O. FEDOROVICH, Yu. PRONCHAKOV, Yu. LESHCHENKO, A. YELIZIEVA

National Aerospace University "Kharkiv Aviation Institute", Ukraine

MODELING THE IMPACT OF THREATS AND VULNERABILITIES IN TRANSPORT LOGISTICS OF A DEVELOPING ENTERPRISE

A scientific and applied problem of modeling the impact of threats and vulnerabilities in the logistics of transportation of goods of a distributed production system was posed and solved. The relevance of the research topic is associated with the identification of significant threats and the emergence of vulnerabilities, which can lead to deterioration in the main indicators of a developing enterprise. The research solves of the task of increasing of logistic processes effectiveness of goods transportation in a distributed manufacturing system in emerging threats and manifestation of vulnerability conditions. A set of possible threats is analyzed and formed, which influence goods transportation in a heterogeneous transport system of distributed manufacture. A virtual experiment method is proposed for using the experts' opinions regarding the identification of threat factors using a developed multifactorial and multi-response experimental plan, where lines represent the factors and a combination of threat factors, and the columns are associated with possible threats. A manifestation of vulnerabilities risks and emerging threats is used as responses. A regressive dependence to identify the most important threat factors is formed. The cost indicators are used for solving optimization problems, which connected with vulnerability removal, the time of events to vulnerabilities neutralization and risks of threat emergence. The cost minimization associated with the removal (neutralization) of vulnerabilities that may appear when threats emerge. The agent model for simulation and event modeling of a logistic of transportation in a distributed manufacture in conditions of threat factors and vulnerability emergence is proposed. Agent-based modeling allows you to determine the time of goods movement without vulnerability emergence and time of goods movement with vulnerability emergence using possible risk generator. Mathematical methods used systems analysis, the theory of experiments planning, integer (Boolean) programming, agent-based and event modeling.

Keywords: distributed manufacture; logistics processes of transportation; vulnerabilities in logistic chains; threat factors; costs optimization; agent and event based modeling.

Introduction

The globalization of the economy has contributed to the development of logistics methods as the main tool that ensures the optimal movement of material flows in a distributed production system (aerospace, shipbuilding, automotive, etc.) [1, 2]. Nowadays the implementation of logistics processes is carried out using different types of interconnected transport systems with their characteristics and requirements for goods [3, 4]. The remoteness of manufacturing facilities and sources of supply leads to high costs, transportation time, and, most importantly, increasing various risks (transport breakdowns, failures, and accidents in transport systems, climatic changes, political and economic factors, terrorist acts, etc.) [5, 6]. Analysis of transport logistics publications [7, 8] showed the questions connected with possible threats impact on goods transportation were not reflected enough:

- analysis of heterogeneous transport systems of goods delivery with the goods transition (transshipment) from the one type of highway to another one (for instance, a goods transshipment from sea transport to rail);

- the factor of logistics globalization associated with routes crossed the state borders is not fully taken into account;

- the impact of terrorist threats on transport systems is not considered in detail;

- the impact of critical weather conditions factors (floods, extreme temperatures, fire, etc.) connected with global warming on the transport system and transportation logistics is not fully taken into account;

- the long and sometimes confusing transportation logistics chains, their impact on management and planning, which lead to failure of a goods transportation, are not reflected enough.

Therefore, the research of the impact of threat factors and the risks of vulnerability manifestation, in the form of restricted and critical places in the logistics of goods transportation of a distributed developing production, is relevant.

Formulation of the problem

Nowadays one of the main problems in logistics systems of goods transportations is sharply increasing risks connected with remoteness manufacturing objects and supply sources as well as using of mixed (heterogeneous) transport systems in long transit logistics chains [9]. Goods transfer from one transport system to another requires additional costs, increasing transportation time and risks regarding the emergence of new possible vulnerabilities.

In transport systems appearing of threats and the manifestation of vulnerabilities are associated with:

- obsolescence of transport systems (for example, obsolete roads and rails which are not corresponded to requirements of modern standards and transportation conditions with intensive transport flows);

- physical obsolescence (wear of materials and buildings, deterioration of strength over time);

- errors in project and design works, as well as during construction, installation, and routine maintenance;

- outdated methods of management and dispatching of transport flows.

The manifestation of vulnerabilities leads to failures and accidents, the occurrence of losses in the form of material losses, as well as emergencies, accidents, and catastrophes in transport systems.

An increasing of political and economic vulnerabilities, climate changings and possible terrorist acts and vandal acts lead to risks increasing connected with vulnerabilities implementation in logistics systems. The goal of the research is a solution to the problem of effectiveness increasing of goods transportation logistics processes in a distributed manufacturing system of developing enterprise in conditions of emerging threats and vulnerabilities.

The following tasks of the research are proposed to solve for the goal achievement:

a) identification of significant threat factors and a vulnerabilities manifestation in a transport logistics;

b) costs minimization, which is connected with the vulnerabilities removal (neutralization);

c) modeling of goods transportations taking into account threats and vulnerabilities.

The main indicators of the impact of threats and vulnerabilities in transport logistics are:

- an indicator of losses associated with the implementation of measures to eliminate possible manifestations of vulnerabilities and threats;

- an indicator of the time spent on measures to eliminate possible manifestations of threats and vulnerabilities;

- an indicator of the risk of vulnerability manifestation after taking measures of its elimination.

Identification of significant threat factors which implement to a vulnerabilities manifestation in a transport logistics

An important moment of a proposed research is an analysis and forming of a probable threat set which impact to goods transportation in a heterogeneous transport system. If the considered goods movement route was used for many times, there is statistics allows you to separate the certain threats as well as possible ones which may emerge when the j-th threat occurs. Difficulties arise in the formation of new transport routes for which there are no statistics. In this case, it is advisable to use an experts experience specializing in transport logistics. In this article for purposeful using of experts' opinions the method of virtual experimentation using the theory of an experiment planning is proposed. In a plan of virtual experimentation, the following components will be separated:

- rows (i) of an experiments plan are factors and combination of factors x_i of threats;

- columns (j) of an experiments plan connect with possible threats y_j;

- columns of responses (k) are implementation risks of separate vulnerabilities and the impact of emerging threats.

A virtual experimentation with using of experts' evaluations consists in the task of combining of possible threats factors for each i-th row of the experiment plan. The proposed virtual experiment is multifactorial and multi-response, which allows you to purposefully evaluate the impact of identified threats and the risks of vulnerabilities in the supply chains of goods transportation.

As an illustrated example, the use of a full factorial experiment (FFE) plan for threats and vulnerabilities studying in logistics chains of goods transportations is considered. Supposed after research a set of threats experts identified three important threats: an accident on a transport highway, a vehicle breakdown, a climatic influence. As columns of responses for threat factors impact evaluation the following vulnerabilities were used: critical part of a transport highway (l_1), critical transport node (l_2). The full factorial experiment involves the conduct of many experiments which corresponds to a complete enumeration of threats factors values. Supposed there are two possible values for each factor which associated with the j-th threat:

$$x_{ij} = \begin{cases} 1, \text{ if the } j-\text{th treat emerges} \\ \quad \text{in the } i-\text{th virtual experiment,} \\ 0, \text{ otherwise.} \end{cases} \quad (1)$$

Further it is necessary to carry out a complete enumeration of factors $N = 2^n$. For this example, the

number of experiments is $N=2^3=8$. In table 1 the full enumeration of values for three factors of threats is represented.

Table 1

A full enumeration of three threats factors values

№ of an experiment	Threats		
	y_1	y_2	y_3
1	0	0	0
2	0	0	1
3	0	1	0
4	0	1	1
5	1	0	0
6	1	0	1
7	1	1	0
8	1	1	1

To change the values of table 1 to the PFE plan representations, it is necessary to replace "1" with "+1", and "0" with "-1", which means the use of the upper and lower values of the factors of threats. In addition, it is need to add columns that are related to a combination of threat factors, as well as response columns l_1 and l_2. In table 2 FFE for three factors of threats is represented:

y_{ij}, y_{ijk} – correspond to combinations of threats factors I, j, k and vulnerabilities manifestation in the logistics of goods transportation;

l_{ij} – values of responses associated with vulnerabilities emergence l_1 and l_2.

As the response values, we will use the values of risks (scale 0...10), which lead to the manifestation of vulnerabilities and threats emergence. After carrying out virtual experiments using experts' assessments the following table was obtained (табл. 3).

Table 2

The FFE plan

№	Threats							Responses	
	y_1	y_2	y_3	y_{12}	y_{13}	y_{23}	y_{123}	l_1	l_2
1	-1	-1	-1	+1	+1	+1	-1	l_{11}	l_{21}
2	-1	-1	+1	+1	-1	-1	+1	l_{12}	l_{22}
3	-1	+1	-1	-1	+1	-1	+1	l_{13}	l_{23}
4	-1	+1	+1	-1	-1	+1	-1	l_{14}	l_{24}
5	+1	-1	-1	-1	-1	+1	+1	l_{15}	l_{25}
6	+1	-1	+1	-1	+1	-1	-1	l_{16}	l_{26}
7	+1	+1	-1	+1	-1	-1	-1	l_{17}	l_{27}
8	+1	+1	+1	+1	+1	+1	+1	l_{18}	l_{28}

Based on the results of the experiments, using the FFE, it is possible to construct an incomplete quadratic regressive dependence:

$$l = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 + b_{12} x_1 x_2 \qquad (2)$$
$$+ b_{13} x_1 x_3 + b_{23} x_2 x_3 + b_{123} x_1 x_2 x_3,$$

where b_i – coefficient that indicates the significance of the influence of the i-th threat factor and the manifestation of appropriate vulnerabilities;

b_{ij}, b_{ijk} – coefficients that indicate the significance of the influence of the threats combination and the certain vulnerabilities responses values l_1 та l_2.

Table 3

Experts' evaluations

№	Threats							Responses	
	y_1	y_2	y_3	y_{12}	y_{13}	y_{23}	y_{123}	l_1	l_2
1	-1	-1	-1	+1	+1	+1	-1	0	0
2	-1	-1	+1	+1	-1	-1	+1	1	1
3	-1	+1	-1	-1	+1	-1	+1	4	3
4	-1	+1	+1	-1	-1	+1	-1	6	5
5	+1	-1	-1	-1	-1	+1	+1	3	3
6	+1	-1	+1	-1	+1	-1	-1	4	3
7	+1	+1	-1	+1	-1	-1	-1	7	6
8	+1	+1	+1	+1	+1	+1	+1	9	8

Coefficients b_i, b_{ij}, b_{ijk} values are quite simple calculated using FFE. For instance,

$$b_1 = (x_{11} l_{11} + x_{12} l_{12} + x_{13} l_{13} + x_{14} l_{14} +$$
$$+ x_{15} l_{15} + x_{16} l_{16} + x_{17} l_{17} + x_{18} l_{18}) / N = 1.5.$$

Values of the other coefficients: $b_2=2.25$, $b_3=0.75$, $b_{12}=0$, $b_{13}=0$, $b_{123}=0.25$.

As the result of calculations will obtain:

$$l_1 = 4.25 + 1.5 x_1 + 2.25 x_2 + 0.75 x_3 + 0.25 x_1 x_2 x_3. \qquad (3)$$

Similarly, after calculations for l_2:

$$l_2 = 3.63 + 1.38 x_1 + 1.88 x_2 + 0.63 x_3 +$$
$$+ 0.13 x_1 x_2 - 0.13 x_1 x_3 + 0.38 x_2 x_3 + 0.13 x_1 x_2 x_3. \qquad (4)$$

The following conclusions can be received from obtained regressive dependences. The most significant threat factor is a vehicle breakdown ($b_2=2.25$ for l_1, $b_2=1.88$ for l_2). The less significant threat factor is a climatic influence on a transport system ($b_3=0.75$ for l_1, $b_3=0.63$ for l_2). An average value of impact of vulnerabilities has an accident in a transport highway. A medium-significant impact on vulnerability is exerted by an accident on a transport highway ($b_2=1.5$ for l_1, $b_2=1.38$ for l_2). When a combination of threats occurs, all three threats have the most impact on the response l_1. The value $b_{123} = 0.25$ is small, compared to alone emerging threats because of the low probability of a threats combination. For response l_2, the combination of the second and third threats (b_{23}) is the most important, but, as for response l_1, its simultaneous emergence is unlikely.

Costs minimization associated with removal (neutralization) of vulnerabilities

Measures associated with removal (neutralization) of vulnerabilities in transportations logistics of distributed manufacturing is the most important for developing enterprise.

It is necessary to minimize the costs of removal of possible vulnerabilities with a large number of possible vulnerabilities in logistics chains. The optimization task in terms of integer (Boolean) programming will be formulated. The following Boolean variables will be used:

$$x_{jk} = \begin{cases} 1, & \text{if for the } j\text{-th threat measures are taken to removal of the } k\text{-th threat,} \\ 0, & \text{otherwise.} \end{cases} \quad (5)$$

When solving the problem, the following indicators will be used: W – costs; T – time of measures regarding removal (neutralization) of vulnerabilities; R – risk of vulnerabilities manifesting after measures. Then, taking into account variables x_{jk}, will obtain:

$$W = \sum_{j=1}^{M} \sum_{k=1}^{n_j} w_{jk} x_{jk},$$

$$T = \sum_{j=1}^{M} \sum_{k=1}^{n_j} t_{jk} x_{jk}, \quad (6)$$

$$R = \sum_{j=1}^{M} \sum_{k=1}^{n_j} r_{jk} x_{jk},$$

where w_{jk}, t_{jk}, r_{jk} – costs, time and risks associated with measures regarding removal (neutralization) of the k-th vulnerabilities manifestation and emergence of the j-th threat.

It is necessary to minimize costs associated with removal (neutralization) of vulnerabilities manifestation and emergence of threats:

$$\min W, W = \sum_{j=1}^{M} \sum_{k=1}^{n_j} w_{jk} x_{jk}. \quad (7)$$

Taking into account the following limit:

$$T \le T', T = \sum_{j=1}^{M} \sum_{k=1}^{n_j} t_{jk} x_{jk},$$

$$\quad (8)$$

$$R \le R', R = \sum_{j=1}^{M} \sum_{k=1}^{n_j} r_{jk} x_{jk},$$

where T' – allowable time allotted for measures associated with removal (neutralization) of vulnerabilities which can manifest and emergence of threats;

R' – allowable risks remained after measures associated with removal (neutralization) of vulnerabilities.

Modeling of goods transportation taking into account threats and vulnerabilities

For studying of dynamic processes in transportation logistics of distributed manufacture in this paper the agent based and event simulation method is used [10]. The studying was carried out using the follow agents:

1 – agent "architecture of a TS", the network structure of the transport system (TS) for goods transportation is being set;

2 – agent "source of goods", nodes of TS from which the goods movement begins are being set;

3 – agent "consumer of goods", nodes of TS associated with receipt of goods are being set;

4 – agent "time delay at a TS node", used to simulate delays associated with interim storage or transshipment of goods;

5 – agent "time delay at a part of a highway", used to simulate a movement time of a good at a part of transport highway;

6 – agent "vulnerability", used to simulate possible failure (stop) in a movement of a good at a node or at a part of highway. Formed using the generator of probabilistic risk values;

7 – agent "time delay because of vulnerabilities", used in case of vulnerability manifestation and influence of emerging threats, to take measures to removal (neutralize) of vulnerabilities;

8 – agent "a threat", used to inject vulnerabilities and the appropriate threat;

9 – agent "a monitor", used for planning and management of events associated with goods movement;

10 – agent "results", used to obtain the modeling results (time of goods transportation without threats, time of goods transportation with emergence of threats and vulnerabilities, percent of time of goods idle because of manifestations of vulnerability, violation of the goods delivery time).

The modeling is performed multiple times to statistically average the results.

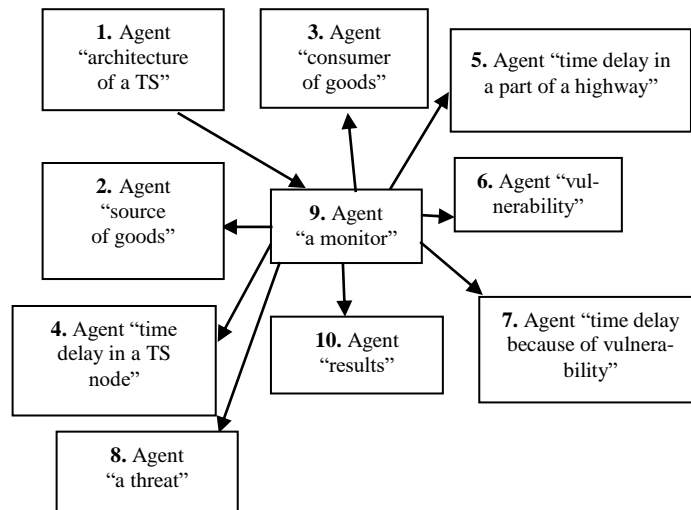In fig. 1 the structure scheme of the agent-based model is represented.

Fig. 1. The structure scheme of the agent-based model

The illustrated example of agent based modeling of a transport network in conditions of threats and emerge of vulnerabilities is considered. The architecture of TS is set using the agent "architecture of a TS" (fig. 2).
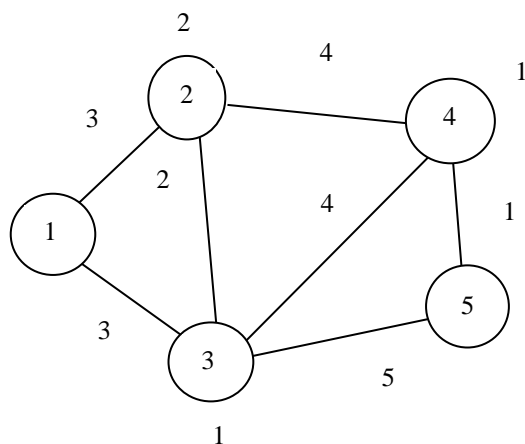

Fig. 2. An example of modeling
with threat factor impact

The agent "source of goods" forms from a node 1 request as a good, which is carried forward in a transport network. The node 5, in which the freight is received, is set using the agent "consumer of goods". All delays in TS are formed in hours using the agent "time delay in a TS node" and the agent "time delay in a part of a highway" (fig. 2). Vulnerability in the form of a bad state of a road cover in a part $3 - 5$ was formed using the agent "vulnerability". Threat in the form of weather conditions decreasing was formed using the agent "threat", which leads to the manifestation of vulnerability in a $3 - 5$ part. Time delay in 2.5 hours (averaging the delay value) due the emerging of threat and the manifestation of vulnerability is formed using the agent "time delay because of vulnerability". Using the

developed method of rational routes searching in a TS [12] the possible routes of good's movement from the first node to the fifth were formed and the duration T in hours was calculated:

1. 1-3-5, $T_1=9$
2. 1-3-4-5, $T_2=10$
3. 1-2-4-5, $T_3=11$
4. 1-2-3-5, $T_4=13$
5. 1-3-2-4-5, $T_5=14$
6. 1-2-4-3-5, $T_6=20$.

Because of the emerging of threats and the manifestation of vulnerability in a $3 - 5$ part the routs' time characteristics changed:

1. 1-3-5, $T_1=12,5$
2. 1-3-4-5, $T_2=10$
3. 1-2-4-5, $T_3=11$
4. 1-2-3-5, $T_4=15,5$
5. 1-3-2-4-5, $T_5=14$
6. 1-2-4-3-5, $T_6=22,5$.

We sort the obtained routes according to the values of the movement time:

2. 1-3-4-5, $T_2=10$
3. 1-2-4-5, $T_3=11$
1. 1-3-5, $T_1=12,5$
5. 1-3-2-4-5, $T_5=14$
4. 1-2-3-5, $T_4=15,5$
6. 1-2-4-3-5, $T_6=22,5$.

The following results of the modeling were formed using the agent "results":
1. The shortest route of goods' delivering with absence of threat is 1-3-5 with time delay in hours $T_1=9$.

2. The shortest route with emerging of threat and the manifestation of vulnerability is 1-3-4-5 with time delay in hours $T_2 = 10$.

Conclusion

In the paper, the research of logistics processes associated with goods transportation in a distributed manufacturing system was carried out. The research of threats impact on a transport logistics of developing enterprise was paid attention mostly. The analysis of possible threats as well as vulnerabilities was carried out. The method of determining significant factors and the emergence of the appropriate vulnerabilities in a heterogeneous transport system is represented. Costs optimization associated with measures regarding removal (neutralization) of vulnerabilities taking into account time limits and possible risks is carried out. The simulation model of goods movement in a heterogeneous transport system taking into account emerging threats and vulnerabilities was created. A scientific novelty of the carried out research associated with approach development directed in removal (neutralization) of threats impact and emerging vulnerabilities in a logistics of manufacturing goods transportation which, in opposite to existing, allows your system and complexity research the problem of transport logistics in a distributed manufacturing system.

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МОДЕЛИРОВАНИЕ ВЛИЯНИЯ УГРОЗ И УЯЗВИМОСТЕЙ В ЛОГИСТИКЕ ПЕРЕВОЗОК РАЗВИВАЮЩЕГОСЯ ПРЕДПРИЯТИЯ

О. Е. Федорович, Ю. Л. Прончаков, Ю. А. Лещенко, А. В. Елизева

Поставлена и решена научно-прикладная задача моделирования воздействия угроз и уязвимостей в логистике транспортировки грузов распределенной производственной системы. Актуальность темы исследования связана с выделением существенных угроз и появлением уязвимостей, что может привести к ухудшению основных показателей развивающегося предприятия. Целью исследования, которое рассматривается в данной публикации, является решение задачи повышения эффективности логистических процессов транспортировки грузов в распределенной производственной системе в условиях возникающих угроз и проявления уязвимостей. Анализируется и формируется множество возможных угроз, влияющих на перевозку грузов в разнородной транспортной системе распределенного производства. Предлагается метод виртуального эксперимента для использования мнений экспертов по выявлению факторов угроз с помощью разработанного многофакторного и многооткликового плана эксперимента, где строки плана представляют факторы и комбинацию факторов угроз, а столбцы связаны с возможными угрозами. В качестве отзыва используются риски проявления уязвимостей и возникающие при этом угрозы. Формируется регрессивная зависимость для выявления наиболее важных факторов угроз. При решении оптимизационной задачи используются показатели расходов, связанных с устранением уязвимостей, проведение мероприятий по нейтрализации уязвимостей и риски проявления уязвимостей. Проводится минимизация расходов, связанных с устранением (нейтрализацией) уязвимостей, которые могут проявиться при возникновении угроз. Предлагается агентная модель для имитационного событийного моделирования логистики перевозок в распределенном производстве, в условиях факторов угроз и проявления уязвимостей. Агентное моделирование позволяет выявить время движения грузов без проявления уязвимостей и время движения грузов с проявлениями уязвимостей с использованием вероятного генератора рисков. Использованы математические методы: системный анализ, теория планирования экспериментов, целочисленное (булево) программирование, агентное имитационное событийное моделирование.

Ключевые слова: распределенное производство; логистические процессы транспортировки; уязвимости в логистических цепях; факторы угроз; оптимизация расходов; агентное имитационное событийное моделирование.

МОДЕЛЮВАННЯ ВПЛИВУ ЗАГРОЗ І ВРАЗЛИВОСТЕЙ
У ЛОГІСТИЦІ ПЕРЕВЕЗЕНЬ ПІДПРИЄМСТВА, ЩО РОЗВИВАЄТЬСЯ

О. Є. Федорович, Ю. Л. Прончаков, Ю. О. Лещенко, А. В. Єлізєва

Поставлено та вирішено науково-прикладну задачу моделювання впливу загроз та вразливостей в логістиці транспортування вантажів розподіленої виробничої системи. Актуальність теми дослідження пов'язана з виділенням суттєвих загроз та появою вразливостей, що може призвести до погіршення основних показників підприємства, що розвивається. Метою дослідження, яка розглядається у даній публікації, є вирішення задачі підвищення ефективності логістичних процесів транспортування вантажів у розподіленій виробничій системі в умовах виникаючих загроз та прояви вразливостей. Аналізується та формується множина можливих загроз, які впливають на перевезення вантажів у різнорідній транспортній системі розподіленого виробництва. Пропонується метод віртуального експерименту для використання думок експертів щодо виявлення факторів загроз за допомогою розробленого багатофакторного та багатовідкликового плану експерименту, де строки плану являють фактори та комбінацію факторів загроз, а стовпці пов'язані з можливими загрозами. В якості відкликів використовуються ризики прояву вразливостей та виникаючі при цьому загрози. Формується регресивна залежність для виявлення найбільш важливих факторів загроз. При вирішенні оптимізаційної задачі використовуються показники витрат, зв'язаних з усуненням вразливостей, час проведення заходів щодо нейтралізації вразливостей та ризики прояви вразливостей. Проводиться мінімізація витрат, пов'язаних з усуненням (нейтралізацією) вразливостей, які можуть проявитися при виникненні загроз. Пропонується агентна модель для імітаційного подійного моделювання логістики перевезень у розподіленому виробництві, в умовах факторів загроз та прояви вразливостей. Агентне моделювання дозволяє виявити час руху вантажів без прояви вразливостей та час руху вантажів з проявами вразливостей з використанням вірогідного генератора ризиків. Використано математичні методи: системний аналіз, теорія планування експериментів, цілочисельне (булеве) програмування, агентне імітаційне подійне моделювання.

Ключові слова: розподілене виробництво; логістичні процеси транспортування; вразливості у логістичних ланцюгах; фактори загроз; оптимізація витрат; агентне імітаційне подійне моделювання.

Федорович Олег Євгенович – д-р техн. наук, проф., зав. каф. комп'ютерних наук та інформаційних технологій, Національний аерокосмічний університет ім. М. Є. Жуковського «Харківський авіаційний інститут», Харків, Україна.

Прончаков Юрій Леонідович – канд. техн. наук, доцент, декан факультету програмної інженерії та бізнесу, Національний аерокосмічний університет ім. М. Є. Жуковського «Харківський авіаційний інститут», Харків, Україна.

Лещенко Юлія Олександрівна – канд. техн. наук, доцент каф. комп'ютерних наук та інформаційних технологій, Національний аерокосмічний університет ім. М. Є. Жуковського «Харківський авіаційний інститут», Харків, Україна.

Єлізєва Аліна Володимирівна – канд. техн. наук, доц. каф. комп'ютерних наук та інформаційних технологій, Національний аерокосмічний університет ім. М. Є. Жуковського «Харківський авіаційний інститут», Харків, Україна.

Oleg Fedorovich – Doctor of technical sciences, professor, head of department of Computer Science and Information Technologies, National Aerospace University "Kharkiv Aviation Institute", Kharkiv, Ukraine,
e-mail: o.fedorovych@khai.edu, ORCID: 0000-0001-7883-1144.

Yurii Pronchakov – Candidate of Technical Sciences, PhD, Associate Professor, Dean of the Software Engineering and Business Faculty, National Aerospace University "Kharkiv Aviation Institute"; Kharkiv, Ukraine,
e-mail: pronchakov@gmail.com, ORCID: 0000-0003-0027-1452.

Yuliia Leshchenko – Candidate of Technical Sciences, PhD, Associate Professor of the Department of Computer Sciences and Information Technologies, National Aerospace University "Kharkiv Aviation Institute"; Kharkiv, Ukraine,
e-mail: j.leshhenko@khai.edu, ORCID: 0000-0001-9232-697X.

Alina Yelizieva – Candidate of Technical Sciences, Associate Professor of the Department of Computer science and information technologies, National Aerospace University "Kharkiv Aviation Institute", Kharkiv, Ukraine,
e-mail: a.elizeva@khai.edu, ORCID: 0000-0002-8228-9383.