Development of Integrated Logistics Paradigm in Solving Complex Multi-Criteria Problems of Material Flow Management

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***Abstract*— The paper considers the historical retrospective of the development of logistics paradigms and analyzes the apparatus used to solve applied logistics problems. Obstacles to the implementation of the integrated paradigm of logistics, its analytical approach and simulation tools are investigated, which allowed to determine the structure of the decision support system in the management of material flow and formulate the concept of logistics coordination. As a result, it was possible to develop a conceptual scheme of the economic mechanism of logistics coordination of the production enterprise and to form a General algorithm for mathematical modeling of simulation and analytical models of logistics coordination and solving complex problems of material flow management in complex organizational and technical systems.**

As a scientific novelty, the paper analyzes existing methods for solving multi-criteria problems of managing material flows and justifies their lack. An integrated approach to the coordination of material flow management based on the method of economic compromise is proposed and justified. The concept of an economic mechanism for logistics coordination has been developed, the interrelated elements of which are: a subsystem for cost management, a subsystem for decision support in operational material flow management, and a subsystem for integrated planning and material flow management.

***Keywords*—** *Paradigms of logistics, economic and mathematical methods in logistics, economic compromise, logistics coordination, mathematical modeling, analytical methods, simulation*

1. Introduction

The problem of solving complex multi-criteria problems of material flow management in logistics is an urgent task. The principle of integration, professed logistics, urging the presentation of a model of activity of the enterprise or the supply chain as a complex multidimensional system, in which you want to define a set of indicators to measure the effectiveness of its work and controlled parameters, by changing which it is possible to define a set of actions or decisions on the management of the system, the best way affecting the performance parameters of this system.

The analysis of the existing paradigms of logistics, analysis of the tools used by them, evaluation of its effectiveness in solving the problems of management of complex systems allows to determine the options for the representation of such models.

We will reveal a number of key concepts and concepts necessary to determine the content of the topic and to introduce the solution of complex multi-criteria problems of material flow management in science and in practice. The approach to solving this class of problems is based on the paradigms and concepts of logistics and the possibility of using one of the functions of logistics – the coordination of material flows. In this regard, concepts such as the mechanism of logistics coordination, the integrated paradigm of logistics come to the fore.

Economic mechanism of logistic coordination (EM LC) is a set of methods and means of harmonization of the values of the controlled parameters of the material flow in the process of solving problems of material flow management (MF), built in accordance with the principles of logistics, implementing a system-wide method of economic compromise and focused on the criterion of minimum total costs, and having the goal of achieving the best in specific conditions of efficiency and effectiveness of material flow management.

Also, EM LC can be defined as an appropriate set of methods, approaches and tools, the unity of which allows to make coordinated decisions in the

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management of material flow, taking into account the interests of all functional subsystems, but with a focus on system-wide efficiency and effectiveness.

Actually, logistic coordination (LC) – is the ordering of various operations related to the movement and transformation of MF, and the rules of their implementation - is to achieve the optimal, in terms of minimum total costs, a combination of intensity of incoming, processed and outgoing from the enterprise MF, and demand, as well as the use of available resources and capacities of the enterprise. Then, under the model of logistic coordination we understand a schema, or the algorithm of the solution of a specific multicriteria problem of control of MF, based on the construction of which is based on the principles of logistics and method of economic compromise.

The formation of logistics principles that influence the development of methods and approaches to solving problems of MF management is associated with the evolution of logistics paradigms: analytical, information, marketing and integrated [6], [8].

Their analysis will determine their contribution, advantages and disadvantages in solving problems of material flow control in complex systems. To analyze the existing methods of solving multi-criteria problems of material flow control and substantiate their shortcomings that prevent the solution of intra-material flow control conflicts. And as a result, to propose and justify an integrated approach to the coordination of material flow management, based on the principles of logistics and the method of economic compromise used in the development of optimization and simulation models of logistics coordination of the enterprise.

2. Literature Review

Based on the above methods, in the context of the search for a conceptual solution to the multi-criteria problems of material flow management in complex systems, which are manufacturing enterprises, we present the results of the study concerning:

- a critical analysis of the existing paradigms of logistics, tools and methods used in the context of solving the problems of coordination of material flow management;
- identification and justification of obstacles and necessary conditions in the implementation of the integrated paradigm through the development of an economic mechanism of logistics coordination;
- critical consideration of existing approaches to solving complex problems of material flow control – analytical approach (mathematical programming), vector optimization and simulation, in the context of solving the problem of material flow control in complex systems;
- description of the structure of the decision support system in the management of material flow and the formulation of the concept of logistics coordination, which in turn made it possible to formulate a conceptual scheme of the economic mechanism of logistics coordination of industrial enterprises and to develop a common algorithm for mathematical modeling of simulation and analytical models of logistics coordination and solving complex problems of management of material flow in complex organizational and technical systems.

2.1 Existing paradigms of logistics, applied tools and methods

A feature of the analytical paradigm is the development and application of fairly complex economic and mathematical models and methods for solving the problems of MF management. It is assumed that the problem has been clearly defined, and the model of its solution is feasible [10], which is not always possible in the description and formalization of sufficiently complex and large systems, which are industrial enterprises. In addition, the implementation of such models requires a large array of source information and the development of complex decision-making algorithms in the management of MF. As a result, today there is a fairly large set of models and methods that have the ability to local use and solve a narrow range of problems of MF management [13], [15]. As for the possibility of using these models and methods for integrated control of MF, aimed at strengthening the coordination function, there are problems in their integration [16], the conjugation of objective functions and the system of restrictions (the development of algorithms for sequential coupling of the results of solving local problems – for example – vector optimization). And also, what is important, to use the available methods and models without their prior adaptation to the specifics of the real problem, is fraught with a distorted solution. Moreover, sometimes so much effort is spent to find, select and adjust the existing model of solving a logistics problem under real conditions that it is easier to create your own model [17], [21]. But the creation of a model of a large and complex system requires a good knowledge of the real system and great ability to formalize the existing system in models. As a result, the analytical paradigm is not able to formalize in an adequate way large dynamic and complex systems, which are production enterprises (PE).

Overcoming some of the shortcomings of the analytical paradigm takes on the information paradigm of logistics, which forms a set of problems, tasks and methods of solving them in the logistics of industrial enterprises, determines the possibility of combining them in the process of material flow management at the PE, and gradually implements the synthesis of all this in the information management system class ERP [9]. At the same time, it is not necessary to speak about the implementation of the integrated approach in the management of MF, because the combination of methods and models considered by the analytical paradigm in the management information system, lost the true objective function (criterion of optimality) of a large system in the web of local performance criteria and a variety of incompatible sets of constraints of local models. As a result, when automating trivial tasks, the goal is to achieve the optimality of the entire process of MF management, information management systems in itself is absent. At the same time, the visibility of the process of operation of a large system is to some extent present, which gives a false reason to believe that the process is controlled by the principle of system optimality and rationality [7].

Achieving flexibility and dynamism is a condition of survival in today's competitive market environment. Marketing paradigm, and developed on its basis models of material flow management, taking into account the stochasticity of indicators related to the dynamics of environmental factors, bring the principle of dynamic accounting.

The development of analytical, information and marketing paradigm leads to the formation of an integrated paradigm of logistics, the achievements of which today are:

- formulation of the concept of integration, which consists in considering the MF as an integrator of the management process of a large system, as a whole, rather than a set of independent parameters, functions;
- development on this basis of new organizational forms (organizational structures of MF management), business process orientation, creating an integral structure of the material flow management process;
- the realization that the basis of MF management is the ultimate goal of the system, effective and optimal demand satisfaction, and not the existing functions of the system.

Therefore, the existing approach to the formation of material flow management models is the adaptation of local methods and models [11], [19], and their implementation in the information system of the ERP class, as well as the structuring in accordance with the new business process management structures, which does not always have a positive effect, and can sometimes generate inadequate information models of large systems. That is, the adaptation of old methods and economic mechanisms to new organizational structures and business processes of MF management is obtained. In fact, the very method of interaction or integration, focused on the principle of system optimization and minimization of the total cost of functioning of the PE, the role of which is performed by the economic mechanism of logistics coordination, is only at the stage of formation.

2.2 Obstacles and necessary conditions for the implementation of the integrated paradigm of logistics

Thus, to implement the integrated paradigm and the principle of system optimization of the MF management process in large systems is an extremely difficult task, which puts forward a number of requirements and conditions in the formation of logistics models, including the model of logistics coordination. The main obstacles to the formation of the economic mechanism of LC and the necessary conditions that should have an economic mechanism of logistics coordination of industrial enterprises are grouped into two categories (described below), as a result, a synthesis of the study of the specifics of existing methods and models of coordination of management of complex economic systems and the needs of solving the problem of the intra-system conflicts, including the supply subsystem, taking into account the principles of logistics [1]-[5], [12], [14], [18], [20], [22].

Obstacles and necessary conditions in the implementation of the integrated paradigm through the development of economic mechanism of logistics coordination are the following.

1. Existing obstacles to the formation of an economic mechanism for the logistics coordination of an industrial enterprise:

- no complete mathematical formulation of the coordination problem;
- the existing mathematical procedures and algorithms are quite complex and cannot describe the whole complex of logistics coordination tasks;
- decision-making methods for this problem are not sufficiently formalized;

- it is extremely difficult, and sometimes impossible, to determine an unambiguous optimum in the task of logistic coordination;
- taking into account the complexity of building an aggregate model of logistics coordination, the need to identify and describe a large number of relationships;
- insufficient systematization and structuring of the theory of economic compromise in solving the complex problems of interaction of several physical functions
- the absence of a detailed cost management system (costs – as a key parameter in the optimization of MF management) in many enterprises: cost accounting and classification for the purposes of MF management, cost analysis, etc.

2. The necessary conditions that must have an economic mechanism of logistics coordination of the industrial enterprise, expressed in the availability of opportunities:

- overcoming limitations in the possibility of mathematical formalization of models of large systems and the development of algorithms for solving the problems formulated in their basis;
- achieving convergence of objective functions and the system of restrictions of local problems in determining the value of the optimal level of total costs in the system and, accordingly, the optimal values from this position of the controlled parameters of the MF;
- achieve visibility in the management and coordination process, both the model of the whole system and its individual elements;
- taking into account flexibility and dynamism, uncertainty in the external environment, predicting the outcome of events that affect the processes taking place in the system;
- taking into account the possibility of using the demand forecasting unit in the model with the assignment of the distribution function with changing parameters (taking into account the dynamics of the external environment);
- taking into account the multi-criteria of the objective function;
- taking into account a large number of interrelated indicators of efficiency of MF management and other factors, the relationship between which is not explicitly defined and can not be clearly formalized;
- taking into account the possibility of scaling and improvement (development) of the LC model;
- scaling and introduction of new conditions, limitations and parameters in the current model of logistic coordination due to the multi-aspect of the LC problem and multi-variant in each specific practical solution;
- changes in model parameters (in particular MF parameters and their values) over time, using mostly the improvement of the model, rather than its new creation;
- research of various cost tradeoffs "on the go", in the process of work of the aggregated model, and analysis of the behavior of submodels of economic compromise in their combination in a large system;
- the concept and method of building a model of logistics coordination should be clear to the analyst-logistician, quickly mastered by them, which implies a minimum of mathematical abilities of formalization of tasks in the models.

It is necessary to pay attention to the fact that currently there are two approaches to the study of complex processes of management of economic systems, the first of them – (1) analytical approach (mathematical programming), the second – (2) simulation.

2.3 Analytical approach (mathematical programming)

Mathematical programming (analytical approach) is based on the development of a mathematical model of the process of functioning of the object, linking together its internal characteristics and external factors affecting it, and on the formulation of tasks to determine such process controls that provide extreme value of some functional characterizing the effectiveness of management.

The study of the state of development of analytical models for solving the problems of conflicts of management and coordination of management in complex economic systems, in particular: the analysis of conflicts in management [5] and the definition of compromises in management [1], leads to the conclusion that the problems of conflicts in economic systems and attempts to solve them in these works are made mainly using complex analytical economic and mathematical methods and the construction of models, many of which are purely theoretical and rarely used in practice, since the creation and even more so the use of optimization analytical models of MF management coordination in large systems is associated with a number of negative aspects, some of which are:

- the complexity of linking all the conditions of the real problem in the mathematical model leads to its simplification, which adversely affects the final result;

- the impossibility of selecting methods for solving a complex model, complex and algorithm solutions, that is, models of large systems are so complex that it is not always possible to solve them optimally;
- changing the situation, the emergence of the need to include in the mathematical model of additional factors, parameters and conditions, requires a radical restructuring of the entire model (mathematical model is created to solve a specific problem, even a slight change in the conditions of the problem requires a new model and adjust the methods of its solution);
- the formulation of the economic problem involved managers,economists, specialists of the subject area, and the development of a mathematical model (mathematization of the problem) – mathematics, so there is a need to coordinate many points and often there is a misunderstanding between them on a number of key issues of the model.

For example, currently in the field of study of complex processes of management of mathematical methods, each task is necessary to build a model or system of models focused on the solution of this problem with the passage of all stages of model development, its programming, identification and verification. The system of existing models is not easy to understand, their use is impossible outside the team of their developers, so it is easier to create a new model than to find and adapt already developed, even if it exists.

The implementation of the analytical method of solving the problem of coordination of MF management is simplified with the use of computers.

We can distinguish two approaches to the creation of analytical economic and mathematical apparatus of integrated information systems class ERP. The first approach involves the formation of a global model of the MF management process, which establishes various relationships between input and output variables, on the basis of which a management decision can be chosen to ensure the optimal functioning of the system. Further, the global model is detailed to individual tasks based on the decomposition method, which allows to take into account all the requirements for integrated control of MF. However, this approach to the construction of optimization models of MF control, due to the technical and mathematical complexity is not always possible to apply, because it has limitations in terms of the dimension of the problem.

The second approach is based on the principle of synthesis into a single system of a set of local economic and mathematical methods and models (EMM), each of which describes a separate or a number of functions, or a separate control problem of MF. This approach is more preferable and technically implementable in the formation of integrated management information systems. Due to the coverage of local EMM all sides of the MF management process, and algorithmization of interconnections of solutions of local problems, it is possible to achieve the overall goal of MF management, but the optimal control of the material flow in terms of the minimum total cost in this case is not always possible to find.

The most significant aspect affecting the principle of the optimality of the solution for the whole PE, not just for local management tasks, MF, is the definition of the interrelationships of the objective functions and constraint of the individual tasks, the choice of the target function or the sequence of particular tasks, the actual matching algorithm and the coordination of local models, the solution of multicriteria problems of control of MF.

To solve many multi-criteria complex economic problems in large systems is impossible to use only methods of mathematical programming, because it is not possible to formulate a single criterion of management efficiency, or simply the problem of MF management is quite complex.

In addition, when analytical modeling of real objects, using optimization methods, the simulation results may not correspond to the behavior of the object, as they give the values of the parameters of the simulated object in steady-state (static) mode. The real objects, in particular the processes of motion and transformation of MF, as a rule, are not in a static state and constantly change their parameters and parameter values, while in a sufficiently dynamic rhythm.

The complexity and great interconnection of MF control processes and their coordination, make it unpromising and even impossible to use only mathematical programming methods in solving complex problems of MF control in large systems. Since the need to formulate ultimately the only criterion of management efficiency, as well as spend considerable effort to find optimal management decisions inevitably leads in most cases to too much coarsening of the model, discarding many significant factors and conditions.

As practice shows, the "optimal" values of controlled quantities obtained by solving individual problems by mathematical programming methods, it is undesirable to use in pure form, because due to the inadequacy of the coarsened model, there are unforeseen negative consequences that overlap the positive effect. So, for example, the calculation of the optimal size of the order by the Wilson method in most cases gives the values of the controlled parameter MF inadequate to practice. Therefore, this model is used as an auxiliary tool.

The problem of multicriteria optimization, in particular in problems of control of MF, it is suggested to solve also by using the method of the vector (multicriteria) optimization [14].

In the most General form, the method of vector (multi-criteria) optimization is formulated as follows.

When making a decision on MF management in accordance with the principles of logistics, all decisions are reduced to choosing the optimal alternative among the many permissible means of achieving the goal or solving the complex problem of MF management.

This approach is often perceived as a subjective goal, which is to optimize the system according to a given criterion. However, in real complex systems, there are several objectives, such as rules, and, accordingly, several objectives can be pursued simultaneously, which are often contradictory, which leads to intra-system conflicts. Establishing a rigid hierarchy of goals is also not always possible, since a characteristic feature of intra-system conflicts is that the subjects of the conflict are at the same level of the hierarchy, and their tasks are equally important.

Therefore, in order to solve multi-criteria problems of MF management it is necessary to determine a "compromise" between different goals, to find a solution that to some extent would satisfy all the requirements, and therefore would not fully satisfy any of them personally.

The problem statement is presented as follows. Let the set of possible variants of the values of the controlled parameters of the material flow X be given (1).

$$X = \{x1, x2, x3, \ldots, xi, \ldots, xn\} \quad (1)$$

Each variant is characterized by a set of parameters for evaluating the efficiency of Y, which are given by scalar vectors of local optimization y1,y2, …, ym (2).

$$Y = \{y1, y2, y3, \ldots, yi, \ldots, ym\} \quad (2)$$

Between each member of the set X and each member of the set Y there is a fuzzy relation in which the vector Y is associated with the solution by the functional map X → Y = F (X), given either analytically, or statistically, or heuristically. It is necessary to find the optimal solution or the values of the controlled parameters of MF (3).

(3)

1

This formulation corresponds to the model of minimizing the total costs of the following types (4).

$$X^{o} = F^{-1}[\underset{X \in D_{x}}{opt} \; Y(x)] \quad (4)$$

Where:
opt – the operator optimization of the vector of efficiency Y;
F^{-1} – the inverse transform of Y in X.

This model is a vector optimization model, since it has a Y – vector efficiency criterion, and the implementation of the model allows to find an optimal solution to the set of Xo values of the controlled parameters of MF.

When creating a coordination mechanism, the basis of which is a model for determining the optimal level of costs, it is necessary to rely on the following provisions of the optimization theory [14].

The optimal state of each functional element is less effective than the optimal state of the entire system (5):

$$\bigcup_{i=1}^{n} \left\{ (y_i)^{opt} \right\} < Y^{opt} \quad (5)$$

Where:
$(y_i)^{opt}$ – optimal condition of the functional element;
Yopt – optimal state of the system;
m – number of functional elements.

Optimization of the state of the whole system leads to suboptimal States of its constituent functional elements (6):

$$Y^{opt} \Rightarrow \bigcup_{i=1}^{n} \left\{ (y_i)^{subopt} \right\} \quad (6)$$

Where:
$(y_i)^{subopt}$ – suboptimal state of the i-th functional element.

Conditions (5) and (6) derive the "principle of joint optimization", which plays a decisive role in the development of a mechanism for coordinating the management of material flow. The main conclusion of this principle is that in order to achieve an effective end result, mutual consistency of functional elements in the management process is important. Following the functional elements only their own goals, that is, the desire for local optimization can harm the interests of the system as a whole and its individual elements.

However, there are three main problems with multi-criteria optimization. Problems and directions of their solution in the vector optimization method are the following.

The first vector optimization problem is related to the choice of the principle of optimality, which quite strictly determines the properties of the optimal solution and answers the question, in what sense the optimal solution exceeds all other permissible solutions? This is because it is necessary to compare the vectors of efficiency on the basis of some scheme of compromise, set by the operator opt.

The problem of solving the problems of MF management is connected with the fact that it is not known how to determine the degree of importance of individual tasks and the corresponding optimization criteria.

Therefore, the main problem is to determine the scheme (algorithm) of the compromise, the scheme of coordination of individual optimization criteria. The formation of the scheme of compromises should be preceded by a comprehensive and in-depth analysis of the object on the basis of which the model of multi-criteria optimization is built.

The second problem is the normalization of the vector Y and is related to different scales and units of measurement of local criteria. Therefore, there is a need to bring the criteria to a single scale of measurement or normalize them. The solution of the second problem is possible on the basis of bringing all tasks to a single criterion of optimization – the cost of performing any functions or operations of movement and transformation of MF.

The third problem is related to the priority (varying degrees of importance) of local criteria. To solve this problem, the importance distribution vector $\Lambda = \{\lambda 1, \lambda 2, ..., \lambda n\}$ is usually introduced, by which the optimality principle is corrected.

The first way to determine the optimal solution for several criteria is to rank the criteria, their location in order of importance. Having ranked the criteria, we move on to finding the optimal solution for the most important criterion. Further, having determined the permissible value of the change of the first criterion (5 – 10%), look for a solution to the second criterion, the best in the resulting area.

The second way to solve the multi-objective problem is to transfer all the target functions, except one, into the system of restrictions.

The third method is the construction of a single integral criterion of efficiency by summing the products of the existing criteria to some "weight" coefficients (coefficients of importance of the criteria). Moreover, if the sum of the objective function have the desired extrema of opposite signs, you must pre-multiply them by negative one. The greatest difficulty in the implementation of the third method (reducing the multi-criteria problem to a single-criterion) is to determine the weight coefficients that determine the relative importance of the particular performance criteria.

The most promising and convenient method of studying complex economic objects, including the processes of motion control and transformation of MF, is the method of simulation.

2.4 Simulation modeling in solving the problem of logistics coordination

The second approach to the study of complex processes of management of economic systems is associated with simulation modeling, in which it is not expected to set and solve mathematical programming problems (optimization problems). Simulation modeling is a reproduction of the flow of the studied process using a model with several control options, followed by an analysis of the results. Each reproduction of the process flow by means of a model is called a simulation experiment.

Simulation modeling, in contrast to analytical mathematical models, is able to apply multi-criteria models without weighing the objective functions and even without sequential optimization of the components of the multi-objective objective function.

The method of simulation was created for the dynamic description of some object under study, the study of the nature of its development and did not take into account the possibility of finding a rational solution, he could only check the effect of many different factors on the course of events.

However, today it is possible to build models that, on the one hand, will be "optimization", and on the other hand - "simulation".

The modern direction of development of the simulation modeling approach is associated with the development of methods of expert synthesis [18] in the framework of simulation models. In this case, during the simulation experiment, "reasonable" management values are developed for the values characterizing the state of the controlled process at a particular moment or period of time, but not by solving optimization problems, but by expert synthesis.

The approach of expert synthesis (or system approach in modeling) involves the simultaneous use of simulation and mathematical programming, by including in the simulation model of the process under study a set of simplified or aggregated models of the same process or its individual sides, together with algorithms that allow solving mathematical programming problems within these models.

2.5 The decision support system

The decision support system (DSS) in the coordination of MF management, implementing the expert synthesis approach can be represented as an object consisting of the following three parts [4], [12]:

1. Simulation model of the process together with the program that implements the model on a computer.
2. A set of simplified models of the process or its individual sides and algorithms that allow to solve optimization problems of the choice of controlled parameters of MF. This part of the DSS is also called its external mathematical support, or mathematical support for decision-making.
3. A set of programs that implement human-computer interaction during simulation experiments that facilitate the use of optimization results in the simulation process, provide information in a form convenient for the Manager's perception, and provide an operational mode of communication with the machine in the process of simulation experiments. This part of the system is also called the internal mathematical support of the simulation system.

The inclusion of a set of optimization models in the simulation system will simultaneously use simulation as a system of analysis (system analysis), and mathematical programming as a synthesis system (system synthesis), to make rational decisions in the management of complex processes. Simulation (simulation model) allows to reproduce at the model level the flow of the studied process in as much detail as it is necessary and technically feasible. The simulation should be based on a sufficiently detailed model. In turn, the system of synthesis or a set of mathematical programming models is a tool for studying the reproducible process, its optimization.

In the process of studying the existing local models for solving the problems of MF management, it was previously revealed that the method of economic compromise plays an important role in solving intra-system conflicts, on which, in particular, models for solving the problems of interaction of several functions are built, for example, the problem of determining the optimal size of the order. In addition, the method of economic compromise is associated with balancing the conflicting costs in order to determine their optimal aggregate level, which is a kind of scheme for determining a compromise solution for costs (compromise scheme).

As a result, it is of practical importance to use the method of economic compromise as a key element in the construction of models of logistics coordination.

Depending on the specifics and scale of the complex task of logistics coordination, it is necessary to select the most appropriate and economical approach to the formation of a model of logistics coordination: the use of mathematical programming or simulation, or a combination thereof, the latter is seen as the most promising direction.

In view of the above, it is possible to formulate the concept of logistics coordination as opposed to a narrow-functional approach to the management of MF following mathematical calculations.

With a functional approach to management, cost minimization takes place separately for each function or operation of movement and transformation of MF, which can be represented in the form (and in addition, depending on the scale of the system under study: functional subsystem or industrial enterprise as a whole).

At the functional subsystem level or as a whole (7).

$$F(c) = \sum \min Ci \qquad (7)$$

Where:

F(c) is the total cost;

Ci is the cost of the i-th operation or function of the movement and transformation of the MF and the cost of decision-making in the field of MF management.

At the level of PE as a whole (8).

$$F(c) = \min Cc + \min Cn + \min Cp \qquad (8)$$

Where:

Cc, Cп , Cp, - costs, respectively, in the functional subsystems of supply, production, sales.

At the level of functional subsystems, or PE in general (9).

$$F(c) = \min Ctr + \min Csk + \min Cgr + \min Cupr + \min Cpr \qquad (10)$$

Where:

Ctr - transportation costs;

Csk – costs of the inventory function;

Cgr – the cost of cargo handling;

Cupr – costs of managing a MF;

Cpr – other costs.

At the level of the functional subsystem or PE as a whole (11).

F(c) = minCA + minCB + minCC + minCD (11)

Where:
CA – costs of functions and operations of movement and transformation of MF;
CB – losses from immobilization of funds in stocks;
CC – losses due to the low level of consumer service;
CD – costs of MF management.

Then, the basis of logistics coordination, through the management of total costs, the solution of intra-system contradictions, the identification and use of hidden reserves to improve efficiency, management of "docking sites", that is, from the point of view of the principles of logistics, cost minimization should take place in accordance with the following conceptual provision (12).

$$F(c) = min \sum opt\ Ci = min \sum (opt\ CA + opt\ CB + opt\ CC + opt\ CD + opt\ CE) \quad (12)$$

Where:
Opt - means the optimal, in accordance with the scheme of compromise, the level of relevant costs, balanced by the criterion of the minimum total cost;
CE – costs of alternative use of capital, the cost of missed opportunities, unaccounted transaction costs and other costs.

It should be emphasized that it is important how optimization is carried out, that is, the principle itself, the scheme of compromise is important, and the options for classifying and grouping costs may be different, in accordance with the scheme of compromise, as well as depending on the task and on the nature of the identified behavior of conflicting costs.

In this approach, the natural economic result of the coordination of the MF management process is the effect expressed in cost savings (13):

$$R = \sum min\ Ci - min \sum opt\ Ci\ ,\ as \sum min\ Ci > min \sum opt\ Ci \quad (13)$$

The difference between these approaches is that with the functional method of cost management, their optimization was not considered from a system perspective. The second method, cost optimization, takes into account a system-wide approach that takes into account economic trade-offs. That is, it is possible to rearrange the costs of certain functions and operations, as a result of which the overall level of costs will be reduced. This is achieved by increasing the cost of some operations and functions and reducing the cost of other operations and functions.

The main problem of determining the optimal level of total costs in the management of MF in the equation F(c) = min ∑ opt Ci, is the presence of antagonism in the behavior of costs for various functions and operations of motion and transformation of MF. The existence of uncoordinated contradictions or conflicts of function goals leads to a decrease in the overall efficiency of MF management:

Overall efficiency of MF management = Result of MF / F(c), where “Overall efficiency of MF management” is the coefficient of economic efficiency of material flow control.

Optimization of costs under the second approach requires the allocation of the studied costs and their accurate quantitative assessment. Determination of the model of their behavior in the interaction of this function with another function, as well as the impact of a set of factors affecting the level of analyzed costs.

Finding a compromise costs will reduce total costs to the best possible level by redistributing the amount of work performed by physical functions and operations on the PE and related costs, changing the values of the controlled parameters of the MF.

The solution of the economic compromise will allow to determine the optimal variant of coordination of material flow management. Economic compromise is designed to keep the optimal balance of costs, inventory and quality of service. Since the same problem can be solved by different means, at different costs and levels of efficiency, a more accurate and reasonable assessment of relationships and costs can have a decisive impact on the profitability of the company.

In the end, the organization will receive a large profit from the sale of its products, achieving, at the same time, the optimal level of customer service, providing them with the necessary amount of goods in the required time and the right place, at the best price.

3. Methodology

The methods used in this work can be divided into stages of the research, which was carried out to develop the concept of the economic mechanism of logistics coordination and determine the General algorithm for mathematical modeling of simulation and analytical models of logistics coordination and solving a set of problems of material flow management (figure 1).

At the first stage, the analysis of existing logistics paradigms, tools and methods used in the context of solving problems of coordinating the management of material flows is performed.

The method of historical retrospective analysis allowed us to show the stages and features of the development of existing logistics paradigms and extrapolate to the future, identifying the main trends and opportunities for their implementation in practice.

The method of comparative analysis made it possible to compare existing methods, identify their advantages and disadvantages, and in combination with the classification method – to implement the selection and grouping of the most significant characteristics of existing logistics paradigms in the context of solving problems of managing material flows of complex organizational and technical systems.

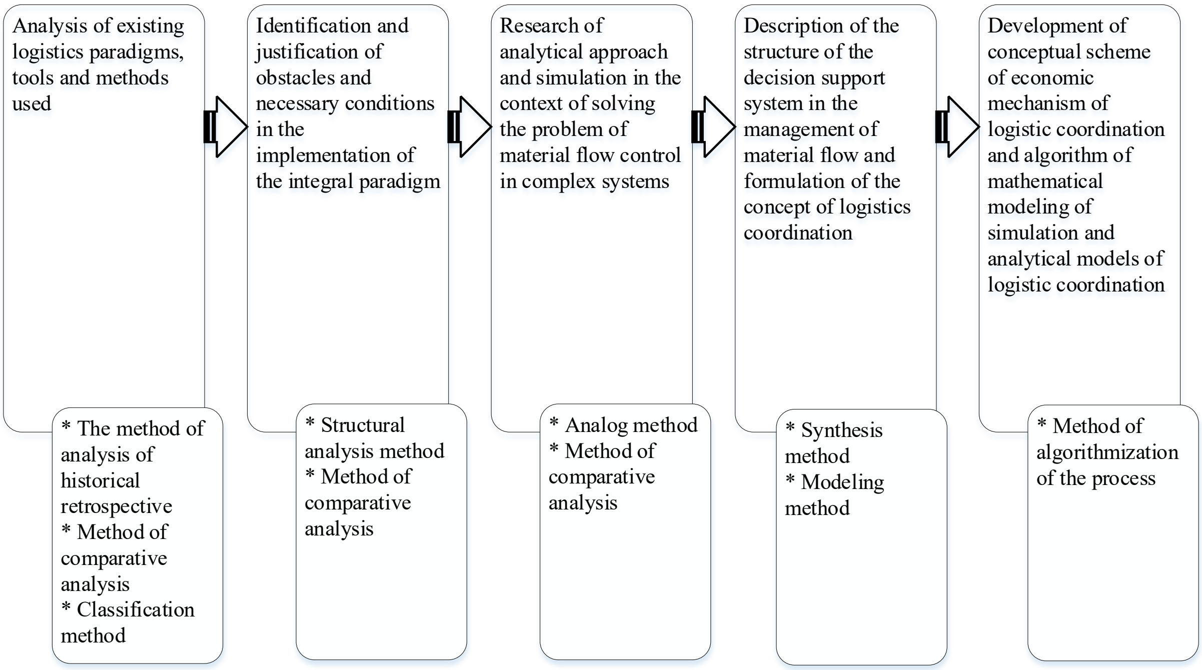

Figure 1. Methods used in the analysis of factors impeding and contributing to the implementation of the integrated paradigm of logistics in solving the problems of coordination of material flow management

At the second stage, the obstacles and necessary conditions in the process of implementing the integrated paradigm through the development of an economic mechanism for logistics coordination are identified and justified. To do this, we used the method of structural and comparative analysis to identify factors that prevent the use of economic and mathematical tools in solving multi-criteria tasks of enterprise logistics, identifying analogies in other areas to work out opportunities that can be used to overcome the identified obstacles. All this made it possible to formulate requirements for the use of an analytical approach and a simulation tool in solving problems of material flow management.

At the third stage, a critical review of existing approaches to solving complex problems of material flow management – analytical approach (mathematical programming), vector optimization and simulation, in the context of solving the problem of material flow management in complex systems. The used methods of analogies and comparative analysis allowed us to identify problems and ways to solve them when using these methods, formulate ideas for the joint application of best practices and synthesis of the considered approaches for developing a decision support system and determining the scheme for solving problems of economic compromise.

At the fourth stage, the structure of the decision support system in material flow management was developed and the concept of logistics coordination was formulated. To solve this problem, it was necessary to use the synthesis method to generalize previously studied information and the modeling method to determine the problem of logistics coordination.

At the last stage, a conceptual scheme of the economic mechanism of logistics coordination of a production enterprise was developed and a General algorithm for mathematical modeling of simulation and analytical models of logistics coordination and solving a set of tasks for coordinating material flow management was formulated. To do this, we used the method of algorithmization of the process, which allowed us to describe the proposed solution in a structured form.

4. Discussion

The new conceptual integrated (logistics) approach is based on the method of economic compromise, which, given the complex and contradictory nature of cost formation and the conflicting nature of costs, is designed to find the optimal level of total costs in the system. However, in the theory of logistics, the use of economic compromise to reduce total costs in the management of MF is fragmented due to the complexity, complexity and interconnectedness of the tasks of MF management. As a result, the coordination aspect of the method of economic compromise in the management of MF is not fully used, and, consequently, the integration and coordination role of logistics in improving the efficiency of material flow management and the enterprise as a whole, is not sufficiently disclosed in theory and, accordingly, is poorly implemented in practice.

On the basis of the formulated definition of the economic mechanism of logistics coordination as an appropriate set of methods and tools that contribute to the development of agreed solutions in the management of material flow, taking into account the principles of logistics and the implementation of an integrated approach to logistics coordination, as the main components and providing elements of this mechanism, we:

1. Subsystem of decision support in the operational management of the MF.
2. A subsystem of cost management.
3. Integrated system of integrated planning and management of MF (ERP-system).
4. Algorithm of mathematical modeling.

The conceptual scheme of the economic mechanism of logistic coordination of the production enterprise is presented in figure 2.

The role of the integrated system of integrated planning and management of MF (ERP-system) is the formation and presentation of the necessary planning information in the subsystem of decision support for the formation of optimal coordinated plans of operational management of MF in various subsystems of the industrial enterprise. Actually, the ERP-system should act as a base on which it is necessary to form the main elements of the economic mechanism of logistics coordination, embedding, adding and scaling the ERP-system itself.

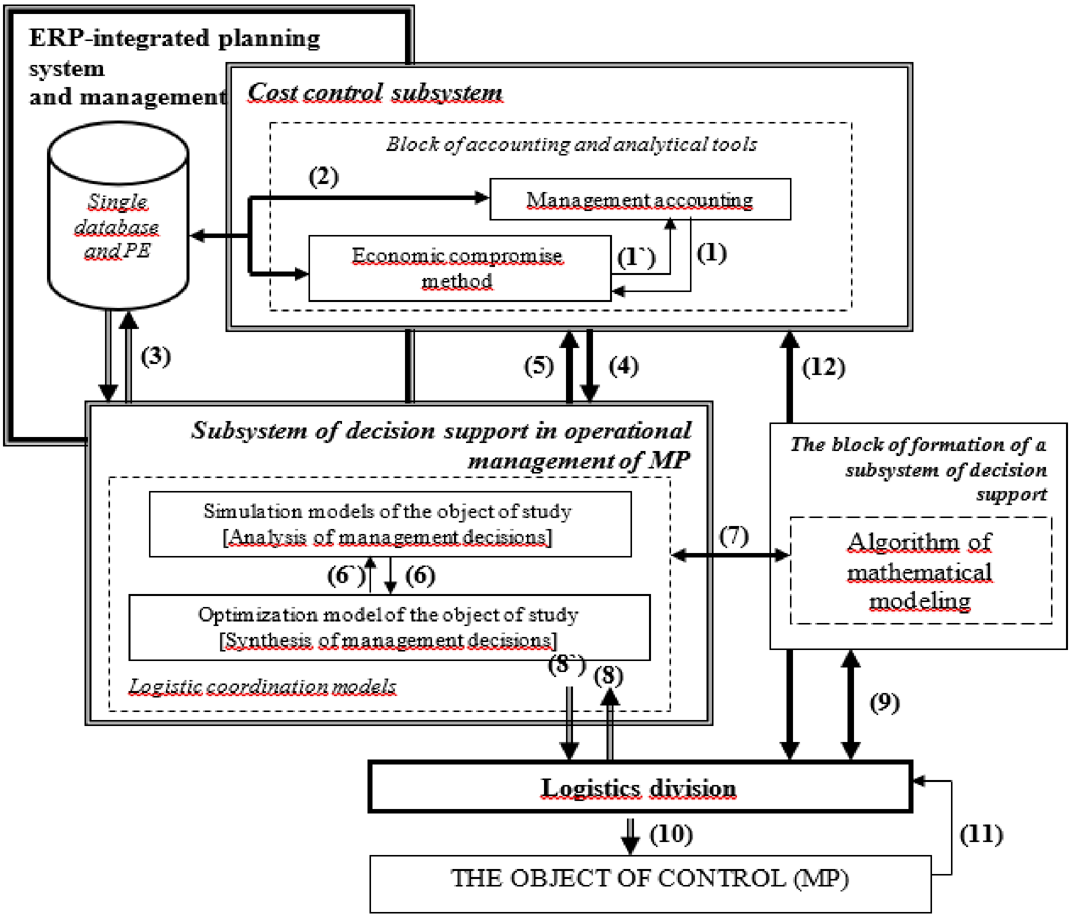

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Figure 1. Methods used in the analysis of factors impeding and contributing to the implementation of the integrated paradigm of logistics

The legend of figure 2:

(1) – Presentation of information on costs in the structure and the nature of the formation required for their subsequent analysis.

(1`) – a Query on the structure and nature of the formation of the analyzed costs.

(2) – Communication with a single database of ERP-system, receiving and transmitting the necessary data, the formation and replenishment of the knowledge base of PE.

(3) – Interactive relationship between the knowledge base of PE and simulation and optimization models of LC. Integration of models into ERP system.

(4) – Providing the necessary information on costs and the nature of their interaction in the process of making cross-functional decisions in the management of MF.

(5) – generation and submission requirements for scope, contents and structure of the cost information, behaviour, dynamics.

(6) – Expanding the understanding of the object of study, the relationships within the object of study and with the environment, the processes of development of the object and its environment, etc.

(6`) – Knowledge of system optimization of the management object and management processes, formalization of relationships, development rules, etc.

(7) – Rules and procedure for the formation and development of simulation and optimization models of logistics coordination, development of decision support subsystem in the management of material flow.

(8) – Management of the management decision development process.

(8`) – Response to control actions in the process of finding solutions.

(9) – definition of objectives, the formulation of multicriteria problems, work on the formation and development of the p/s support management decisions.

(10) – Control actions or management decisions developed using the decision support subsystem.

(11) – feedback Loop from the control object to the control subject.

(12) – goal Setting, setting of multi-criteria tasks, work on the formation and development of the cost management subsystem.

The task of the cost management subsystem is to account for and analyze, process and provide to the decision support subsystem information on groups of relevant (essential for decision-making) costs, their dynamics and behavior, as well as other necessary adapted economic information about the flow of the process of movement and transformation of MF, the costs of future periods and alternative costs, in order to include them in the decision-making process in the models of logistics coordination.

The subsystem of decision support in the management of MF is a key element of the economic mechanism of the LC and is designed to contribute to the development of optimal or rational solutions to complex, multi-criteria tasks of MF management in complex and large economic systems.

Simulation and optimization models of logistics coordination serve as a tool for decision-making.

Since earlier the approach of simulation and optimization modeling in solving LC problems has been generally considered, at this stage we focus on the specifics of their interaction, which is the key to the possibility of implementing an integrated approach in the management of material flows in complex economic systems, including industrial enterprises.

The simulation model is presented in the form of a program that implements some algorithm or scheme of operation of the object (process) on a computer, which allows a comprehensive study of the various aspects of the operation of the object in the process of applying management actions to it, which involves an experiment with the model of the object. The adequacy of the simulation model to the real system can be very high, at least much higher than any optimization model.

In contrast to simulation models, optimization models allow to set and solve optimal control problems using computers. Compared with simulation models, they are characterized by a less detailed description of the process, a significant simplification and lack of consideration of many factors, the coarsening of model relationships, and a relatively small number of values, which as a result lead to the need to build a set of optimization models of large systems.

When using any mathematical models to solve problems of management of real processes, the key issue is to establish the adequacy of the model description and the process under study, to determine the scope of possible use of the model, to create information support for the model.

Then, carrying out simulation experiments on sufficiently detailed models will allow to carry out the necessary analysis of the adequacy of optimization models and to investigate the relationship of the results of several optimization models to determine how this will affect the total result of MF control, that is, simulation models are a kind of equivalent to the real situation for optimization models.

Thus, in the process of planning the experiment with the help of a simulation model, parameters are used – control actions chosen by the Manager-analyst. The choice of control actions is carried out from a certain set and usually has a quality criterion of this choice, that is, a function that should be optimized. Then before entering the control actions into the simulation model, you can first solve the optimization problem of finding them, and only then the optimal values found to enter into the simulation model LC. In this case, the simulation allows you to simulate the response of the system to the optimal in a certain sense of its management.

Another link between simulation and optimization models can be implemented. If the set of control actions is not too large, then all of them with some degree of accuracy can be tried in the simulation model. The result of the simulation in this case allows to evaluate the control actions – to discard the obviously bad and to order the quality of the remaining ones.

In addition, simulation allows deeper understanding of the object under study, which sets the problem of optimal control, to understand what criteria best describe the various specific situations, the nature of the patterns of behavior of the individual controlled parameters of the MF, to explore the interaction of conflicting costs and thus develop a method of economic compromise.

Depending on the specifics of a particular task of logistics coordination in an industrial enterprise, it is necessary to develop, configure or select the appropriate model of logistics coordination and methods of its solution, which use mathematical modeling.

To build a mathematical model, depending on the type of operations, research tasks and the accuracy of the original data, use a mathematical apparatus of varying complexity. Mathematical programming methods (linear, dynamic, inventory management models, etc.) can be used. In the most complex cases, when the problem depends on a large number of complex intertwined random factors, analytical methods may be insufficient to solve the problem, and then it is necessary to use the method of simulation.

The best solution in the construction of a decision support subsystem for a large economic system can be obtained through the use of simulation and optimization modeling. When the analytical model makes it possible to understand in General terms the essence of the object of study and the process of its management, to outline a kind of "contour" of the basic laws of a complex and interrelated process, and any clarification and developing an idea of the object information can be obtained by simulating the functioning of the same object.

Thus, the simulation model of logistic coordination allows to identify and study the unformalized patterns in the process of MF management, movement and transformation of MF and the behavior of the corresponding costs that affect the efficiency of MF management in order to develop an approach to rationalize the studied relationships and to form or develop an appropriate model for optimizing the controlled parameters of material flow.

The General algorithm of mathematical modeling of simulation and analytical models of logistic coordination and solution of a set of tasks is the following.

1. The definition of goals, formulation of complex problems of the research object, formulation of the basic questions about his behavior, the answers to which you must obtain by the model.
2. Building a conceptual model of the object.

2.1. Comprehensive survey of the modeling object:
- Meaningful description of the object, the presentation of the basic laws of the process of functioning of the object.
- Determination of the boundaries within which the study of the object and the identification of individual aspects of its functioning.
- Determination of relationships between individual elements of the object of study.

2.2. Preliminary formalization of the object.
- Formulation of parameters and indicators used in the description of the object. Determination of endogenous (internal), exogenous (external) indicators and control parameters.
- Partial formalization of the main relationships between indicators.
- Conceptual representation of the model.
- Choice of modeling method.
- Description of the model formation process

3. Development of mathematical model and its verification.
- Formalization of model elements and parameters, their interrelations.
- Mathematical representation of all model elements and their interrelations.
- Development of the algorithm of the model.
- Algorithmization and programming of the structure and content of the model for its implementation on a computer.
- Checking the model and algorithms.
- Assessment of model suitability,

verification of model adequacy to the simulated object of study.
- The definition and formalization of requirements to the visualization of the individual stages of the research (use of models) and outcomes.

The specificity existing in the process of building simulation and optimization models in the General algorithm of mathematical modeling is not considered in this article and will be developed in the future.

The choice of mathematical modeling methods for solving a specific problem is commensurate with the art of modeling and correctly constructed model – a matter of experience and professionalism of the subject area specialist, his knowledge of existing mathematical methods.

5. Conclusion

Thus, an integrated approach to the coordination of material flow management, based on the principles of logistics and the method of economic compromise used in the development of optimization and simulation models of logistics coordination of industrial enterprises, which is the basis for the development of economic mechanism of logistics coordination, is proposed and justified. Thus, the implementation of the principles of logistics in the management of material flow requires restructuring and improvement of models for solving problems of material flow management, which are mainly multi-criteria and complex. In addition, the integrated approach involves the use of features of the method of economic compromise, which consists in the possibility of taking into account the complex and contradictory nature of cost formation and the conflicting nature of costs in the search for a compromise solution to the values of the controlled parameters of the material flow, which (values) are objects of intra-system conflicts.

As a result of the study, the results were achieved:

• the existing methods of solving multi-criteria problems of material flow management are analyzed and their shortcomings that prevent the solution of intra-system conflicts of material flow management are substantiated;

• an integrated approach to the coordination of material flow management based on the method of economic compromise used in the development of optimization and simulation models of logistics coordination of the production enterprise is proposed and justified, which is the basis for the development of an economic mechanism of logistics coordination;

• the concept of the economic mechanism of logistic coordination was developed, the interrelated elements of which were: the subsystem of cost management, the subsystem of decision support in the operational management of material flow and the subsystem of integrated planning and management of material flow.

From the point of view of the practical significance of the study, it can be said that the developed concept of the economic mechanism of logistic coordination and the model of logistic coordination of procurement activities in manufacturing enterprises will provide a significant increase in the organization and efficiency of material flow management and gain additional competitive advantages by reducing the level of total costs.

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