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MATHEMATICAL TOOLS FOR SOLVING PRACTICAL PROBLEMS OF CONSTRUCTION USING CONSTRUCTION LOGISTICS APPROACHES

The paper considers the advantages of using mathematical tools for solving practical problems of construction. Modern methods of optimizing logistics systems are analyzed. For the development of the construction complex in modern conditions, a new approach is presented that allows organizing a set of problems (tasks) in the form of a system, taking into account numerous connections, as well as determining the optimal solution. As a result of the study, an economic and mathematical model was developed, taking into account the influence of intersystem relations of construction logistics, presented in the form of a directed graph.
Keywords*: economic-mathematical model, construction logistics, defect exclusion algorithm.*

У роботі розглядаються переваги використання математичного інструментарію на вирішення практичних завдань будівництва. Проаналізовано сучасні методи оптимізації логістичних систем. Для розвитку будівельного комплексу в сучасних умовах представлений новий підхід, який дає можливість організовувати комплекс проблем (завдань) у вигляді системи з урахуванням численних зв'язків, а також визначати оптимальне рішення. Як результат дослідження розроблена економіко-математична модель з урахуванням впливу міжсистемних зв'язків будівельної логістики, яка представлена у вигляді орієнтованого графа.
Ключові слова*: економіко-математична модель, будівельна логістика, алгоритм виключення дефекту.*

Problem's Formulation

When performing construction processes, important conditions are the timely supply of material resources (structures, parts) of the appropriate quality and in accordance with the construction technology. Organizations, companies, enterprises that are part of the production base system of the construction complex guarantee the fulfillment of these conditions. Failure to fulfill obligations on material and technical support gives rise to a number of negative factors, such as disruption of the construction schedule, loss of working time for employees, downtime of construction equipment, an increase in construction costs, loss of the company's credibility [1,2].

Therefore, today it is important to introduce rational approaches to managing the activities of the production base of the construction industry, which consists, first of all, in changing priorities between various types of economic activities of building systems in favor of increasing the importance of flow management activities.

Lately, our country has been in need of ongoing reforms on programs to revitalize and develop the construction industry. This applies to such tasks as reforming the production base of the construction industry, changing the sectoral structure of production as a result of its adaptation to the new demand structure and the emergence of a mass of small enterprises, changing the conditions of foreign economic activity, combined with a difficult investment climate and limited resources. [3,4].

Developed countries are using a new platform paradigm of the knowledge sub-sector of logistics, which has a significant degree of efficiency in the organization, management, and planning of construction production.

This positive phenomenon makes it possible to ensure targeted work related to the organization and management of material flows that correspond to new technological and production processes, improve regulatory and technical documentation aimed at creating competitive products through the formation of logistics information systems, and establish strict control over the conjuncture of the needs of the consumer market.

The construction complex includes a production system in the form of links between its participants (construction organizations — enterprises of the construction industry). For the effective reproduction of these systems, it is necessary to take into account the organization and management of material and accompanying information flows.

Analysis of recent research and publications

Like any manufacturing industry, construction at the current active stage of development faces a number of different problems. The main ways to overcome them, according to a wide range of scientific researchers, include optimization of the organization of the production process, improvement of logistics and management components, widespread introduction of information technology and others [3]. It is not surprising that in this context, the study of logistics systems and methods for their optimization has become widespread in many works of modern scientists. In the course of the analysis of scientific works related to the methodology of management and organization of construction based on logistics, complex variants of traveling salesman problems and vehicle routing problems in the field of production and service are considered [4,5,6,7]. The developed heuristics are evaluated using reference and derived datasets. Article [8] provides an extensive and up-to-date overview of the concepts behind the advanced APS scheduling system. Particular attention is paid to supply chain modeling and the successful implementation of APS in the industry.

The work [9] considers the range of problems that an enterprise faces in the process of supply chain management and logistics, offers a wide range of resources on many aspects of supply chain management, including modern application programs. In addition, general methods and specific approaches to a wide range of tasks and issues in this industry, the solution of which requires a modern organization of production, are described in detail.

The work [10] is devoted to the study of the interaction of material and information flows in the transport and logistics system. The paper substantiates the condition for providing reliable information on transport logistics as one of the key factors in the competitiveness of the system of such basic logistics operations as the delivery of goods according to the Just-in-time logistics concept.

The article [11] considers the issues of applying the development of a software implementation of a management decision support system for transport logistics tasks, in particular, choosing the optimal option for delivering goods to a group of consumers. From the point of view of mathematics, the so-called traveling salesman problem is considered, for the solution of which the algorithm of two-phase optimization of the transport network is used. At the second stage, the resulting solution is additionally compared by the cost criterion with the options offered by alternative specialized enterprises.

When planning the business processes of an enterprise, it is especially important to create tools for building models of multi-stage tasks of its production and transport logistics. The solution of such tasks is problematic, since it leads to the need to develop interrelated models, methods and algorithms. The authors of [12] propose a mathematical apparatus for the formal representation of multi-stage problems by using families of unified models with the necessary free parameters that allow one to construct models of multi-index problems.

Formulation of the study purpose

For the development of the construction complex in modern conditions, a new toolkit is required that allows organizing a set of problems (tasks) in the form of a system, taking into account intersystem communications and finding the optimal solution for this system [5].

Presenting main material

Based on the term "Logistics", a new vision of the use of the concept of "Construction Logistics" has been developed, which meets the scientific foundations for the development of the construction complex by optimizing resource supply flows.

Construction logistics is a separate transformational management system in construction, consisting of complex organizational and structured production subsystems (elements of an integral system), and allows you to effectively interconnect the essence of the production cluster of the construction complex, its analytical capabilities and information models in an unstable market due to a specialized scientific-practical tools.

The adaptability of a construction company to changes in the external environment is a multifaceted phenomenon. From the point of view of construction logistics, the adaptability of a construction company is manifested in the ability of decision makers to quickly adapt to the transformation of market conditions and the nature of the main economic flows. Typically, the level of adaptability increases as inventories and reserves increase. But, increasing adaptability by increasing stocks and reserves, it is always necessary to take into account the final effectiveness of logistics, which should ensure the achievement of company-wide goals at the lowest cost [2,3].

The reserves for solving most organizational and technological problems are located in the complex of interconnections of the functional subsystems of construction logistics, and not only at the junctions and no man's zones of individual subsystems. Violation of the system methodology (a system of principles and methods for organizing and constructing theoretical and practical activities) led to disunity of approaches in information and functional aspects, lack of unity of the modeling space and end-to-end information support in solving a set of problems of organizational and technological preparation, as well as compatibility and a common denominator.

The problem of planning and development of construction logistics requires its solution, taking into account intersystem links, which should reflect the whole range of problematic functional issues and be embodied in the proposed economic and mathematical model [5,6].

Problematic issues arise when setting the task of determining the optimal variant of the distribution of production volume. According to world standards, there is a typical project management methodology in the approach to solving systemic problems, which includes seven stages. In addition to setting the problem, it is necessary to make a description of it and develop a model, after which a solution method is proposed according to which an algorithm is compiled and programming issues are resolved, while the effect of introducing the proposed methodology is determined. The task model should be of an integrated nature and minimize the disunity between the butt blocks (functional subsystems).

To solve the problem of planning production systems, taking into account intersystem links, we use an enlarged algorithm in which the following decision-making conditions are specified: the principle of modeling is the special states of the system; the intensity of the work — constant and continuous; there are severe resource constraints [5,6,7]. The DEA algorithm is a primal-double algorithm, so the given initial solution may not satisfy the conditions of either the primal or dual problem. Other algorithms do not have this flexibility [5,6].

Mathematical setting and solution processes:

I. Input of initial data — determination of the optimal amount of building resources (BR); c_{ij} — the cost of transporting building resources; upper (U) and lower (L) throughput — volumes of building resources.

II. Definition of an arc with a defect.

During the operation of the DEA algorithm, the values of dual changes are determined (π_i) and flows of material resources, taking into account the optimality conditions (f_{ij}).

With the defect elimination algorithm, arbitrary flows are set for arcs (fulfillment of the conservation condition), and arbitrary values are set for nodes π_i.

To fulfill the optimality conditions, it is necessary to check the state of the arc using a procedure that allows you to determine how to change the flows after all arcs and which path to choose.

III. Labeling procedure.

1) In order for the arc i, j to cease to be defective, the flow along it should be increased, then it is in one of the states $\alpha_1 \beta_1 \delta_1$. Assign to the node j a flag $[q_j, i^+]$, which means that the node j can receive q_j additional flow units from the node i. If the arc is in state α_{1} 1, then set q_j equal to $min[q_i, L_{ij} - f_{ij}]$, and if in the state β_1 or δ_1, then q_j determine equal to $[q_i, U_{ij} - f_{ij}]$.

2) If the flow along the arc (i, j) should be reduced, then it is in one of the states α_2, β_2, δ_2. Assign to the node i a mark $[q_i, j^-]$, which means that the flow leaving the node i and enters the

node j, can be reduced by the value q_i. If the arc is in state α_2 or β_2, then set q_i equal to $min[q_j, f_{ij} - L_{ij}]$, and if in the state δ_2, then q_i determine equal to $min[q_j, f_{ij} - U_{ij}]$.

3) If the arc (i, j) is in one of the states α, β, δ, then it is not defective, and the flow along it does not need to be changed.

The method for further solving the problem is as follows. A defective arc (i, j) is selected, the flow along which should be changed so that it ceases to be defective. To fulfill the flow conservation condition, an additional path from node i to node j (or from j to i) is determined, and then the flows along the arcs of this path are changed in accordance with the last one with a mark q_i (or q_j). A change in flow along the arc is not allowed if it will cause the defect-free arc to become defective or the defect in the arc will increase. Therefore, a situation may arise that we will reach a certain node from which further movement is impossible. In this case, it is impossible to build a path from j to i, which means that the problem has no solution. In this case, it is useless to go to another defective arc and start the process anew, since in order to find the optimal solution, it is necessary to choose the arc indicated above. This situation is called non-breakthrough. When a non-break occurs, there is another way to find the optimal flow.

Let's move on to the analysis of the methodology of the next block:

IV. The state of the arc is uniquely determined by the value $\hat{c}_{ij} = \pi_i + \pi_j$ and therefore it can change due to changes in the values π. According to the definition of the dual problem, which was given above, each node is associated with some variable π. Therefore, for the flow problem with n nodes, there are exactly n dual variables π. When a non-break occurs, it is necessary to determine the value of which variables π should be changed in order to build a path from node j to node i (or from i to j, if the flow decreases). When a non-break occurs, there are two non-intersecting sets of marked and unmarked nodes. Consider those numbers π, that correspond to the arcs connecting the marked nodes with the unmarked ones. Let us represent the set of all marked nodes by A, and the set of all unmarked nodes by $\overline{A}$. Let us use the concept of forward and backward arcs. In the first case, the flow can flow from A to $\overline{A}$, in the second - from $\overline{A}$ to A.

Denote the set of all arcs that leave the nodes belonging to A, and enter the nodes with $\overline{A}$ and for which $\hat{c} > 0$, and the flow that does not exceed the upper limit by B. The set of all arcs leaving nodes and belonging to $\overline{A}$, and entering nodes A with and for which $\hat{c} < 0$, and the flow is not less than the lower bound, we denote by $\overline{B}$. Since the value c can be calculated for any arc from the sets B and $\overline{B}$, the calculation process should be continued as follows:

1) Case I: $\hat{c} > 0$.
   Define $\xi_1 = min[c_{ij}]$, when $B = \varnothing$, and $\xi_1 = \infty$ otherwise.
2) Case II: $\hat{c} < 0$.
   Define $\xi_2 = min[c_{ij}]$, when $B = \varnothing$, and $\xi_2 = \infty$ otherwise.
3) Let $\xi = min[\xi_1 \xi_2]$,
4) For each node $k \in \overline{A}$, change the corresponding node number π_k by adding to it the value ξ.
5) Save all previous marks.

Then, returning to the procedure for placing marks, we continue to perform calculations.

V. Conclusion of the results.

As a result of solving the problem on a computer, the following is printed:

- movement of resources;
- data calculation table, which lists the numbers (in order) of all works, the need for resources, the actual volumes of implementation of measures.

But there are difficulties in solving problems of this nature.

Therefore, first of all, there is a discrepancy (mismatch) in the units of production and transport of material flows, for example, the organization of the production of reinforced concrete products to meet the needs of the region, the delivery of initial raw materials of concrete is carried out in m^3, transport in tones, production of products in m^2, transportation of products in tones; and consumers (reinforced concrete blocks) in m^2. And the problem is considered single-product, hence its dimensions must be compatible.

The next feature is the formulation of the problem. For this, a standard methodology is used, taking into account the features of the second stage, which are characterized by well-known difficulties. The structure of the development and placement model must be flexible in modeling actions and reflect the diversity of relationships of all participants in the production process. A pure LP model cannot reflect the linkage of the diverse participants in the process. Model construction covers the number of variables that reflect the essence of the situation, and does not require much time to form initial models.

Thus, the model should not be rigidly dependent on the influence of individual facts, it should be universal. An economic-mathematical model may have the form of a matrix representation (for example, the simplex method), the solution is not an insurmountable obstacle. The network representation of the situation has a linear nature, like the simplex method, but the latter option is associated with difficulties in representing the problem to the canonical form, and as a rule, the variety of constraints has a significant impact on the dimension of the problem, and often the initial transformation is reduced to solving the so-called M-problems LP. In addition to these difficulties, there is the impossibility of a physical interpretation of the problem, and the network interpretation has advantages in this respect.

Development of an economic-mathematical model, taking into account the influence of intersystem relations of construction logistics

The model is a directed graph $G(U,A)$ with limited capacity, i.e. there are always given upper and lower boundaries of the material flow for all $(i,j)\in A$ and this restriction should not be violated. The boundaries of flow change can be equal to zero or infinity, i.e. $f_{ij}-[0-\infty]$, f_{ij} — material (arc) flow.

To formulate the problem, we use the following designations: f_{ij} — arc material flow, L_{ij} — lower arc (i,j) throughput, F_{ij} — upper arc (i,j) throughput, $C_{i,j}$ — unit cost of the flow from i to j the node.

The general problem can be formulated as a special programming problem.

Minimize objective function

$$L(f)=\sum_{a} C_{ij}f_{ij}\rightarrow min, \tag{1}$$

with restrictions on the bandwidth of the arcs

$$f_{ij}\le F_{ij},\ (i,j)\in A; \tag{2}$$

$$f_{ij}\ge L_{ij},\quad (i,j)\in A. \tag{3}$$

Flow save condition

$$\sum f_{ij}-\sum_{ji}=0 \text{ for all } i\in U,\ i\ne j. \tag{4}$$

The problem of determining the optimal flow corresponding to the minimum cost circulation is presented as a special optimal programming problem (1—4).

This is the basic formulation for describing DEA(defect elimination algorithm).

The nature of the duality theory of linear programming assumes the presence of a dual problem and the equality of the objective functions of the direct and inverse problems.

Condition (1) is reformulated as follows:

$$L(x) = \sum_A -C_{ij} f_{ij} \to max \quad (5)$$

under restrictions:

$$\sum_i f_{ij} - \sum_i f_{ji} = 0, \quad (6)$$

for all $i \in U$ (flow conservation condition) restriction on the flow from below and from above:

$$L_{ij} \le f_{ij} \le F_{ij}; \quad (7)$$

$$f_{ij} \ge 0. \quad (8)$$

To use the standard procedure of the defect elimination algorithm (DEA), the values (1) were multiplied by -1 and this problem is considered as a direct one, according to the well-known result in linear programming, we formulate the dual problem (5—8).

Determine the objective function of the problem

$$Z(x) = \sum_A F_{ij}\alpha_{ij} - \sum_A L_{ij}\delta_{ij} \to max \quad (9)$$

provided that

$$\pi_i - \pi_j + \alpha_{ij} - \delta_{ij} > -C_{ij}, \text{ for } (i,j) \in A \quad (10)$$

π_{ii} has no sign restrictions for all $i \in U,$

$$\alpha_{ij} \ge 0 \quad (i,j) \in A;$$

$$\delta_{ij} \ge 0 \quad (i,j) \in A.$$

Variables π_i (they are also called node numbers) are presented at the top of the event, correspond to the constraints that describe the condition for maintaining the flow in the direct problem, and acquire arbitrary values, since these constraints have the form of equality.

Variables α_{ij}, δ_{ij} in the dual problem correspond to the upper and lower constraints on the flows of operations $(i,j) \in A,$ and F_{ij} L_{ij} — double variables.

Consideration of construction logistics allows us to conclude that construction should be attributed to a system of interrelated and interdependent flows of information, material, technical, financial and labor resources. In order to achieve results in reducing construction time, improving the quality of construction products, minimizing costs, it is necessary to improve the methods of organizing and managing the above resource flows through the introduction of logistics approaches.

Conclusions

Construction logistics is a specialized scientific and applied module of the modern development of construction, which, unlike the existing ones, allows:

- change the idea of the terminological essence of the term "logistics" as a scientific theory, methodology and practice in application to the needs of the construction industry in conditions of uncertainty;
- consider "construction" as a dynamic, modular, mobile complex structured branch of the national economy;
- to model construction projects as specialized functional and logistical elements;
- to interconnect the essence of the production cluster of the construction complex, its analytical capabilities and mathematical and logistical models in an unstable market.

References

[1] Arutiunian I., Poltavets M., Bondar O., Anin V. & Pavlov F (2020). Structural Information Management of Production Systems in Construction. *International Journal of Advanced Trends in Computer Science and Engineering. (Vols. 9*), *4.* 4794–4797.

[2] Tsimoshynska, O., Koval, M., Kryshtal, H., Filipishyna, L., Arsawan, W. E., & Koval, V. (2021). Investing in road construction infrastructure projects under public-private partnership in the form of concession. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu, 2,* 184–192.

[3] Richards G. & Grinstead S. (2020). *Toolkit for logistics and supply chain management*. Axelot.

[4] Anbuudayasankar S., Ganesh K. & Mohapatra S. (2014). *Models for Practical Routing Problems in Logistics*. Design and Practices Springer International Publishing, Switzerland.

[5] Berkuta A.V., Osyns'ka V.A., Halins'kyy O.M. & Vakhovych I.V. (2010). Orhanizatsiyni ta ekonomichni aspekty zarubizhnoho dosvidu samorehulyuvannya v budivnytstvi. [Organizational and economic aspects of foreign experience of self-regulation in construction] *Budivel'ne vyrobnytstvo – Construction production. 52*. 3–8 [in Ukrainian].

[6] Krykavsky, E., Pokhilchenko, O., & Furch, M. (2017). *Logistics and supply chain management*. Lviv Polytechnic Publishing House [in Ukrainian].

[7] Kozik, V. (2020). *Organization of production: a textbook.* Lviv Polytechnic Publishing House [in Ukrainian].

[8] Stadtler, H., Kilger, C., & Meyr, H. (2015). *Supply Chain Management and Advanced Planning: Concepts, Models, Software, and Case Studies*. Springer.

[9] Liang, Z., Chaovalitwongse, W., & Shi, L. (2016). *Supply Chain Management and Logistics: Innovative Strategies and Practical Solutions.* CRC Press

[10] Bazhan L. & Yablokov Y. (2015). Kontseptual'ni osnovy synkhronizatsiyi material'noho ta informatsiynoho potokiv v transportno-lohistychniy systemi. Zbirnyk naukovykh prats' [Conceptual bases of synchronization of material and information flows in the transport and logistics system. Collection of scientific works] *Ekonomiko-matematychne modelyuvannya sotsial'no-ekonomichnykh system – Economic and mathematical modeling of socio-economic systems, 20.* 115–138 [in Ukrainian].

[11] Shapovalova O., Kamardin A. & Petukhova O. (2018). Systema pidtrymky pryynyattya rishen' pry vykonanni lohistychnykh zavdan' [Decision support system for logistics tasks]. *Systemy obrobky informatsiyi – Information processing systems, 3(154).* C. 57–63. [in Ukrainian].

[12] Hambarov L., Kuz'mynchuk N & Chernyshova N. (2015). Instrumentariy pobudovy modeley bahatoetapnykh zavdan' vyrobnycho-transportnoyi lohistyky [Tools for building models of multi-stage tasks of production and transport logistics]. *Visnyk ekonomiky transportu i promyslovosti – Bulletin of Transport Economics and Industry, 49.* 221–229. [in Ukrainian].

МАТЕМАТИЧНИЙ ІНСТРУМЕНТАРІЙ РОЗВ'ЯЗАННЯ ПРАКТИЧНИХ ЗАДАЧ БУДІВНИЦТВА ВИКОРИСТОВУЮЧИ ПІДХОДИ БУДІВЕЛЬНОЇ ЛОГІСТИКИ

Арутюнян Є.Е., Арутюнян І.А., Міхайлуца О.М., Пожуєв А.В.

У статті розглянуто переваги використання математичного апарату для вирішення практичних завдань будівництва. Аналізуються сучасні методи оптимізації логістичних систем. Актуальність застосування раціональних аспектів управління діяльністю виробничої бази будівельної галузі спонукає до використання підходів будівельної логістики. Для розвитку будівельного комплексу в сучасних умовах представлено новий інструментарій, який дозволяє організувати комплекс проблем (завдань) у вигляді системи з урахуванням багатьох зв'язків, а також визначити оптимальне рішення.

Проблема планування та розвитку будівельної логістики потребує пошуку рішення з урахуванням міжсистемних зв'язків. Вони представлені в запропонованій економіко-математичній моделі та відображають увесь спектр проблемних функціональних питань. Для вирішення задачі планування виробничих систем з урахуванням міжсистемних зв'язків використовується укрупнений алгоритм, в якому задається набір умов прийняття рішень: принцип моделювання (особливі стани системи); інтенсивність виконання роботи (постійна та безперервна); серйозні обмеження ресурсів. Гнучкість представленого алгоритму полягає у тому, що за-

дана початкова умова може не задовольняти умовам ні прямої, ні двоїстої задачі. Аналізуються існуючі труднощі у вирішенні завдань такого характеру.

В результаті дослідження розроблено економіко-математичну модель, яка враховує вплив міжсистемних зв'язків будівельної логістики, та представлена у вигляді орієнтованого графа. Розгляд будівельної логістики дозволяє зробити висновок про те, що сьогодні будівництво слід віднести до системи взаємозалежних та взаємозалежних потоків інформаційних, матеріально-технічних, фінансових та трудових ресурсів. Методи організації та управління вищезазначеними потоками ресурсів потребують вдосконалення задля досягнення значних результатів у скороченні термінів будівництва, підвищенні якості будівельної продукції, мінімізації витрат за рахунок впровадження логістичних підходів.

Література

1. Arutiunian I., Poltavets M., Bondar O., Anin V., Pavlov F. Structural Information Management of Production Systems in Construction. *International Journal of Advanced Trends in Computer Science and Engineering*. 2020. T. 9. № 4. P. 4794–4797.
2. Tsimoshynska, O., Koval, M., Kryshtal, H., Filipishyna, L., Arsawan, W. E., & Koval, V. Investing in road construction infrastructure projects under public-private partnership in the form of concession. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, 2021. № 2, P. 184–192.
3. Ричардс Г., Гринстед С. Инструментарий логистики и управления цепями поставок. Axelot, 2020. 376 с.
4. Anbuudayasankar S., Ganesh K., Mohapatra S. Models for Practical Routing Problems in Logistics. Design and Practices Springer International Publishing, Switzerland, 2014. 173 p.
5. Беркута А., Осінська В., Галинський О., Вахович І. Організаційні та економічні аспекти зарубіжного досвіду саморегулювання в будівництві. *Будівельне виробництво*. Київ, 2010. № 52. С. 3–8.
6. Крикавський Є., Похільченко О., Фертч М. Логістика та управління ланцюгом поставок. Видавництво Львівської політехніки, 2017. 848 с.
7. Козік В. Організація виробництва: навч. Видавництво Львівської політехніки, 2020. 256 с.
8. H. Stadtler, C. Kilger, H. Meyr, Supply Chain Management and Advanced Planning: Concepts, Models. Software, and Case Studies. Springer, 2015. 512 p.
9. Liang Z., Chaovalitwongse W., Shi L. Supply Chain Management and Logistics: Innovative Strategies and Practical Solutions. CRC Press, 2016. 288 p.
10. Бажан Л.И., Яблоков И.В. Концептуальні основи синхронізації матеріального та інформаційного потоків в транспортно-логістичній системі. Збірник наукових праць *Економіко-математичне моделювання соціально-економічних систем*. Київ, 2015, вип. 20. С. 115–138.
11. Шаповалова О.О., Камардін А.С., Петухова О.А. Система підтримки прийняття рішень при виконанні логістичних завдань. *Системи обробки інформації*, 2018, вип.3 (154). С. 57–63.
12. Гамбаров Л. А., Кузьминчук Н.В., Чернишова Н. П. Інструментарій побудови моделей багатоетапних завдань виробничо-транспортної логістики. *Вісник економіки транспорту і промисловості*, № 49, 2015. С. 221–229.