

$$P_1^* = 1 - (1 - 1 \cdot 0{,}834)^2 = 0{,}972$$

So, we have managed to increase the purchase reliability on $\Delta = \frac{0{,}972 - 0{,}834}{0{,}972} \cdot 100 = 14\%$ at the expense of external reservation.

Let us examine the logistic operation 'the formed order control' which, substantially, implies the 'perfect order' evaluation. According the table 1 the calculation must be carried out by the total probability formula, but in this case we can only use formulas (3) and (4) for the faultless work probability for the serial and reserve components connection.

Let us assume that the faultless order picking probabilities according to the quantity P_{31} and quality P_{32} are even and equal to 0,9 and the reliable document processing probability is P_{33}=0,95. Then, if there is no reservation, the perfect order picking probability P_3 is calculated by the formula (3)

$$P_3 = 0{,}9 \cdot 0{,}9 \cdot 0{,}95 = 0{,}77$$

To figure the reservation by using insurance stocks at supplier warehouse we will use formula (4). If we take the initial data, and also P_{3C}=0,9 and $P_{\Pi 3}$=1, we will get

$$P_з^* = \left[1 - (1 - 0{,}9 \cdot 0{,}9)(1 - 1 \cdot 0{,}9)\right] \cdot 0{,}95 = 0{,}93,$$

where P^*_3 is probability of the perfect order forming with reservation.

Let us calculate the faultless implementation probability of all SSC operations, accordingly, without reservation

$$P_{\Sigma_{WR}} = 0{,}834 \cdot 0{,}894 \cdot 0{,}77 \cdot 0{,}773 \cdot 0{,}988 = 0{,}432$$

taking into account the external and internal reservation

$$P_{\Sigma_R} = 0{,}972 \cdot 0{,}894 \cdot 0{,}981 \cdot 0{,}84 \cdot 0{,}999 = 0{,}678$$

The calculations results for all logistic operations included SSC are given in Table 2.

Table 2: The Calculations Results Of The Implementation Probability Of The SSC Logistic Operations

Logistic operation	The P_i evaluation model	Calculation variants	
		Without reservation	With reservation
1. Purchase	'Demand-supply'	0,834	0,972
2. Picking (supplier's warehouse, transportation)	'Just in time'	0,894	0,894
3. Formed order control	'Perfect order'	0,810	0,981
	The same but in the view of documents accuracy	0,770	0,930
4. Transport ation (supplier-consumer)	'Just in time'	0,773	0,840
5. The control at the consumer's warehouse	'Perfect order' in the view of inventory management strategy	0,977	0,998
	The same but in the view of alternative (goods substitute)	0,988	0,999
For all the SSC operations		0,432	0,678

In Table 3 the expenses (fines) calculation results are brought for the two variants of supply chain. The analysis of table 3 shows that the reservation (as a result of competent management and process organisation) gives a substantial effect. Certainly, the first variant can serve as a base for the search of logistic operation parameters optimal combination to minimize the SSC costs and expenses.

It is obvious that the second variant reflects only one of possible solutions, as costs and expenses are calculated in the view of corresponding logistic operations faultless implementation.

If the random variables used in the examined models of logistic operations failures submit to the normal law, then calculations can be executed by means of the worked out formulas. However, for some SSC the row of parameters submits mainly to the asymmetrical distribution laws (Rayleigh, Veibulla, gamma distribution and others.). In this case the receiving of the adequate and transparent results is possible with the use of simulation modelling.

Table 3: Expenses (Fines) For The Logistic Operations Implementation In SSC

Logistic operation	Variants of expense calculation (c. u.)		Reliability recovery factors
	Without a reservation	With a reservation	
Purchase	900	250	Engaging the second supplier
Order picking (amount and quantity account)	1050	492	Supplier's insurance stocks forming
Transportation	115	70	Route changing (toll road sector)
Supply control	975	317	Consumer's insurance stocks forming
Total costs (taking into account $C_{\sum min}$)	4450	2539	

Calculations on the basis of block diagram (see figure 2) allows us to do the following conclusions:

- for most logistic operations models the amount of the modelled random variables hesitates from 2 to 6, and logical ones switch to 2;
- for some operations (for example, "purchase" or "placement at the warehouse") a modelling and calculation based on analytical dependences give close results;
- for the project calculations it is possible to be limited by the worked out failures models due to the lack of necessary statistical data for a modelling;
- maximal calculation results deviations obtained by a modelling and on the basis of failures models for logistic operations are 15-20%.

Thus, the SC examining as a renewable system due to the internal and external reservation allows to increase the indexes of faultlessness. So, for example, the registration of supplier and consumer's insurance stocks, engaging the second supplier possibility, the transportation route changing, for example (Kabashkin and Lučina 2015; Kopytov and Abramov 2013), and the use of goods substitute caused the increase of the SC reliable functioning probability for 36%.

5. CONCLUSION

1. An offered hypothesis legitimacy about intercommunication of total logistic costs and SC reliability indexes is confirmed, wherein the failure models of logistic operations and functions are the basic connective components.

2. The worked out approach originality lies in the fact that the first time formed complex for the SC efficiency and reliability evaluation which include the equation of total costs, model of renewable SC by reservation and failures models of basic logistic functions and operations complex.
3. The worked out methodical approach allows to calculate not only the reliability indexes but also to increase accuracy of total logistic costs evaluation by taking into account the expenses (fines), possible varying of separate logistic operations parameters, and also the latent connections.
4. It is necessary to emphasise that the row of questions requires the further researches related to the multi-nomenclature supply, necessity of various limitations registration, structuring and development of greater failure models amount for the SC, the calculations implementation possibility for the multilevel distributive systems.

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