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MATHEMATICAL MODELING OF THE LOGISTICS MANAGEMENT SYSTEM OF AN ENTERPRISE

МАТЕМАТИЧНЕ МОДЕЛЮВАННЯ ЛОГІСТИЧНОЇ СИСТЕМИ УПРАВЛІННЯ ПІДПРИЄМСТВОМ

The paper considers the current problem of mathematical modeling of the organization's logistics system management. Representing all processes of organization management in the form of a logistics system allows to unify the main operations and functions and to build generalized mathematical models for effective enterprise management. The research has built a logistics management system of a hotel business enterprise, consisting of elements combined in the process of managing service and related financial and information flows. For each direction of the logistics system, corresponding mathematical models have been built and examples of their implementation are given using graph theory, network planning and matrix calculation tools.

The necessary numerical calculations have been performed in the MathCAD computer mathematics system and in Excel spreadsheets.

The results obtained can be applied in the organization of logistics management, when solving applied problems of managing a certain direction of activity of the hotel and restaurant business organization.

Keywords: logistics system, logistics management, logistics flows, hierarchy, graph theory, graph route, network graph, matrix calculus.

У роботі розглянуто актуальну проблему математичного моделювання управління логістичною системою організації. Представлення всіх процесів управління організацією у вигляді логістичної системи дозволяє уніфікувати основні операції та функції та побудувати узагальнені математичні моделі для ефективного управління підприємством.

Метою роботи є побудова математичних моделей управління діяльністю організації, що ґрунтуються на положеннях теорії графів та матричного числення. Для досягнення мети розв'язано наступні завдання: побудовано алгоритм представлення процесів управління логістичною організацією у вигляді логістичної системи; узагальнено особливості логістичних потоків та встановлено залежності між виконанням логістичних функцій та перетворенням різних видів логістичних потоків — інформаційних, фінансових, матеріальних, які в організації готельного бізнесу утворюють сервісний потік та потік гостей; визначено особливості логістичних стратегій організації готельно-ресторанного бізнесу, основу яких складають управління потоком гостей та задоволення потреб споживачів; побудовано і реалізовано математичні моделі управління діяльністю організації, що ґрунтуються на положеннях теорії графів та матричного числення.

У дослідженні побудовано логістичну систему управління підприємства готельного бізнесу, що складається з елементів, поєднаних у процесі управління сервісними та пов'язаними з ними фінансовими та інформаційними потоками. За кожним напрямом логістичної системи побудовані відповідні математичні моделі і наведені приклади їх реалізації з застосуванням теорії графів, мережевого планування та засобів матричного числення.

Необхідні чисельні розрахунки виконано у системі комп'ютерної математики MathCAD та в електронних таблицях Excel.

Отримані результати можуть бути застосовані в організації управління логістичною організацією, при розв'язанні прикладних задач управління певним напрямом діяльності організації готельно-ресторанного бізнесу.

Ключові слова: логістична система, логістичне управління, логістичні потоки, ієрархія, теорія графів, маршрут графа, мережевий граф, матричне числення.

Problem's formulation

The economic activity of an enterprise depends on the effectiveness of the organization's management of its resource flows. The presentation of the organization's activities in the form of a logistics system and the mathematical modeling of its logistics strategies reflect qualitatively new approaches to enterprise management. Logistics provides tools for ensuring effective coordination of the activities of managers of various divisions of the enterprise along the chain "innovation - procurement of raw materials - production of products - sales - delivery - distribution" based on the integration and coordination of operations, procedures and functions performed within this process in order to minimize the total cost of resources. The developed mathematical models will allow organizing effective management of the organization and establishing dependencies between the performance of logistics functions and the transformation of material flows.

Analysis of recent research and publications

The functioning of enterprises in modern conditions requires the solution of complex, multi-level problems in order to ensure a certain level of competitiveness, increase the volume of sales of goods and services and increase the efficiency of production. Solving all these tasks in total is possible provided that logistical approaches are used in the functioning and management, while opportunities arise to ensure the development of the enterprise [1]. Logistics management is a purposeful influence on the spatial-temporal balancing of business processes associated with the formation of flows of material and intangible resources [2]. A significant contribution to the scientific substantiation of the provisions of logistics management by the organization is highlighted in the works of J. R. Stock, D. Lambert, A. Baskin, J. Kelly, M. Linders, E. Boyko, G. Vardanyan, A. Gadzhinsky, T. Dudar, E. Krykavsky, Yu. Ponomaryova, V. Smyrychynsky, O. Tridid, S. Churylov, N. Chukhray. Scientists N. Zubar, M. Hryhorak, and I. Smirnov substantiated the relevance of logistics in enterprise management as an effective mechanism for establishing a balance between the level of satisfaction of employees and consumers and the resources spent on it.

Formulation of the study purpose

The purpose of the work is to form mathematical models of management of the organization's activities as a logistics system, based on the provisions of graph theory and matrix calculus. To achieve the goal of the study, the following tasks were set:

- to build an algorithm for representing the processes of managing a logistics organization in the form of a logistics system;
- to generalize the features of logistics flows and establish the dependencies between the performance of logistics functions and the transformation of various types of logistics flows — information, financial, material, which in the hotel business organization form a service flow and a flow of guests;
- to determine the features of logistics strategies of hotel and restaurant business organizations, the basis of which is the management of the flow of guests and the satisfaction of consumer needs
- to build and implement mathematical models of management of the activities of logistics organizations, based on the provisions of graph theory and matrix calculus and using matrix algebra tools.

The object of the study was the activities of a logistics organization, the subject of the study was represented by mathematical models and methods of managing the activities of organizations.

Presenting main material

The main paradigm of modern logistics is the construction of an economic and mathematical management model focused on increasing the efficiency of the functioning of enterprises based on the optimization of logistics flows [3]. Logistics approaches in management allow you to optimize the flows of products, information and finances and create various options and models of rational management activities of the organization in order to reduce costs. The logistics activity of the organization is considered as the practical implementation of a complex of logistics functions and elementary logistics operations. A logistics function is a group of logistics operations that are aimed at implementing the goals of the logistics system. The logistics system is a holistic set of elements that interact with each other. The main components of the logistics system are information, financial and material flows and logistics operations.

Thus, logistics provides tools for ensuring effective coordination of the activities of managers of various divisions of the enterprise and creates conditions for building effective mathematical models for managing its activities.

To structure a certain logistics system, analyze and select methods for building mathematical models in managing a certain type of logistics activity, a Kaoru Ishikawa cause-and-effect diagram was constructed (Fig. 1).

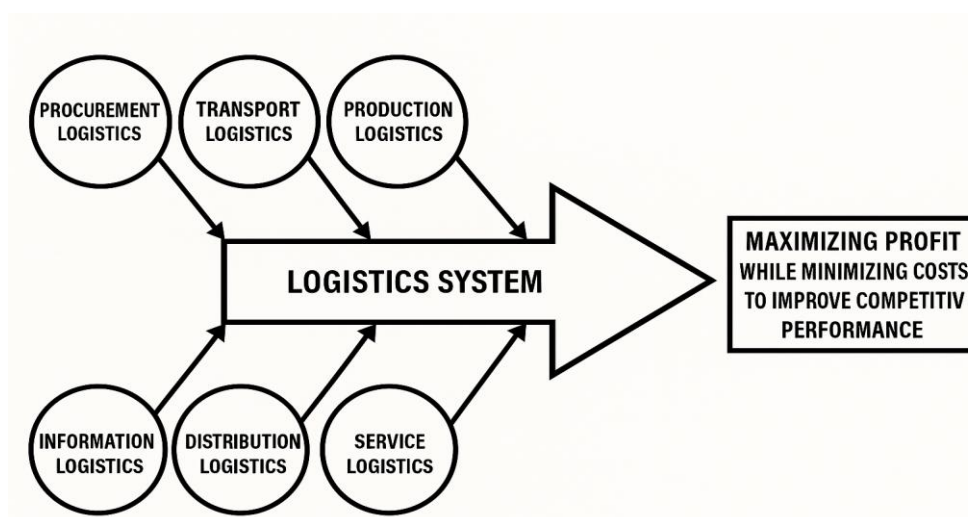


Fig. 1. Logistics system structuring diagram

The diagram determined the algorithm for studying the state of the logistics system:

1) Determining the main goal of analyzing the activities of the logistics system — the research profile and formulating it in the right corner of the diagram.

The main goal of analyzing the logistics system is to maximize the profits of the logistics organization while minimizing costs in order to increase its competitiveness.

2) Identifying the main elements of the logistics system $L_1, L_2, \dots, L_6$ — the attributes of the profile and representing them by the side edges of the diagram, where

L_1 — Purchasing logistics — logistics of managing material flows in the process of providing the system with material resources.

L_2 — Transport logistics, which solves problems related to organizing the movement and storage of goods during transportation and ensuring the transport and warehousing process.

L_3 — Production logistics implements inventory management methods, organizing and ensuring production, accounting for material flows [1];

L_4 — Information logistics is one of the main attributes of the system. Its main tasks are to collect, process, store and transmit to all links of the system relevant information, which is necessary for planning, organizing and optimal movement of material flows and for making management decisions.

L_5 — Distribution logistics. Its main task is to rationalize the process of physical distribution of material stocks and material flows and guest flows in the hotel and restaurant business.

L_6 — Service logistics, personnel occupy a leading place in the logistics system. Service logistics organizes, systematizes and optimizes the flows of services that the enterprise provides to consumers. Personnel are the main resource for the effective implementation of service logistics by the organization, since it is the personnel who directly interact with customers and provide the necessary services.

3) Determination of the parameters of each of the identified system elements $l_{ij}, i = \overline{1, n}, j = \overline{1, m}$ to analyze the impacts on the specified attributes. When analyzing the attributes of the logistics system profile, the following parameters of the L_i elements were identified:

– L_1 attribute parameters

l_{11} — types of goods and their quantity, volume;

l_{12} — selection of suppliers;

l_{13} — order processing, control over the fulfillment of contract terms;

l_{14} — procurement methodology, inventory management.

– L_2 attribute parameters

l_{21} — selection of the type and type of vehicles;

l_{22} — joint planning of the transport and warehouse process with the production process;

l_{23} — coordination of transport processes on different types of transport;

l_{24} — determination of optimal delivery routes.

– L_3 attribute parameters

l_{31} — optimization of production processes;

l_{32} — planning, organization, coordination of the movement of raw materials, semi-finished products, materials, finished products, customer flows;

l_{33} — rational use of production capabilities and warehouses;

l_{34} — implementation of automation and innovative technologies to increase efficiency.

– Attribute parameters L_4

l_{41} — provision of the necessary information for making optimal decisions at different levels of logistics system management;

l_{42} — optimization of information flows, ensuring data security and storage;

l_{43} — interaction of information systems and support for making effective management decisions;

l_{44} — implementation of innovative technologies.

– Attribute parameters L_5

l_{51} — selection of a material flow distribution scheme;

l_{52} — planning the implementation process;

- l_{53} — organization of delivery and control over transportation;
- l_{54} — management of the process of passing material flow, flow of guests, customers.
- Attribute parameters L_6
- l_{61} — effective delivery of goods or services to consumers;
- l_{62} — customer service, meeting their needs;
- l_{63} — courses on logistics process management, customer service training;
- l_{64} — personnel training and development.

4) Analysis and refinement of the list of parameters and determination of mathematical methods and models for their description depending on the type of objective function and initial conditions and constraints.

All defined parameters of the logistics system for its attributes should be presented in the form of a matrix $L_{6 \times 4}$, the elements of which are parameters $l_{ij}, i = \overline{1,6}, j = \overline{1,4}$.

Based on the obtained Ishikawa diagram and analysis of its data and their types, a mathematical model of management of a given attribute of a certain element of the logistics system is constructed.

A feature of the hotel and restaurant business enterprises from the point of view of logistics is their duality, since they act as both consumers of logistics services (in the production of restaurant products, organization of service) and its providers (accommodation services, additional services) [4].

In the hotel and restaurant business, logistics is understood as methods and means of managing information and financial flows that are necessary for the provision of hotel services and satisfying customer needs in the optimal way [5].

Information flows are divided into external (clients, companies — consumers, intermediaries, competitors) and internal (reservation, advertising, information processing, production relations).

Guest flows (clients, residents), which are the main type of flows in the logistics of hotel services and for which hotels of various types, types and sizes are actually created and operate, are reflected in the hotel business in the form of their information and financial projection, that is, information and financial flows. And this is a characteristic feature of the logistics of hotel services. The resource base of hotels for receiving guests is limited by the available number of rooms, both quantitatively and in terms of value. Therefore, the main characteristics of the flow of guests in hotels are its information and financial indicators, that is, information and financial flows, which are usually formed by the flow of guests. Therefore, the logistics system of hotel management is a structured system that contains elements combined in the process of managing service (material) and accompanying financial and information flows [6].

Logistic flows are interdependent, therefore, when building a hotel logistics management system, it is advisable to first perform multi-criteria ranking using the Analytical Hierarchy Process (AHP) method. This method was developed by the American mathematician T. Saati, and allows you to structure a certain problem of making management decisions in the form of a hierarchy, compare and quantitatively evaluate its solution options.

It is appropriate to carry out the corresponding research in several stages. First, the connection of the information flow with the corresponding income and expense financial flows is determined. Then the value of the income and expense financial flows is used to determine the coefficients of the corresponding information flows. At the next stage, according to the obtained coefficient values, the ranking of information flows is performed:

- I — requirements coming from consumers;
- II — orders for hotel services;
- III — other orders for which management resources are distributed.

According to the specified initial data of information, financial and service (material) flows, the organizational structure of the logistics system is formed. Its internal environment consists of four subsystems:

- 1 — Advertising and booking;
- 2 — Statistical operations with information;
- 3 — Management of production processes of the organization;
- 4 — Generation of output data.

In the conducted study, the structure of the mathematical model of optimal management of the logistics system of the hotel and restaurant complex at all levels of the hierarchy during the implementation of all stages of the logistics process was determined. The developed structure is shown in Fig. 2.

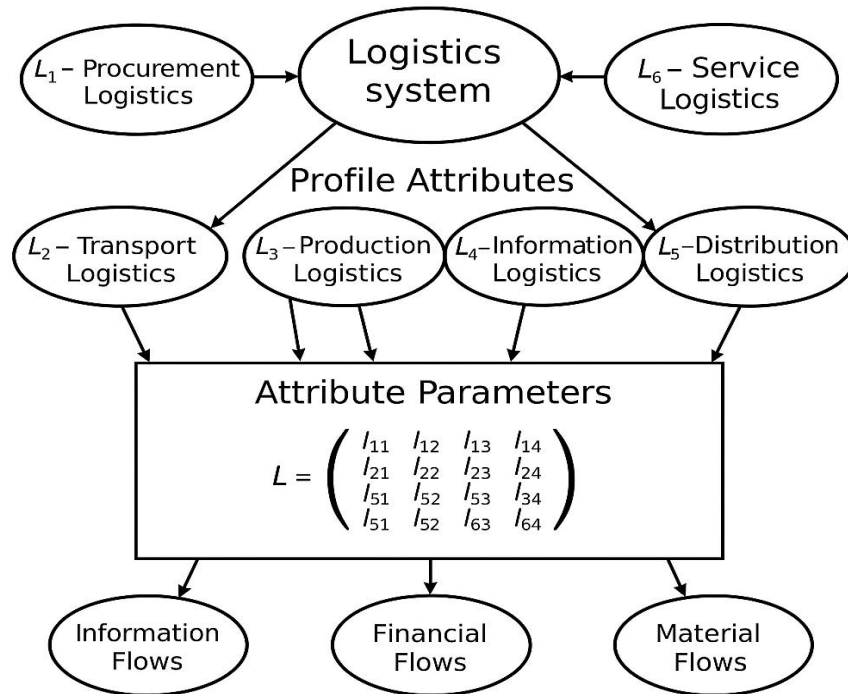


Fig. 2. Levels of the hierarchical structure of the hotel logistics system

To develop and implement a mathematical model of management of the hotel logistics system, it is advisable to apply the method of hierarchy analysis (HAI). The resulting model requires the construction of a structure of three hierarchical levels:

- the first level of the hierarchy — goal (profile) — optimal management of the hotel logistics system;
- the second level of the hierarchy — selection criteria (profile attributes and their parameters);
- the third level of the hierarchy — logistic flows, their interaction, connection and mutual transformation.

To perform pairwise comparisons at each level of the hierarchy, based on the results of qualitative (expert) and quantitative assessments — attribute parameters, pairwise comparison matrices (PCM) $M = \{m_{ij}\}$, $i, j = 1, \dots, n$ are determined, which are symmetric positive definite matrices

$$M = \begin{pmatrix} 1 & a_{12} & \dots & a_{1n} \\ \frac{1}{a_{12}} & 1 & \dots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & \dots & 1 \end{pmatrix} \quad [7], \text{ the elements of which have the property } m_{ij} = \frac{1}{m_{ji}}.$$

The study proposes appropriate mathematical management models for each of the attributes of the L₁–L₆ profile.

Graph models are advisable to use both for organizing the management activities of the hotel logistics system and for developing optimal logistics supplies throughout the hotel network [8].

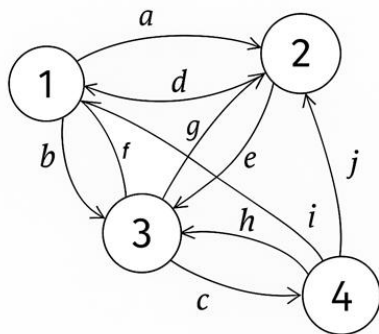


Fig. 3. Hotel organizational and management structure graph

The main task of the hotel logistics system is to implement optimal management of these flows to ensure effective and high-quality guest service and minimize the resources used in this process.

Fig. 3 shows the graph of the hotel's organizational and management structure obtained as a result of the study of information, financial and service flows of the hotel's logistics system, which visualizes the interaction between its constituent elements.

This graph $G(V, E)$, the set of vertices $V = \{V_1, V_2, V_3, V_4\}$, the set of edges $E = \{a, b, c, d, e, f, g, h, i, j\}$ is an oriented unweighted graph $|V| = 4, |E| = 10$ the vertices of which are the nodal

vertices of the graph of the hotel's logistics system and its administrative network:

- 1 – V_1 — Banking and cash service;
- 2 – V_2 — Customer information service;
- 3 – V_3 — Interaction with the external environment;
- 4 – V_4 — Activity planning and performance control.

Using the properties of graphs, it is possible to solve problems of optimal management of logistics flows.

Network graphs serve as convenient mathematical models for organizing work and managing a certain unit of the logistics system. The results of the analysis of network graphs make it possible to optimize the set of necessary operations and minimize the costs of human, material and financial resources of the enterprise.

Each network graph has at least one critical path, which determines the minimum time for performing the operations required by the technology. Reducing the time for performing the work that is located on the critical path saves time for performing the entire set of operations of this procedure. Therefore, network graphs are used to solve the problems of optimizing the time for performing a set of technological actions.

For effective management of the hotel logistics system, it is currently convenient to use mathematical models that use matrix calculation tools. For example, based on the occupancy data of rooms of the corresponding class during the months of 2024 (Tabl. 1), using the matrix product operation, you can calculate the total revenue.

Table 1. Room occupancy

Room type	Employment, days per month											
	January	February	March	April	May	June	July	August	September	October	November	December
Classic Single	89	82	87	84	90	87	84	86	88	89	88	86
Classic	270	190	269	265	275	270	273	272	256	265	266	271
Standard	1000	990	890	1023	892	1020	997	1004	980	1005	980	999
Superior	700	679	705	723	690	645	712	698	721	709	698	726

Continue of the table 1

Deluxe Business	12	15	14	21	17	19	18	13	16	21	18	21
Deluxe Louis	11	12	11	15	13	16	17	11	18	9	14	21

To do this, we will present the prices for the corresponding rooms (UAH) in the form of a row matrix V : $V = (1879 \ 2047 \ 2346 \ 2697 \ 4428 \ 4428)$.

And we will write the occupancy of the numbers in the form of a matrix $N_{6 \times 12}$

$$N := \begin{pmatrix} 89 & 82 & 87 & 84 & 90 & 87 & 84 & 86 & 88 & 89 & 88 & 86 \\ 270 & 190 & 269 & 265 & 275 & 270 & 273 & 272 & 256 & 265 & 266 & 271 \\ 1000 & 990 & 890 & 1023 & 892 & 1020 & 997 & 1004 & 980 & 1005 & 980 & 999 \\ 700 & 679 & 705 & 723 & 690 & 645 & 712 & 698 & 721 & 709 & 698 & 726 \\ 12 & 15 & 14 & 21 & 17 & 19 & 18 & 13 & 16 & 21 & 18 & 21 \\ 11 & 12 & 11 & 15 & 13 & 16 & 17 & 11 & 18 & 9 & 14 & 21 \end{pmatrix}$$

Then the total revenue (ZV) from hotel rooms for each month of the year is equal to the product of the matrices V and N , and the mathematical model of this problem has the form:

$$ZV := V \cdot N = \begin{array}{|c|c|c|c|c|c|c|c|} \hline & 0 & 1 & 2 & 3 & 4 & 5 & 6 \\ \hline 0 & 5055665 & 4816367 & 4814141 & 5209588 & 4818437 & 5003628 & ... \\ \hline \end{array}$$

All calculations in the study were performed in the symbolic mathematics system MathCAD, which contains a wide range of built-in matrix operations.

Tabl. 2 shows the number of business lunches ordered at the hotel restaurant and their cost (UAH) during the first half of the year.

Table 2. Number and cost of business lunches for the first half of 2024

Number of business lunches	January	February	March	April	May	January
Menu 1	300	320	260	310	315	312
Menu 2	400	420	410	405	380	390
Cost (UAH)						
Menu 1	1100	1200	1250	1280	1280	1290
Menu 2	2000	2050	2080	2100	2110	2110

According to the tabl. 2 data for each month (i), we set the row matrices of the number of business lunches $A_i = (a_{i1} \ a_{i2})$ and the column matrices of their cost $B_i = \begin{pmatrix} b_{1i} \\ b_{2i} \end{pmatrix}$ and multiply them.

Each product is equal to the total revenue of the hotel restaurant from business lunches for a certain month. And the total revenue will be:

$$V = \sum_{i=1}^6 A_i B_i.$$

Thus, the total revenue for the half year is equal to $V = \sum_{i=1}^6 A_i B_i = 7230480$ (UAH).

To determine the optimal delivery routes from the central office to the network cities, it is advisable to use graph traversal methods from graph theory. First, the optimal type of procurement is selected and the appropriate method of graph traversal is selected according to it (Tabl. 3).

Table 3. Types of procurement and effective delivery methods according to graph theory

Type of procurement	Effective methods for developing delivery routes using graph theory
Wholesale purchases	Shortest path search methods: Dijkstra's algorithm, Bellman-Ford, Floyd-Warshall, Breadth-First Search (BFS) algorithm for unweighted graphs
Regular purchases in small batches	Depth-first search (DFS) algorithm, maximum flow search methods (Ford and Fulkerson)
Procurement according to needs	The choice of methods depends on the volume of each purchase, the supplier's conditions, and its location.

The study developed an optimal route for delivering regular purchases from the central office in Kyiv to the «Optima Collection Troitska» hotel in Dnipro.

Conclusions

The work investigates logistics approaches in enterprise management and builds an algorithm for representing the processes of managing a logistics organization in the form of a logistics system; identifies the features of logistics strategies of hotel and restaurant business organizations, the basis of which are the processes of managing the flow of guests and satisfying consumer needs. According to the developed algorithm, a mathematical model of the hotel logistics system and its administrative network in the form of a generalized graph was built. For each of the areas of logistics activity, appropriate mathematical management models based on the provisions of graph theory and matrix calculus were proposed. With the help of the developed mathematical models, mathematical modeling problems in managing a logistics organization were solved using the example of hotel activities using network graphs, graph traversal algorithms, and matrix calculus tools.

The results obtained can be applied in organizing the management of a logistics organization, when solving applied problems of managing a certain area of activity of a hotel and restaurant business organization.

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