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LOGISTICAL SUPPLY AND SALES MANAGEMENT IN HETEROGENEOUS CARGO TRANSPORT INFRASTRUCTURE

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Abstract:

The article deals with crucial task involving development of methods and models of cargo traffic logistical management in the product supply and sales chain in the context of geographical dispersion of logistical chain participants and complicated cargo delivery channels in heterogeneous transport network. A method for creating cargo delivery channels has been developed. The author has proposed a method for calculating the main indicators of cargo traffic using a multiphase simulation model with due account for intensity of cargo traffic in the distribution centers and availability of additional cargo transshipment points in heterogeneous transport network. The article describes a model of cargo traffic management using fractals and agent-based modeling, and proposes a sequence of formation of fractal management model where fractal hierarchy corresponds to hierarchy of logistical chain.

Introduction

Nowadays global activity of the companies has led to dispersion of such operations as supply, production, product distribution and customer service among multiple organizations around the world, therefore, complexity of transport networks used for cargo delivery to end consumers should be taken into account [1-3]. As a result, the importance of supply chains that provide timely cargo delivery of required quality and in the required amount with minimal cost for storage and transportation has greatly increased [4]. In addition, it should be taken into consideration that companies and corporations dealing with mass production often use different traffic arteries for cargo delivery, which in turn requires development of methods for justification and selection of cargo transshipment points in case of interchange of traffic arteries [5]. Transition of goods from one traffic artery to another leads to additional problems and costs that should be taken into consideration in the logistics of multimodal transportation. Optimization of these costs is an urgent task in the logistical delivery of goods to consumers [6].

Problem statement

Development of an effective cargo traffic distribution logistical system involves a reasonable selection of distribution channels of finished products from a producer to end consumers in the context of changing requirements for cargo delivery. Selection and justification of methods and models of cargo traffic management in a distribution logistical supply and sales chain with due account for heterogeneous transport network in the context of multimodal transportation have not been received adequate attention in scientific publications. Therefore, development of methods and models of cargo traffic logistical management in the context of geographical dispersion of logistical chain participants and complex cargo delivery channels in heterogeneous transport network is a crucial task.

Main part: In this article logistic distribution system (LDS) means a logistic system which includes not only producers and consumers, but also a lot of transshipment points (TP) and products distribution points in heterogeneous transport network which are created if traffic arteries of heterogeneous transport network are located close enough to each other or located in the same area. Selection of transshipment points of heterogeneous transport network may vary depending on the selected route of cargo delivery. Taking into account specific nature of TPs, two types of TPs are described herein:

– stationary TPs intended for stocking and storage of products which serve as distribution centers (DC);

– temporary TPs intended for cargo transshipment in heterogeneous transport network where different traffic arteries are located close enough to each other or in the same area which serve as junction points of the sales network.

The subject matter of the article is a constantly changing and evolving system associated with the use of heterogeneous elements in the construction of the system structure, the need for joining various transport systems, and complex dynamics of cargo traffic the channels of which are formed through integration of channels of separate networks. In this connection it is necessary to analyze structural, dynamic and managerial aspects of the system, which will enable to comprehensively assess effectiveness using proposed indicators and to provide advice for planning, upgrading and management of supply and distribution channels.

Solution of the task involving formation of the structure of cargo delivery channels includes several stages.

1. Justification for the use of stationary TPs for storage, stocking and cargo transshipment. This requires:

a) segmentation of finished product consumers based on the analysis of consumption rate and geographical proximity of consumers, which is carried out by means of cluster analysis (figure 1) in order to form multiple location options for storage and stocking of products.

This segmentation results in the formation of a set of clusters the dispersion centers of which constitute location options for DCs;

b) comparison of multiple options (possible options of DCs location obtained earlier) on the basis of multi-criteria optimization in the context of possible fuzziness of input data [7]. The use of fuzzy ranking (evaluation of the degree of importance / conformity of criteria and options using fuzzy membership functions) enabled to use the method for both quantitative and qualitative criteria. The advantage of the proposed method includes identification of both the best and worst options of DCs location. It is expected that a compromise option should be the closest to the positive (ideal) solution, as well as it should be at an acceptable distance from the negative (worse) solution. As a result of the task solution, many location options for DCs have been ranked based on specified criteria, and the best options of DCs location have been selected.

Step 1. To represent multiple consumers as a set of clusters $I=\{I_1, I_2, ..., I_n\}$ $\{I_1\}$, $\{I_2\}$, …, $\{I_n\}$. Each consumer is assigned the coordinates $\{X, Y\}$ and product consumption rate Λ which determine the distance between the clusters. To take Euclidean metric square as a measure $d_{ij}^2=\left(X_i-X_j\right)^2+\left(Y_i-Y_j\right)^2+\left(\Lambda_i-\Lambda_j\right)^2$ and to determine the distance matrix $D=\left\{d_{ij}^2\right\}$

↓

Step 2. To select two clusters $\{I_i\}$ and $\{I_j\}$, the distance between which is minimal: $d_{ij}^2=\min\left\{d_{ij}^2, i\neq j\right\}$, and to combine them into a single cluster $\{I_i, I_j\}$. To obtain a new set of clusters which already consists of $n-1$ clusters: $\{I_1\}$, $\{I_2\}$, $\{I_i, I_j\}$, …, $\{I_n\}$ and to build a new distance matrix $(n-1)\times(n-1)$

↓

Step 3. The process is repeated until the cluster which consists of n objects and coincides with the initial set I. Thus, if during this step the clusters with the power greater than or equal to two are combined, the dispersion centers of these clusters are added to the set of possible alternative location of DCs.

Figure 1 – Sequence of end consumers clustering

2. Justification of temporary TPs intended for joining different traffic arteries using the method of integer linear programming and multi-criteria optimization to reduce logistic costs. The following indicators have been introduced for assessment of logistical costs: rental cost of an area for TP; the cost of technological equipment for TP creation; the cost of works associated with the creation or modernization of TP; TP personnel costs; risks associated with the creation of TP; time spent for cargo transshipment (e.g. a container); the volume of transported cargo. We

propose a multi-objective task involving optimization of costs associated with connection of various traffic arteries using TPs with introduction of comprehensive criterion for cost estimation. In this case there are two possible task statements: modernization (optimization) of existing distribution channels (in this case, it is necessary to minimize logistical costs for transporting cargo the volume of which is no less than the acceptable value), and creation of new distribution channels (in this case, the optimization is carried out according to all indicators, including the volume of transported cargo to be increased).

3. Structural analysis which includes enumeration of optional cargo delivery channels, taking into account possible types of distribution centers, as well as the network level (regional and multiregional) using the methods of enumeration theory. At this stage the following tasks have been solved:

a) options for creation of marketing channels together with existing DCs located within heterogeneous transport hubs are specified;

b) possible options for creation of new distribution channels (modernization) with possible location of TPs on multi-regional and regional levels taking into account the types of TPs are specified.

In order to analyze dynamic aspects of LDS we have developed a method for calculating the main indicators of cargo traffic in heterogeneous transport network using a multiphase model of the queue system (QS). The method takes into account intensity of cargo traffic within transport service that enables to calculate the sales performance goals. Sales channel is formed as a trajectory of cargo movement from a producer to end consumers through a variety of DCs and TPs in view of available traffic arteries. The study has been conducted for a variety of presentation levels of sales channel:

a) at the regional level, DCs may be represented as cargo transshipment points from the k artery to the traffic artery (k + 1). In case of cargo traffic simulation, Markov model of birth-death process has been applied, with the states (n, k), $0 \le n \le N$, $0 \le k \le S$, where n – the number of consumers served by the existing DC; k – the number of products stored in the warehouse and which can be shipped to customers. The following indicators have been obtained for stationary points: stock levels; the number of orders delayed (due to lack of commodity stock); the number of requests in the system; waiting time, etc;

б) at the multiregional level, in addition to DCs used for cargo storage, additional TPs are introduced for cargo delivery to end consumers, such TPs provide interchange of different traffic arteries. Due to availability of additional TPs, each of which has its own intensity of incoming cargo processing, we can represent LDS as a multiphase system and apply appropriate methods for QS calculation. The proposed method has enabled to determine the frequency f (t) and functions F (t) of time distribution for requests in the system for such cases [8]:

1) TPs have identical service rate:

$$f(t) = \frac{c(ct)^{n-1}}{(n-1)!}e^{-ct},\ F(t) = \int_0^t f(t)dt = -\sum_{i=1}^{n}\frac{c(ct)^{i-1}}{(i-1)!}e^{-ct}\Bigg|_0^t = 1-\sum_{i=1}^{n}\frac{c(ct)^{i-1}}{(i-1)!}e^{-ct};$$

2) TPs have different service rate :

$$f(t) = \sum_{i=1}^{n} A_i e^{-c_i t},\ \text{где}\ A_i = \frac{\prod_{j=1}^{n} c_j}{\prod_{\substack{k=1\\k\neq i}}^{n}(c_i - c_k)};$$ n –number of links in the system;

$$F(t) = \prod_{i=1}^{n} c_i \sum_{j=1}^{n} \frac{e^{-c_j t} - 1}{\prod_{\substack{j,k,m=1\\k>m\\k=j\ \text{або}\ m=j}}^{n} (-1)^{j+1} c_j (c_k - c_m)};$$

3) mixed case:

$$f(t) = \sum_{i=1}^{n_i}\sum_{j=1}^{n_i}\frac{A_{ij}t^{(n_i-j)}}{(n_i-j)!}e^{-c_i t},\ \text{where}\ A_{ij} = \frac{1}{(j-1)!}\frac{\partial^{j-1}}{\partial s^{j-1}}\Big[(s+c_i)^{n_i}B(s)\Big]\Big|_{s=-c_i};$$

$$F(t) = \sum_{i=1}^{n_i}\sum_{j=1}^{n_i}\frac{A_{ij}}{(n_i-j)!}\int_0^t t^{(n_i-j)}e^{-c_i t}dt = \sum_{i=1}^{n_i}\sum_{j=1}^{n_i}\frac{A_{ij}}{(n_i-j)!}\left(\frac{t^{(n_i-j)}e^{-c_i t}}{-c_i} + \frac{n_i - j}{c_i}\int_0^t t^{(n_i-j)-1}e^{-c_i t}dt\right),$$

Where $B(s)$ – Laplace transformation of time distribution for a request in the system with a constant $c = \mu(1-\rho)$ (for identical links) or $c_i = \mu_i(1-\rho_i)$ (for different links); λ – intensity of request inflow into the system; ρ – load in one link, $\rho = \frac{\lambda}{\mu}$, $\rho_i = \frac{\lambda}{\mu_i}$; s – differentiation variable.

The results obtained were used to determine average values of the time indicators of cargo transportation from a producer to end consumers through DCs and TPs, in particular, the full time of request processing in the system determines the time of goods delivery to consumers, the total waiting time determines the " stocking” time prior to the dispatch of goods to consumers. To create a model of cargo traffic management in heterogeneous transport network an agent-based [9] and a fractal model [10] were used. For the purpose of this article the fractals mean a set of self-similar agents which add to the basic fractal properties (self-similarity, self-organization, self-optimization, target-oriented approach, agility) important characteristics of agents, such as autonomy, mobility and cooperativity that enable to improve the efficiency of cargo management system. Formation of fractal management model (figure 2) consists of a sequence of steps [11]:

1) to represent each LDS component as a fractal;

2) to determine basic relationships such as manufacturer - supplier between fractals and to select fractals that implement these relationships;

3) if at step 2 we obtain a fractal fully reflecting LDS structure, the formation of a fractal structure has to be completed, otherwise – go back to step 2.

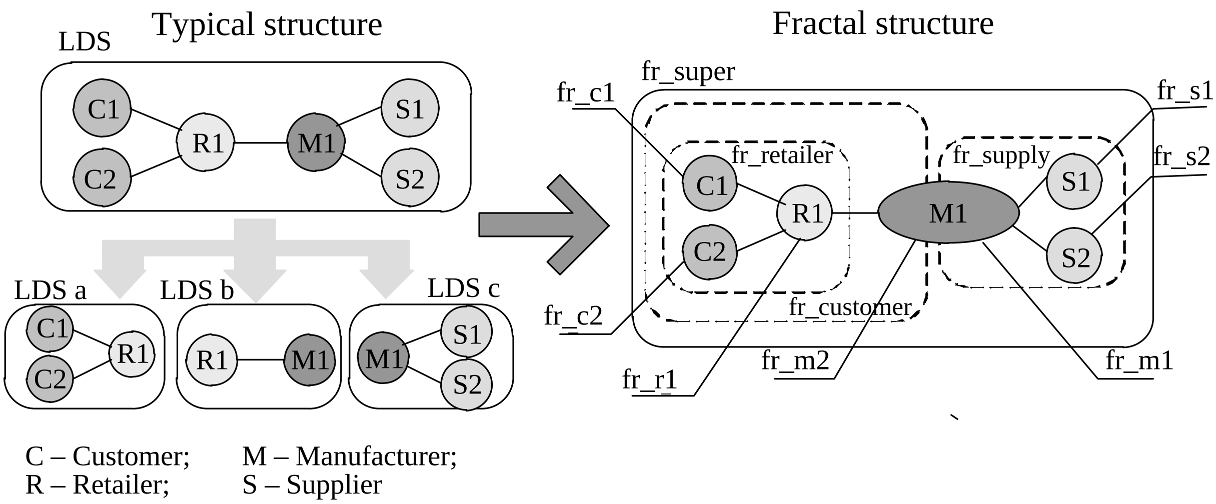

Figure 2 – Formation of the fractal management model.

In the cargo traffic management model obtained in this way the fractal hierarchy corresponds to the hierarchy of supply chain.

The developed methods and models have been used as a mathematical tool for creating applied information technology of logistical cargo traffic management in heterogeneous transport network which can be used by a transport logistics manager to form systematic representation of cargo transportation channels and management process, analysis of optional structures, cargo traffic measurement.

Conclusion

Summarized results obtained as part of the study allow us to draw the following conclusions:

1. We have developed a method for forming the structure of cargo delivery channels in heterogeneous transport network enabling to justify the use of storage places and transshipment points in heterogeneous transport

network based on the sales market segmentation using multi-criteria optimization, fuzzy logic and the theory of enumeration.

2. We have proposed a method for calculating the main indicators of cargo traffic based on the multiphase QS model which describes the main phases of cargo movement along delivery channels.

3. We have developed a model of cargo traffic management based on the fractal theory and agent-based modeling where fractal hierarchy corresponds to hierarchy of supply chain enabling to obtain an adequate representation of individual controlling actions at each stage of cargo traffic management with due account for possible conflict situations and prescribed management scripts. The proposed management structure complies with essential logistical requirements and enables to solve management tasks such as planning and cargo traffic control.

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