Information Risk Analysis for Logistics Systems

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Abstract. The algorithm for calculation of the information risk is suggested. The algorithm takes into account the flows of all the components of the transportation system, the quality of their interaction, restrictions, and probability distribution. By using this algorithm the logistics company or intelligent transportation system gets the data on the assessment of the information risks, which helps the decision maker to decide whether it is reasonable to conclude the contract or not.

Keywords: Information risk analysis · Algorithm · Logistics information system

1 Introduction

The importance of management of information risks is undoubtful. Effective management of material and related (information, financial) flows aimed at achieving corporate objectives with optimal resource expenditures is a key factor for the success in today's business. Selection of the optimal relations between the risk and business activity level and the profitability and reliability based on a risk assessment is a significant part of the business decision-making process.

Information technologies have transformed many industries and now are transforming transportation systems. Almost all modern transportation systems use information technologies and specialized software products to solve the problem of rationalization of product flows and related financial and informational flows. An important aspect of this problem is management of risks in the supply chains [1, 2].

Risk management is the process of risk identifying and assessing and taking steps to reduce the risk to an acceptable level [3]. Organizations use the risk assessment, the first step in the risk management methodology, to determine the extent of the potential threat, vulnerabilities, and the risk associated with an information technology system. The output of this process helps to identify appropriate controls for reducing or

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eliminating the risk in support decision making in business. In solving the problems of purchase, transportation, and distribution of goods (transport tasks) intelligent transportation system (ITS) take into account the risk factors, the effects of which should be considered in the process of information flow management [3, 4].

This paper considers an algorithm for the calculation of the information risks that arise in the transportation and distribution of material resources in logistics systems. The algorithm relies on the mathematical apparatus of Markov chains based on the Kolmogorov differential equations.

2 Algorithm for Assessment of Information Risks

Optimization of information flows is accompanied by various information risks. The Information Risk (IR) is the risk of loss (in the form of damage or lost profit) resulting from the use of information technologies by a company. In this context the IR is obtained by multiplying the maximum possible damage by the probability of passing through the entire route. IR is a function of time. In other words, IR can be presented in terms of the damage expressed in monetary units by which the logistics information system operates.

The transportation task involves the solution of the problem of delivery of goods to specified places at specified times. It is assumed that the routes to the points of delivery and the capacities of these routes are known. By analyzing the maximum loss Sloss in the case of nonperformance of the order and the imposition of penalties and also the acceptable risk approved in a particular logistics company, the decision maker (DM) must accept or reject the order for the transportation of goods.

The available models of solution of such tasks of the calculation of information risks typically use standard methods [3–7]. However, these models do not use the mathematical apparatus of Markov chains based on Kolmogorov differential equations [4] which allows one to increase the reliability of the assessment and which has demonstrated its efficiency. Such an approach to the solution of the problem of IR assessment is new.

Let us give a formalized statement of the problem in the general form. There are N points at different locations (district, city, several cities, etc.). We refer to one point as a point of departure, and the remaining N-1 points are called points of delivery. (If there are k points of departure, it is necessary to solve the problem k times).

The means of communication between all points are given. There can be both a one-way or two-way traffic between the points. In addition, we set the function of traffic capacity between the vertices (points) $f\_prop_{ij}(t)$ that depends on the time of the day. The function is expressed by dimensionless values ranging from 0 to 1.

We assume that a logistics company has received a commercial offer to enter into a contract for the delivery of goods from the point of departure to n ($n < N$) points of delivery. In addition, the shipping and delivery times are strictly defined. The decision maker who knows the admissible risk approved by the logistics company (for example, 30 monetary units) and takes into account the information from intelligent transportation system, the most important part of which is the IR calculated by ITS, accepts or rejects the proposal. After this the problem is considered to be solved.

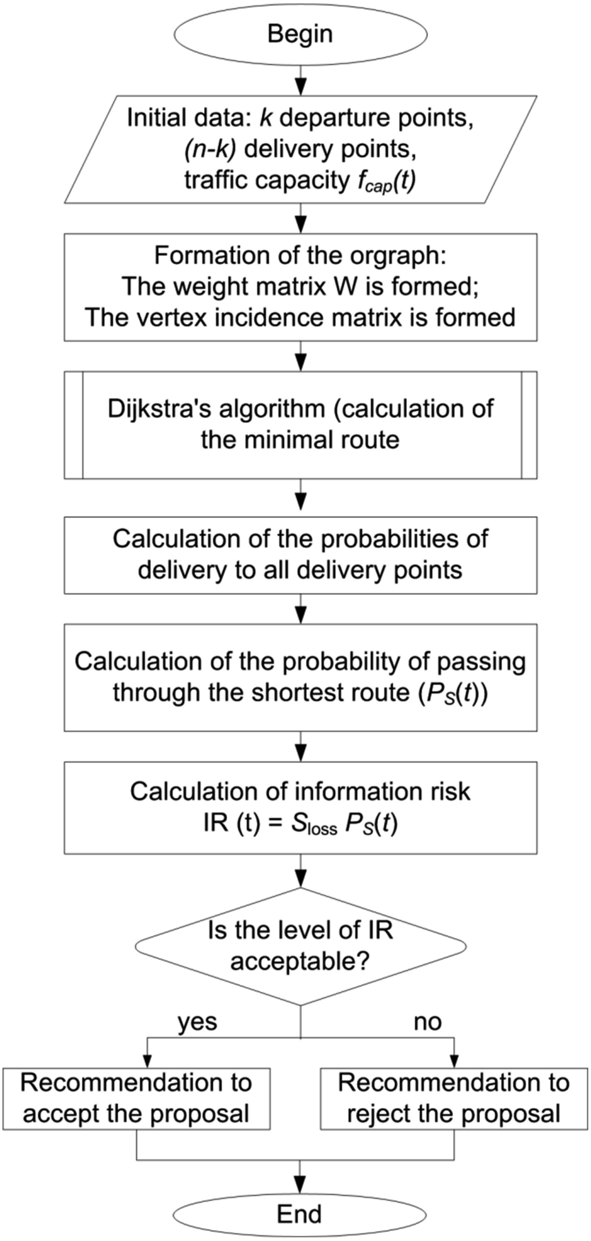

Fig. 1. The decision support algorithm

The decision support algorithm for assessment of information risks we suggest can be represented by the diagram shown in Fig. 1.

Let us consider basic steps of the algorithm.

1. **Formation of the Digraph**

A mathematical model in the form of a digraph (for instance, the or graph) shown in Fig. 2) is built. The choice of the digraph is based on the initial data on existing routes, and a possible type of traffic (one-way or two-way) is taken into account. In the digraph the two-way traffic is shown by bi-directional arrows and one-way traffic is shown by unidirectional arrows.

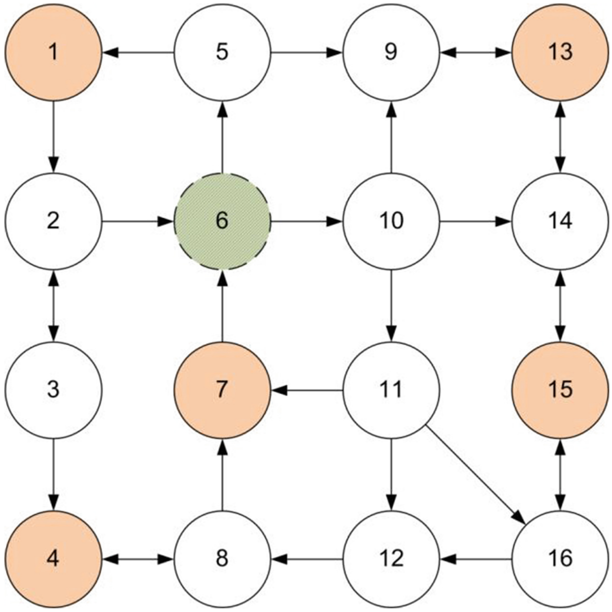

Fig. 2. Schematic of the vertices of departure and delivery 6 – vertices of departure. 1, 4, 7, 13 and 15 – vertices of delivery

The points of departure and destination are vertices G_1 and the roads are the arcs that connect the vertices. In the case of one-way traffic, different weights are assigned to the arcs connecting node i and node j and node j and node i. If there is no traffic between the points, the weight of the corresponding arc is considered to be infinite. In this case there is no bi-directional or unidirectional arrow at the digraph.

The weight matrix **W** is formed. Element w_{ij} is taken to be the time required to move cargo from node i to node j multiplied by the road capacity between the i-th and j-th vertices $f\_prop_{ij}(t)$ [8–10]. The time is equal to the distance between the i-th and *j*-th vertices divided by the allowed velocity between these vertices. All the necessary data are available in the database of the ITS. By using the information on the connections between the vertices obtained from the ITS database, the vertex incidence matrix $\mathbf{A}_{\text{vert.inc.}}$ is formed [11]. The digraph is formed on the basis of information on all *n* vertices of destination.

2. **Calculation of the Shortest Route**

At this stage, the Dijkstra's algorithm is performed *n* times, and the shortest route in the digraph is calculated. As a result, the shortest route passing through all the given vertices is formed.

3. **Calculation of the Probability of Reaching Vertices**

The probability of delivery of goods to specified points as a function of time is calculated. These points are indicated by the vertices which are finite at the portions that constitute the shortest route. For this purpose, the Kolmogorov systems of ordinary differential equations (SODE) are generated and solved for all portions of the resulting route.

4. **Calculation of IR**

By using all the solutions of Kolmogorov SODE and the theorem of multiplication of probabilities, the probability of passing through the shortest route ($P_S(t)$) including all the given vertices as a function of time *t* is calculated [16]. The information risk is calculated as [3, 12]

$$\mathrm{IR}(t) = S_{\text{loss}} \cdot P_S(t). \tag{1}$$

3 Implementation of the Method

Let us calculate the IR according to the algorithm of IR assessment we have developed. First of all we specify the initial data.

We assume that there is a supplier (vertices 6) of goods. At 2 PM he got an offer to conclude a contract for the delivery of goods to five consumers which are at different locations (vertices 1, 4, 7, 13, and 15). We assume that the maximum loss S_{loss} is 80,000 rubles. The acceptable risk is 30,000 rubles.

The decision maker rejects or accepts the proposal on the basis of the assessment of IR with the help of ITS.

According to the algorithm given above, the calculation of IR is performed as follows.

Step 1. Figure 2 shows schematically the vertices of departure and delivery.

We specify, according to this figure, the vertex incidence matrix **A** [11]. Element $a_{i,j} \in A$ shows the number of arcs emerging from the *i*-th node and coming to the *j*-th node.

$$A = \begin{pmatrix}
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 & 0
\end{pmatrix}$$

Let us calculate the matrix of weights W. To this end, we specify the distance between the vertices (in the form of a list where the first number in the square brackets shows the number of the node from which the arc of the digraph emerges and the second number shows the number of the node to which the arc of the digraph comes. After the square brackets there is the number indicating the weight of the arc, i.e., the distance between the vertices in km.

{[1,2],12},{[2,3],11},{[2,6],11},{[3,2],11},{[3,4],14},{[4,8],12},{[5,1],7},{[5,9], 11},{[6,5],14},{[6,10],11},{[7,6],8},{[8,4],12},{[8,7],10},{[9,13],8},{[10,9],11}, {[10,11],8},{[11,7],15},{[11,12],6},{[11,16],5}, [12,8],12}, {[13,9],8}, {[13,14],11}, {[14,13],11},{[14,15],8}, {[15,14],8},{[15,16],7}, {[16,12],6}, {[16,15],7}.

For simplicity, we assume that the road capacity between the points $f\_prop_{ij}(t)$ is the same at all routes and is equal to 0.8. We also assume that the allowed speed in this area is the same everywhere and is equal to 50 km/h.

Then we calculate the matrix of weights W and construct the digraph shown in Fig. 3.

By applying the algorithm developed above, we calculate the shortest route including vertices 1, 4, 7, 13 and 15. This route is as follows

[[6,5,1],[1,2,3,4], [4,8,7], [7,6,10,9,13], [13,14,15]].

Step 2. According to the data obtained at the first step, we write the Kolmogorov SODE.

$$\begin{cases}
\dot{P}_1(t) = P_5(t) \\
\dot{P}_5(t) = -P_5(t) + P_6(t) \\
\dot{P}_6(t) = -P_6(t) \\
P_6(0) = 1,\ P_1(0) = P_5(0) = 0,\ P_1(t) + P_5(t) + P_6(t) = 1.
\end{cases}$$

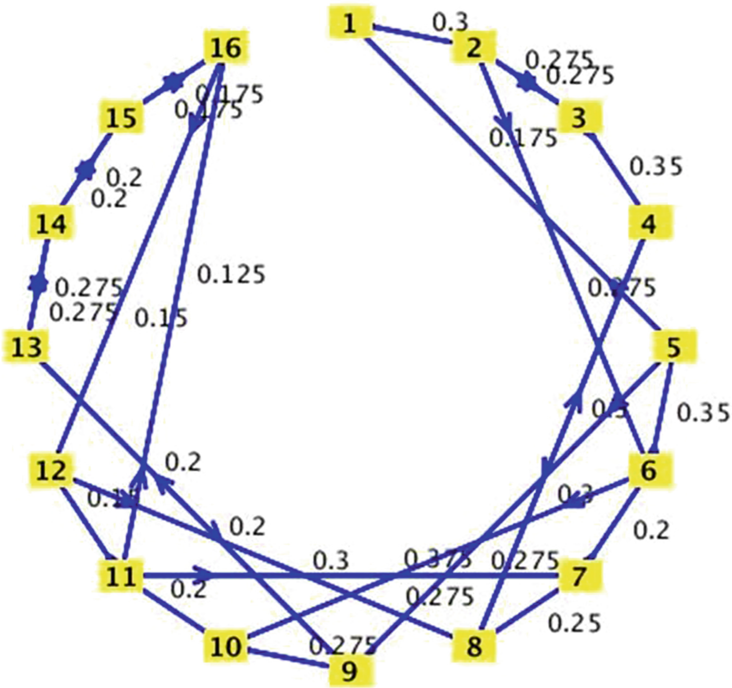

Fig. 3. Digraph built from the data of the example

$$\begin{cases} \dot{P}_1(t) = -P_1(t) \\ \dot{P}_2(t) = -P_2(t) + P_1(t) \\ \dot{P}_3(t) = -P_3(t) + P_2(t) \\ \dot{P}_4(t) = P_3(t) \\ P_1(0) = 1,\ P_2(0) = P_3(0) = P_4(0) = 0,\ P_1(t) + P_2(t) + P_3(t) + P_4(t) = 1. \end{cases}$$

$$\begin{cases} \dot{P}_4(t) = -P_4(t) \\ \dot{P}_7(t) = P_8(t) \\ \dot{P}_8(t) = -P_8(t) + P_4(t) \\ P_4(0) = 1,\ P_7(0) = P_8(0) = 0,\ P_4(t) + P_7(t) + P_8(t) = 1. \end{cases}$$

$$\begin{cases} \dot{P}_6(t) = -P_6(t) + P_7(t) \\ \dot{P}_7(t) = -P_7(t) \\ \dot{P}_9(t) = -P_9(t) + P_{10}(t) \\ \dot{P}_{10}(t) = -P_{10}(t) + P_6(t) \\ \dot{P}_{13}(t) = P_9(t) \\ P_7(0) = 1,\ P_6(0) = P_9(0) = P_{10}(0) = P_{13}(0) = 0,\ P_6(t) + P_7(t) + P_9(t) + P_{10}(t) + P_{13}(t) = 1. \end{cases}$$

$$\begin{cases} \dot{P}_{13}(t) = -P_{13}(t) \\ \dot{P}_{14}(t) = -P_{14}(t) + P_{13}(t) \\ \dot{P}_{15}(t) = P_{14}(t) \\ P_{13}(0) = 1,\ P_{14}(0) = P_{15}(0) = 0,\ P_{13}(t) + P_{14}(t) + P_{15}(t) = 1. \end{cases}$$

We solve these SODE. The result of the solution of SODE will be the probability of reaching a particular node vs time. In this example analytical solutions are possible.

Step 3. By using all the solutions of Kolmogorov SODE obtained at Step 2 and the multiplication theorem of probabilities, we calculate the probability of passing through the shortest route ($P_S(t)$) including given vertices as a function of time t (general probability). After this we calculate IR [3, 12]:

$$IR(t) = S_{loss} \times PS(t). \tag{2}$$

The results obtained at this Step are shown in Figs. 4 and 5 in a graphic form.

As one can see from the data presented in Fig. 5, the accessible risk equal to 30 monetary units is achieved if the terms of the contract on the delivery of the goods state that the delivery time may be greater than 9.1 h. Therefore, in this case the decision maker has the data which can reduce the risks at the conclusion of the contract.

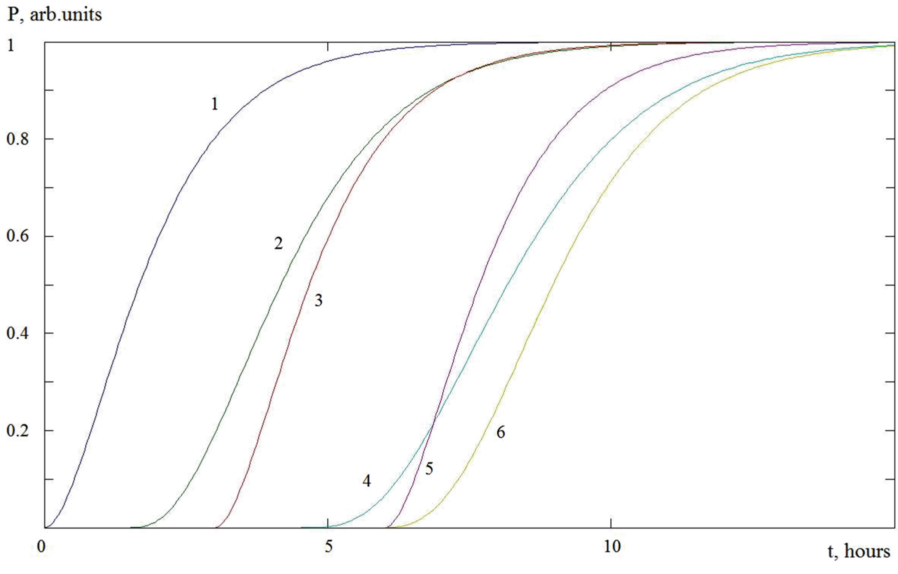

Fig. 4. Probabilities of reaching specified vertices and general probability as a function of time for passage through the shortest route: 1 – vertex 1, 2 – vertex 4, 3 – vertex 7, 4 – vertex 13, 5 – vertex 15, 6 – total probability

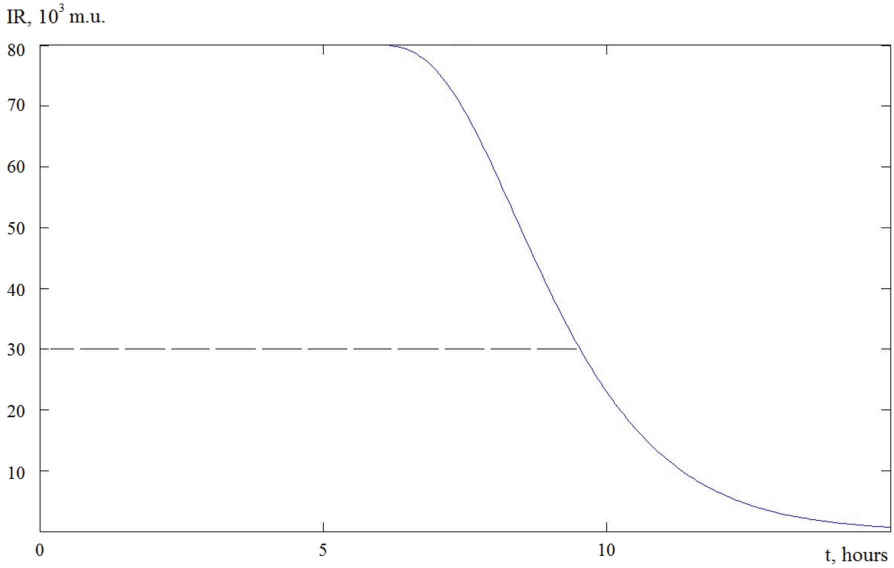

Fig. 5. Variation in information risk as a function of passage through the shortest route

4 Conclusion

The algorithm suggested in the paper allows one to assess the information risks arising in transportation or distribution of material resources. The algorithm for calculation of the information risk takes into account the flows of all the components of the vehicular network, the quality of their interaction, restrictions, and probability distribution. By using this algorithm the logistics company or intelligent transportation system gets the data on the assessment of the information risks, which helps the decision maker to decide whether it is reasonable to conclude the contract or not.

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