Optimizing of Product Logistics Digital Transformation with Mathematical Modeling

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Abstract. The purpose of the paper is to demonstrate the possibility of improving the quality of logistics in a rapidly changing situation based on mathematical modeling. The evolution of information technology worldwide goes from separate accounting of individual operations to their integration based on cloud and integrated technologies. Adaptive optimization is required, taking into account the dynamics of the external environment. The paper proposes a flexible mathematical model of management transformation in logistics. For this, a single digital logistics platform is formed as a connecting link for all participants in the value-added chain, including product manufacturers, suppliers of resources and services, product consumers, and logistics companies. At the same time, intermediaries who do not create added value could be excluded from the supply chain.

1. Introduction
Russia ranks the 95th place in the ranking of logistics efficiency in the world. Therefore, the need for the digital transformation of this type of activity is obvious. One of the significant factors of improving the country's logistics quality is improving various types of interconnections between all logistics chains' participants by forming a single information space and applying optimization methods. This requires the introduction of modern modeling methods and end-to-end digital technologies, including artificial intelligence.

This paper presents the result of an analytical review of the experience of creating integration associations of participants in supply chains, and then, in this context, we propose a mathematical model for optimizing the logistics activities of a coalition of participants.

2. Overview of integration associations of participants in supply chains
As a result of the evolution of Information and Communication Technologies (ICT) in logistics, the following types of associations can be distinguished according to the degree of their integration: Subcontracting Supply Network (SSN), Information Subcontracting Network (ISN), Production and Logistics Network (PLN) [1, 2]. Unlike SSN and ISN, which are a kind of "bulletin board," in the PLN a Single Information Space (SIS) is a platform for planning and managing projects on the Internet with a common database in the digital cloud, which contains data on the performance of logistics operations, classifiers, standards, common for all registered participants.
In the concept of the PLN, only a small part of various autonomous enterprises with a limited set of information content is included in the SIS. But in the concept of the national platform "Digital Agriculture," the authors proposed a mathematical model for the formation of a single digital logistics platform [3]. This work is devoted to expanding this model to provide the ability to form supply chains of arbitrary configuration with the participation of the majority of economic entities in almost all sectors of the country.

The logistics fields of implementation in the context of supply chain engineering include inventory control, radio frequency identification, flexible manufacturing systems, assignment and scheduling methods, warehousing technologies [4].

During constructing the model, it was taken into account that the digital and intellectual transformation now occupies a special place in the development of logistics activities in the world. Thus, it is shown [5] that it is fundamentally impossible to build a “smart” city without smart supply chains. At the same time, among smart solutions, it is worth highlighting:

- Intellectual transport systems;
- Autonomous logistics providing unmanned movement of people and goods;
- Physical Internet for the most efficient movement of goods;
- Intellectual cargo that has all the knowledge about its movement;
- Self-organizing logistics that can work without the effort of managers.

Logistics activities vary in scale. Thus, it is noted [6] that global logistics operations associated with electronic commerce have become very time-dependent in recent years. International couriers face day-to-day issues related to time windows, delays, express delivery management, security, and value-added tax refunds. There are supply chain management methodologies that, based on lean manufacturing principles, integrated with the concepts of Industry 4.0, already solve these problems quite well. E.g., in [7], the logistic parameter is one of the main ones for prioritization and segmentation of the country's agro-industrial products export.

In logistics, it is worth highlighting the methods of direct problem solving with tight synchronization of the stages of product delivery and the inverse problem solving, in which optimal supply chains are promptly synthesized for newly emerging user needs. An important place is occupied by institutional structures, mechanisms for managing responsibility and motivation, modern methods of building a space of trust using block-chain technologies (distributed ledgers), the Internet of things, cloud and fog computing.

Against this background, it seems expedient to propose a fairly universal model for the formation of optimal logistics chains.

3. Mathematical model for optimization of the logistics activities of participants’ coalition

This section formalizes the most demanded external logistics management system from the point of view of logistics activities to more efficiently analyze, plan, and design supply chains. We will exclude such types of logistics as production, purchasing, customs, and stock logistics. In this case, the participants in the supply chain of the following groups: suppliers of suppliers, suppliers, consumers of consumers, consumers will be combined into groups of suppliers and consumers, based on the criterion of entry - exit of the product. The same organizations can act as both suppliers and consumers of products.

Then the participants in the supply chain will be represented by the following groups: suppliers, consumers, warehouses, transport companies, installation companies, recycling companies. The scheme analysis shows that the supply chain formation block gives a significant effect and is most in-demand in terms of optimizing logistics activities based on mathematical modeling. Therefore, we formalized this block first. The choice of installation and disposal organizations with cost optimization was the second step of formalization. Since these two models can be separated, they belong to the class of block programming, i.e., related only to financial constraints and delivery time of installation equipment.
So, we consider a system consisting of many suppliers of goods, many consumers, many transport companies, many warehouses. The task is to form optimal supply chains of supply by suppliers of products to consumers by transport companies using warehouses based on minimizing the total costs of products, their transportation, and warehouse services. At the same time, there should be a choice of suppliers of products, a choice of warehouses, and transport companies with loading vehicles. Due to this, the following tasks will be solved in a complex: tracking transport, managing orders (requests), and managing costs for transport and warehouse services. At the same time, we consider the case with enough transport companies to satisfy all the needs; the supply of goods exceeds the demand.

The management process is periodically realized as assumed with a period of $T$, such that during this period there should be no delays in the production and delivery of goods, and all logistics operations' parameters are averaged over time. The choice of the period $T$ is influenced by such characteristics as the number of orders, the volume of cargo transported from suppliers to the warehouse and from the warehouse to consumers, as well as directly from suppliers to consumers in order to load vehicles to the maximum. The need to increase the rate of turnover of funds, goods in warehouses, and the urgency of fulfilling orders also matters. If, for example, $T$ is too small, then the model will give out a large underutilization of vehicles, if it is large, then queues will form, there will be not enough capacity of warehouses, vehicles, the participants in the supply chain will be mired in loans. The optimal value of $T$ can be found out in at least three ways. The first one is based on information about all transport flows (time characteristics of loading, unloading, warehousing, transportation, cash flows; volumetric characteristics of the transported goods, types of vehicles, etc.) for a long period of time to find out some average characteristics and then calculate $T$ (in this case, if all the information is available, you can try to build an optimization model). In the second method, the desired value $T$ is found based on the model in the simulation mode. The third method is based of expert opinion.

Note that $T$ in the model is needed to start the supply chain modeling. It can be called $T_0$. In the future, while using the model for operational management in dynamics, when any failure occurs in the supply chain, new requests will appear. The next planning period $T_t (t = 1, 2, \ldots)$ will be dependent on the same characteristics as $T$.

Let us take into account that of all the characteristics of vehicles, such as carrying capacity, the volume of cargo transported, etc., the only actual carrying capacity of the vehicle will be considered with the specific volumetric carrying capacity. If necessary, the other characteristics can be considered, which will lead to the complication of the model. At the same time, under the unit of the product, the volume of supplies, storage, we mean both the unit and the volume of the specific volumetric carrying capacity of the product.

3.1. Mathematical model of supply chain optimization

3.1.1. Constants

The following constants were introduced:

- $v_{ik}$ – the volume of demand of the $i$-th consumer in the $k$-th product, $i = (1, 2, 3, \ldots I), k = (1, 2, 3, \ldots K)$;
- $w_{jk}$ – the volume of potential availability of the $k$-th product at the $j$-th supplier, $j = (1, 2, 3, \ldots J)$;
- $p_{jk}$ – the unit price of the $k$-th product from the $j$-th supplier;
- $n$ – the transport company number (CN), $n = (1, 2, 3, \ldots N)$;
- $s$ – the warehouse number, $s = (1, 2, 3, \ldots S)$;
- $r$ – the vehicle type number, $r = (1, 2, 3, \ldots R)$;
- $R_n$ – the number of types of vehicles in the $n$-th CN;
- $N_{rn}$ – the number of vehicles of the $r$-type in the $n$-th CN;
• $g_{rn}$ – the vehicle identification number of the $r$-th type of the $n$-th CN;
• $\mu_r$ – the specific volumetric carrying capacity of the $r$-type of vehicle, calculated as the ratio of the total weight of all products to their volume intended for transportation by the $r$-type of vehicle;
• $A_s$ – the warehouse capacity $s$ (in specific volumetric capacity) is calculated by means of the table for converting pallet capacity into specific volumetric capacity (when developing an information system, users will work in their usual terms);
• $G_r$ – the passport carrying capacity of the $r$-type vehicle;
• $V_r$ – the body volume of the $r$-type vehicle;
• $d_r = \min (\mu_r, G_r/V_r)$ – the actual carrying capacity of the $r$-type vehicle, taking into account the specific volumetric carrying capacity;
• $D_{rn}$ – the total actual carrying capacity of all vehicles of the $r$-th type at the $n$-th transport company, taking into account the specific volumetric carrying capacity, $D_{rn} = d_r \times R_{rn}$;
• $d_{ks}$ – prices for storage and handling of a unit of the $k$-th product in the $s$-th warehouse, this value reflects the sum of the average specified costs for the period $T$ (when developing an information system, users will work in their usual terms, and will be calculated automatically, if, of course, the corresponding operations being performed are written to the operation database);
• $f_{iwh}^1$ – prices for transportation of a unit of product from point $s$ (warehouse) to point $i$ (place of delivery of the $i$-th consumer) by the $r$-type of vehicle at the $n$-th CN through the $h$-th point, based on the specific volumetric capacity of the $r$-type of vehicle ($h = 1, 2, 3, \ldots I$);
• $f_{jwh}^2$ – prices for the transportation of a unit of product from point $j$ (location of the product of the $j$-th supplier) to point $s$ (warehouse) by the $r$-type of vehicle at the $n$-th CN, based on the specific volumetric capacity of the $r$-type of vehicle;
• $f_{jwh}^3$ – prices for transportation of a unit of product (without transshipment) from point $j$ (location of the product of the $j$-th supplier) to point $i$ (place of delivery of the $i$-th consumer) by the $r$-type of vehicle at the $n$-th CN, based on the specific volumetric carrying capacity $r$- of the type of vehicle.

3.1.2. Variables

The following variables were introduced:
• $x_{ijk}$ – the volume of supplies of the $k$-th product from point $j$ to point $i$, where $i \in I$, $k \in K$, $j \in J$;
• $y_{jwh}^1$ – volume of product deliveries from point $s$ to point $i$ with the $r$-type of vehicle of the $n$-th CN;
• $y_{jwh}^1$ – the volume of deliveries of the product from point $s$ to point $i$ with the $r$-type of vehicle of the $n$-th CN through the $h$-th point, $h \in I$;
• $y_{jwh}^2$ – the volume of product deliveries from point $j$ to point $s$ with the $r$-type of the vehicle of the $n$-th CN;
• $y_{jwh}^3$ – the volume of direct deliveries of a product from point $j$ to point $i$;
• $y_{ksh}^4$ – storage volumes of the $k$-th product in the $s$-th warehouse.

3.1.3. Equations and inequalities

The following equations were solved and inequalities were used:
• $\sum_{j} x_{ijk} = v_{ik}$;
\[ \sum_{i} x_{ijk} \leq w_{jk} ; \]
\[ \sum_{is} y_{irns}^1 + \sum_{js} y_{jfrns}^2 + \sum_{ij} y_{ijrn}^3 \leq D_{rn} ; \]
\[ \sum_{irns} y_{irns}^1 = \sum_{jrn} y_{jfrns}^2 , \]
\[ \sum_{ik} y_{ik}^j = \sum_{jrn} y_{jfrns}^2 + \sum_{irn} y_{irn}^3 , \]
\[ \sum_{jrns} y_{jrns}^2 = \sum_{k} y_{ks}^4 , \]
\[ y_{lirns}^1 = \sum_{l} y_{lirns}^1 , \]
\[ \sum_{irn} y_{irn}^3 = \sum_{k} y_{ks}^4 ; \]
\[ d_{ij} - \varepsilon \leq y_{irnsh}^3 - \text{almost full load requirement (} \varepsilon \text{ – permissible underload)} \text{ of direct deliveries of a product from point } j \text{ (location of the product of the } j\text{-th supplier)} \text{ to point } i \text{ (delivery point of the } i\text{-th consumer)} \text{ of the } r\text{-type of vehicle of the } n\text{-th transport company}; \]
\[ d_{ij} - \varepsilon \leq \sum_{i} y_{irnsh}^3 \text{ – the requirement for almost complete loading of the } r\text{-type of vehicle of the } n\text{-th transport company when the product is delivered from point } s \text{ (warehouse) to point } i \text{ through the } h\text{-th point}; \]
\[ \sum_{k} y_{ks}^4 \leq A_{s} . \]

3.1.4. Efficiency criteria

The following efficiency criteria were used:
\[ c_0 = c_1 + c_2 + c_3 + c_4 + c_5 \rightarrow \min , \text{ where:} \]
\[ c_1 = \sum_{irnsh} f_{irnsh} y_{lirns}^1 ; \]
\[ c_2 = \sum_{jfrns} f_{jfrns} y_{jfrns}^2 ; \]
\[ c_3 = \sum_{ijrn} f_{ijrn} y_{ijrn}^3 ; \]
\[ c_4 = \sum_{ks} d_{ks} y_{ks}^4 ; \]
\[ c_5 = \sum_{jk} p_{jk} x_{jk} ; \]

Thus, as a result of solving this problem, the specific values are obtained: \( x_{jk}^* , y_{lirns}^{*1} , y_{lirnsh}^{*1} , y_{jfrns}^{*2} , y_{irnsh}^{*3} , y_{ks}^{*4} \).

3.2. Mathematical model of vehicle loading optimization

To solve the new problem of loading each vehicle with specific products, heuristic algorithms were applied for three traffic streams.
3.2.1. Direct deliveries

Let’s introduce new variables \( x_{ijk}^* = x_{ijk}^* \), \( y_{ijk,n}^* = y_{ijk,n}^* \), \( g_{rn} \) — counter of the vehicle number of the \( r \)-th type of the \( n \)-th transport company. \( i=1, k=1, j=1, r=1, n=1, g_{rn} = 1 \). Let’s also introduce the set \( K^* = K \).

Step 1. If \( y_{ijk,n}^* \geq d_r \), then go to step 2, otherwise, go to step 5.

Step 2. \( y_{ijk,n}^* = y_{ijk,n}^* - d_r \), if at the same time \( x_{ijk}^* \geq d_r \), then go to step 3, otherwise, go to step 4.

Step 3. \( x_{ijk}^* = x_{ijk}^* - d_r \).

The vehicle \( g_{rn} \) is loaded with good \( k \) from point \( j \) (location of the product of the \( j \)-th supplier) to point \( i \) (place of delivery of the \( i \)-th consumer). If \( g_{rn} < N_m \), then \( g_{rn} = g_{rn} + 1 \). If \( g_{rn} = N_m \) and \( r < R_n \), then \( r = r + 1 \), if \( r = R_n \), then \( n = n + 1 \) and go to the Step 1.

Step 4. The optimization problem is solved: \( \max \sum_{m \in K^*} x_{ijm}^* \leq d_r \). Find a solution \( x_{ijk}^* \) for some \( k^* \). Define \( \alpha = d_r - \max \sum_{m \in K^*} x_{ijm}^* \), \( K^* = K \setminus k^* \), if \( \alpha = 0 \), then go to the Step 4.1, otherwise, if \( K^* = 0 \), then go to the Step 4.1, otherwise we accept \( x_{ijk}^* = x_{ijk}^* - x_{ijk}^* \) and find \( x_{ijk}^* \), such that \( x_{ijk}^* \geq \alpha \) and \( k^* \in K^* \). If this is not found \( k^* \), then go to the Step 4.1, otherwise for this \( k^* \) we find \( x_{ijk}^* = x_{ijk}^* - \alpha \) and go to the Step 4.1.

Step 4.1. The vehicle \( g_{rn} \) is loaded with good \( k^* \) and part \( \alpha \) with number \( k^1 \). If \( g_{rn} < R_m \), then \( g_{rn} = g_{rn} + 1 \). If \( g_{rn} = N_m \) and \( r < R_n \), then \( r = r + 1 \), if \( r = R_n \), then \( n = n + 1 \) and go to the Step 1.

Step 5. If \( y_{ijk,n}^* \leq d_r \), the vehicle \( g_{rn} \) is loaded with the product residue \( x_{ijk}^* \) from point \( j \) (location of the product of the \( j \)-th supplier) to point \( i \) (place of delivery of the \( i \)-th consumer).

If \( g_{rn} < N_m \), then \( g_{rn} = g_{rn} + 1 \). If \( g_{rn} = N_m \) and \( r < R_n \), then \( r = r + 1 \), if \( r = R_n \), then \( n = n + 1 \) and go to the Step 6.

Step 6. If \( j < J \), then \( j = j + 1 \) and go to the Step 1, otherwise \( j = 1 \). If \( i < I \), then \( i = i + 1 \) and go to the Step 1, otherwise go to the Step 7.

Step 7. The calculations are over with receiving the direct deliveries \( x_{ijk}^* \).

3.2.2. Deliveries to warehouses

As a result of previous calculations, suppliers have balances \( x_{ijk}^* \). Let’s introduce the variables \( y_{ijk,n}^{2r} = y_{ijk,n}^{2r} \), \( y_{ks}^{4r} = y_{ks}^{4r} \). Define \( j=1, s=1 \) and the set \( K^* = (1, 2, 3, ... K) \). Insofar as \( y_{ijk,n}^{2r} = \sum x_{ijk}^{2r} \), then we will use this value for the distribution by vehicles in the future.

Step 1. If \( y_{ijk,n}^{2r} \geq d_r \), then go to the Step 2, otherwise, go to the Step 5.

Step 2. \( y_{ijk,n}^{2r} = y_{ijk,n}^{2r} - d_r \). If at the same time \( x_{ijk}^* \geq y_{ks}^{4r} \) and \( s = S \), then go to the Step 7, otherwise \( s = s + 1 \) and go to the Step 3, otherwise, if \( x_{ijk}^* < y_{ks}^{4r} \) then go to the Step 4.

Step 3. \( x_{ijk}^* = x_{ijk}^* - d_r \).

The vehicle \( g_{rn} \) is loaded with good \( k \) from point \( j \) (location of the product of the \( j \)-th supplier) to the point \( s \) (warehouse). If \( g_{rn} < N_m \), then \( g_{rn} = g_{rn} + 1 \). If \( g_{rn} = N_m \) and \( r < R_n \), then \( r = r + 1 \), if \( r = R_n \), then \( n = n + 1 \) and go to the Step 1.
Step 4. The optimization problem is solved: \( \text{max} \sum_{m \in K^*} x_{ijm}^{*r} \leq d_r \). Find a solution \( x_{ijk}^{*r} \) for some \( k^* \). Define \( \alpha = d_r - \text{max} \sum_{m \in K^*} x_{ijm}^{*r} \), \( K^* = K^* \setminus k^* \), if \( \alpha = 0 \), then go to the Step 4.1, otherwise, if \( K^* = 0 \), then go to the Step 4.1, otherwise we accept \( x_{ijk}^{*r} = x_{ijk}^{*r} - x_{ijk}^{*r} \) and find \( x_{ijk}^{*r} \) such, that \( x_{ijk}^{*r} \geq \alpha \) and \( k^* \in K^* \). If this is not found \( k^* \), then go to the Step 4.1, otherwise for this \( k^* \) we found \( x_{ijk}^{*r} = x_{ijk}^{*r} - \alpha \) and go to the Step 4.1.

Step 4.1. The vehicle \( g_m \) is loaded with good \( k^* \) and part \( \alpha \) with number \( k^1 \). If \( g_m < R_m \), then \( g_m = g_m + 1 \). If \( g_m = N_m \) and \( r < R_n \), then \( r = r + 1 \), if \( r = R_n \), then \( n = n + 1 \) and go to the Step 1.

Step 5. If \( y_{ijk}^{*r} \leq d_r \), the vehicle \( g_m \) is loaded with the product residue \( x_{ijk}^{*r} \) from point \( j \) (location of the product of the \( j \)-th supplier) to the point \( s \) (warehouse).

If \( g_m < N_m \), then \( g_m = g_m + 1 \). If \( g_m = N_m \) and \( r < R_n \), then \( r = r + 1 \), if \( r = R_n \), then \( n = n + 1 \) and go to the Step 6.

Step 6. If \( j < J \), then \( j = j + 1 \) and go to the Step 1, otherwise \( j = 1 \). If \( s < S \), then \( s = s + 1 \) and go to the Step 1, otherwise we have go to the Step 7.

Step 7. The calculations are over with receiving the goods’ \( k \) deliveries from the point \( j \) (location of the product of the \( j \)-th supplier) to the point \( s \) (warehouse) \( x_{ijk}^{*r} \), as well as loading warehouses \( y_{ik}^{*r} \).

3.2.3. Delivery from the warehouse

As a result of previous calculations, suppliers did not have any goods left for delivery, and consumers had undelivered goods \( v_{ik}^{*r} = \sum_j x_{ijk}^{*r} \) from the warehouses. Let's introduce the variables \( y_{ik}^{*r} \), \( y_{ks}^{*r} \) (vehicle loading \( g_m \)). Let's define \( i = I, s = S, k = K, h = H, y_{ik}^{*r} \) (vehicle loading \( g_m = 0 \), the set \( K^* = \{1, 2, 3, \ldots K\} \).

Step 1. If \( y_{ik}^{*r} \geq d_r \), then go to the Step 2, otherwise go to the Step 4.

Step 2. \( y_{ik}^{*r} = y_{ik}^{*r} - d_r \). If at the same time \( y_{ik}^{*r} \geq v_{ik}^{*r} \), then the vehicle \( g_m \) is loaded with good \( k \) from the point \( s \) (warehouse) to the point \( i \) through the point \( h \). \( y_{ik}^{*r} = y_{ik}^{*r} - d_r \). If \( g_m < N_m \), then \( g_m = g_m + 1 \). If \( g_m = N_m \) and \( r < R_n \), then \( r = r + 1 \), if \( r = R_n \), then \( n = n + 1 \) and go to the Step 1. Otherwise, when \( y_{ik}^{*r} < v_{ik}^{*r} \) go to the Step 3.

Step 3. If \( d_r \leq y_{ik}^{*r} \), then \( y_{ik}^{*r} = y_{ik}^{*r} - d_r \). The vehicle \( g_m \) is loaded with good \( k \) from the point \( s \) to the point \( i \) through the point \( h \). If \( g_m < N_m \), then \( g_m = g_m + 1 \). If \( g_m = N_m \) and \( r < R_n \), then \( r = r + 1 \), if \( r = R_n \), then \( n = n + 1 \) and go to the Step 1. When \( y_{ik}^{*r} < d_r \) and \( y_{ik}^{*r} + y_{ik}^{*r} \leq d_r \), then go to the Step 3.1, when \( y_{ik}^{*r} + y_{ik}^{*r} > d_r \), go to the Step 3.2.

Step 3.1. The vehicle \( g_m \) is loaded with good \( y_{ik}^{*r} \), \( y_{ik}^{*r} = y_{ik}^{*r} + y_{ik}^{*r} \), \( v_{ik}^{*r} = v_{ik}^{*r} + y_{ik}^{*r} \), \( y_{ik}^{*r} = y_{ik}^{*r} - y_{ik}^{*r} \), \( y_{ik}^{*r} = y_{ik}^{*r} - y_{ik}^{*r} \), \( k = k + 1 \) and go to the Step 3. If for any \( k \), \( y_{ik}^{*r} = 0 \) holds, then go to the Step 6, otherwise go to the Step 1.
Step 3.2. The vehicle \( g_{rs} \) is loaded with good \( y_{s}^{dr} = (d_r - y_{s}^{it}) \), from the point \( s \) (warehouse) to the point \( t \) through the point \( h \). \( y_{s}^{dr} = y_{s}^{dr} - (d_r - y_{s}^{it}) \), \( y_{s}^{it} = 0 \). Go to the Step 3.1.

Step 4. If \( y_{s}^{it} < d_r \), then go to the Step 4.1, if \( y_{s}^{it} > d_r \) \( y_{s}^{it} = 0 \). Go to the Step 4.2.

Step 4.1. The vehicle \( g_{rs} \) is loaded with good \( y_{s}^{dr} = y_{s}^{dr} - (d_r - y_{s}^{it}) \), from the point \( s \) (warehouse) to the point \( t \) through the point \( h \). \( y_{s}^{dr} = y_{s}^{dr} - (d_r - y_{s}^{it}) \), \( y_{s}^{it} = 0 \). Go to the Step 4.1.

Step 5. If \( i < l \), then \( i = i + 1 \) and go to the Step 1, otherwise go to the Step 1, otherwise go to the Step 1, otherwise go to the Step 1, otherwise go to the Step 6.

Step 6. The calculations are over. Product shipments \( y_{s}^{d} \) are received from warehouses \( s \) to the points \( s \)-th consumers through points \( h \) with the \( k \)-th product loading of each vehicle.

This completes the procedure for optimizing the formation of a logistics supply chain. Solving the optimization problem can be fixed by an agreement in the form of smart contracts. This model can also be used for operational management in dynamics. When a failure occurs in the supply chain, new requests will appear. To do this, it is necessary to enter the parameter \( t \) (planning period) into the model. If appropriate changes are made to the model, it will also be applicable for long-term planning with the definition of investments in infrastructure, such as the optimization of the placement of new warehouse premises through construction or lease. In improving management based on the optimization of logistics activities, the parameters of the model will also change, for example, prices. When forming a single Internet space of logistics operations, it would be possible to add the ability to connect suppliers, transport companies that are not part of the planned coalition and carry out transportation on opposite routes, to minimize idle mileage on both sides.

The loading of each vehicle with specific products based on the considered heuristic algorithms for three traffic flows was carried out in ascending order of their conditional numbers. This sequence could be changed by introducing restrictions on arrival time, waiting time, time of unloading vehicles, the throughput of warehouses, dimensions and compatibility of products (cargo), etc.

3.3. Mathematical model for choosing an assembly (utilization) organization

The mathematical model for optimizing logistics activities in the above setting consists of a mathematical model for optimizing external logistics management and a mathematical model for choosing an assembly (utilization) organization. Since these two models, as already noted, are related only by financial constraints and the delivery time of installation equipment (installation work begins only after the delivery of the corresponding equipment), these models can be calculated separately (refer to the block programming class) with the subsequent integration of finance.

Let us introduce the notation:

- \( p_{ijk} \) - the cost of the \( k \)-th type of work (installation, utilization) of the \( j \)-th contractor (supplier) of work for the \( i \)-th consumer;
- \( \alpha_j \) - reputation of the \( j \)-th contractor (supplier) of works, \( \alpha_j = (0,1) \), the value of \( \alpha_j \) is increasing with the level of supplier’s reputation.

Then the choice of the executor (supplier) of the \( k \)-th type of work for the \( i \)-th consumer, taking into account his reputation, is found from the solution of the following optimization problem \( j^{*} \):

\[
p_{ijk} (1 - \alpha_j) \rightarrow \min .
\]
4. Discussion and conclusions

As can be seen, the given model makes it possible to reduce the nonlinear problem of forming a supply chain with the loading of each specific vehicle to a linear setting by combining the resources of vehicles and products with different costs and prices. However, this loses the detail of the loading of each vehicle with specific products. As a result of solving this linear problem, only generalized product flows are obtained with distribution to groups of vehicles.

The nonlinearity of the initial task of forming a supply chain is associated with loading each specific vehicle with products from different suppliers at different prices. The solution of a similar class with a nonlinear problem setting can be found in [8].

The logistic process is multifaceted. A huge number of factors affect the organization of a digital platform for activities of a coalition of companies. Many large international companies are cautiously testing new products in the field of logistics, hiding their best practices so as not to harm the established supply chain of a large number of participants and not to lose their competitiveness. This is partly because many participants, for various reasons, are at different levels of integration of information systems, which will restrain their integration into a single system.

Small logistics enterprises, due to the significantly lower complexity of the supply chain, greater flexibility in decision-making, can afford to experiment with the formation of a digital platform that meets their needs at the current moment and perspective, taking into account general trends in the development of the IT industry in logistics. The proposed model for organizing a digital platform for the logistics activities of a coalition of companies in digital economy can be a technological breakthrough that will provide participants with better management of relationships; customer service; fulfillment of orders; production; delivery; reverse flows, etc.

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