Optimization Solutions of a Multistage Balanced Transport Problem with using of the Potential Method

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Abstract. Route optimization is an important issue because it allows improving the economic component in production. Its generalization to optimization problems on networks is shown. The transport task is formulated in the network setting: to make a plan of cargo trans-portation on the transport network so that the cargo stocks were taken out of the points of depar-ture, the needs of consumers at the destinations were met, and the total cost of transportation was minimal. The algorithm of its solution is given, revealed on a concrete example of delivery of products to customers who sell these products on a daily basis. Tables of the basic and optimal plan, a transport network of the optimal plan of transportations are made. The process of solving such a problem by modeling in the environment is proposed. The simulation model of this process was created with using the FlexSim software. The process of creating the simulation model is demonstrated.

1 Introduction

The formulation of any optimization problem begins with a set of independent variables and conditions that characterize the possible values of the variables. These conditions are called problem constraints. Another component of the description is the scalar measure of "quality", which is called the objective function and depends in some way on the variables. The solution of the optimization problem is an admissible set of values of variables, which corresponds to the optimal value of the objective function. By optimality is meant maximum or minimum, for example, profit maximization or weight minimization. There are different approaches to analyze different stages of transport tasks [1,2]. Mathematical and geometric modeling are an effective means of changing the quality of the delivery process [2] .The modern information technologies is also useful for optimization special stages of delivery process [3, 4].

In this article, we introduce a mathematical programming algorithm designed for addressing the universal transport problem [5, 6]. This algorithm aids in resolving the challenge of efficiently transporting products from suppliers to customers, elucidating each step involved in the solving process[7]. The focus of our study involves contrasting the conventional one-stage[8] transport problem with the practical scenario commonly encountered in real-world situations. In practice, it is not uncommon for products to initially reach intermediate points, such as transport network nodes, distribution centers, or warehouses, before reaching the final destination.

1.1 The algorithm for analizing technological process in transportation used the principle of mathematical programing and simulation of process

1.1.1 The optimal solution of a multistage balanced transport problem

The aim of the work is to find the optimal solution of a multistage balanced transport problem with using intermediate points and to build a simulation model which based on the transport network of the several stages transport task.

The main contribution of this paper can be summarize as follow:
1. it is designed the network statement of multistage transport problem, which allowed to see the interconnections between suppliers and consumers; the optimization of practice transport problem helps to calculate the continent way of cargo's delivery from start point (suppliers) to end point (consumers) using intermediate points of transportation;
2. it is developed an algorithm for building a simulation model of a multistage transport type problem that based on based on the transport network;

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3. it is built simulation model that helps to visualize a practical transportation problem and helps to find optimal solution

1.2 Materials and Methods

The problem of mathematical programming is formulated in such stage: it is necessary to turn into an optimum (minimize or maximize) some function, which is called the goal:

$$f(x) \to opt\ (min,\ max), \quad (1)$$

when performing a system of restrictions:

$$h_i(x) = 0, \quad j = \overline{1,m} \quad (2)$$

$$g_i(x) \geq 0, j = \overline{m+1, p} \quad (3)$$

and conditions that are directly imposed on the values of the required variables:

$$x \in E^n \quad x = (x_i; i = \overline{1,n}) \quad (4)$$

So, the task of mathematical programming is to find a vector of values of variables x_i; $i = \overline{1,n}$ which satisfy all restrictions and conditions and provide functions *f(x)* of the smallest or largest value.

The vector $x = (x_i; i = \overline{1,n})$ defines a point in n - measurable Euclidean space $x \in E^n$.

Depending on the content of the problem, the values of independent variables can be subject to requirements such as bivalence, inherence, belonging to a given segment of the numerical axis etc.

An example of a mathematical model for the general problem of mathematical programming is such following: it is necessary to distribute the planned task between enterprises in such way that the total cost of production was minimal. Input data:

n - number of enterprises $(r = \overline{1,n})$

m - number of types products $(i = \overline{1,m})$

k - number of resource types $(j = \overline{1,k})$

b_i - production plan for creation i –th - type of products

b_{ij} - resources costs standard of costs j-th type for each one product of i-th type

a_{rj} - the amount of resources of the j-th type at the r - enterprise

p_{ri} - the costs of producing each product of the i-th type at the k – enterprise.

Variables that have to be found are $r = \overline{1,n}$ x_{ri} production plan for creation *i* - type of products at the *r* – enterprise $r = \overline{1,n}$; $i = \overline{1,m}$.

The mathematical model for such data has the form:

$$f(x) = \sum_{r=1}^{n} \sum_{i=1}^{m} p_{ri}\, x_{ri} \to \min$$

$$\sum_{r=1}^{n} x_{ri} = b_i; \; i = \overline{1,m};$$

$$\sum_{i=1}^{m} b_{ij}\, x_{ri} \leq a_{rj}\; ; \; r = \overline{1,n}\; ; \; j = \overline{1,k}$$

$$x_{ri} \geq 0, \; r = \overline{1,n}, \; i = \overline{1,m}$$

If the objective function (1) and constraint (2, 3) are superimposed on the linearity conditions, then we have the problem of linear programming. Thus, the general task of linear programming is to find the maximum (minimum) of a linear function

$$W = c_1x_1 + c_2x_2 + ... + c_nx_n \sum_{r=1}^{n} c_j x_j \to \max(\min) \quad (5)$$

with conditions of use restrictions:

$$a_{i1}x_1 + ... + a_{in}x_n = \sum_{j=1}^{n} a_j x_j = b_i (i = \overline{k+1, m}) \quad (6)$$

$$x_j \geq 0 \; (i = \overline{1,n})$$

which form the domain of admissible solutions G, which must satisfy the vector of control variables $X = [x_1 \; ..., x_n]^T$. The function W is the efficiency index or the objective function, the criterion of optimality, or a linear form. The set of values of unknown control variables $X = [x_1 \; ..., x_n]^T$, that satisfy the conditions of the problem is called the solution.

Among modern methods of optimization and management of production processes, a significant role belongs to network methods. A large class of mathematical programming problems can be given in a network problem. This is especially true for transport tasks, which have a completely natural interpretation as network tasks associated with a particular network of transport routes. The mathematical model of the transport problem:

$$Z = \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij} \cdot x_{ij} \to \min\, ; \quad (7)$$

with restrictions:

$$\sum_{j=1}^{n} x_{ij} = a_i \; \left(i = \overline{1,m}\right) \quad (8)$$

$$\sum_{i=1}^{m} x_{ij} = b_j \; \left(j = \overline{1,n}\right) \quad (9)$$

$$x_{ij} \geq 0 \; \left(i = \overline{1,m}; \; j = \overline{1,n}\right), \quad (10)$$

where x_{ij} - the number of products transported from the i-th supplier to the j-th consumer; c_{ij} - cost of transportation of a unit of production from the i-th supplier to the j-th consumer; a_i - stocks of products of the i-th supplier; b_j - demand for products of the j-th consumer.

If in the transport problem the total number of products of suppliers is equal to the total demand of all consumers:

$$\sum_{i=1}^{m} a_i = \sum_{j=1}^{n} b_j \ , \quad (11)$$

then such a transport task is called balanced, or closed. If this condition is not met, the transport task is called unbalanced, or open. The transport task can be connected both in matrix (tabular), and in a network (network) statement. Each of the approaches to the connection of the transport problem has its advantages and disadvantages.

Let us analyze the classical transport problem. Suppose there are m suppliers of a product. The product is concentrated in suppliers in $a_1, a_2, ... a_m$. Suppliers can be factories that produce something, or warehouses where something is stored. Suppose the cost of transporting a unit of cargo from supplier i to consumer j is c_{ij}, n consumers of this product with needs $b_1, b_2, ... b_n$. We have to make such a transportation plan so that the needs of all consumers are met and the total cost of transportation is minimal. The condition of the transport task can be given in the form of the following Figure 1.

	b_1	b_2	…	b_n
a_1	c_{11}	c_{12}	…	c_{1n}
a_2	c_{21}	c_{22}	…	c_{2n}
…	. . .	. . .	…	. . .
a_m	c_{m1}	c_{m2}	…	c_{mn}

Fig. 1. Caption of the Figure 1. Below the figure.

- vector of needs $A = \{a_1, a_2, ... a_m\} = \{a_i\}_{i=1}^{m}$;
- vector of needs $B = \{b_1, b_2, ... b_n\} = \{b_j\}_{j=1}^{n}$;
- matrix of transportation costs $C = \{c_{ij}\}_{i=1, j=1}^{m \quad n}$.

Let's consider the solution of the problem based on the transport network, which are most common in practice [10, p. 56; 11, p. 8], named the network transport task.

Let us analyze transport task which is shown as graph. Each top of the graph is responsible for the entire transport point, and each edge - a certain area between the points. The graph is weighted, with each vertex and each edge being placed in response to certain parameters.

We formulate a transport problem in a network setting. Suppose a transport net-work with s vertices (transport points) and e edges (sections between transport points) is given. Among the transport points (network vertices), we will select the set A of suppliers (points of departure), the set B of consumers (destinations), the set T of intermediate (transit) points. Each of the transfer points is displayed by a large spare load $a_i (i \in A)$, and each destination - the value of load needs $(j \in B)$. For each edge between points *i* and *j* the cost of transportation of a unit of cargo c_{ij} and throughput of this site is set d_{ij}. We have to build a plan for the carriage of the cargo on the transport network in such way that the stocks of cargo have been taken out of the departure's points, the needs of consumers in the destinations have to be met, and the total cost of transportation has to be minimal. If the cost of c_{ij} is the distance of transportation, so it is necessary to make such a transportation plan so that the total mileage was minimal. Let's us denote the amount of cargo transported along the network between points *i* and *j* as , then the transport problem on the network can be mathematically consider

$$C = \sum_{1}^{e} c_{ij} x_{ij} \to \min \quad (12)$$

The total cost of the transportation must be minimal. The conditions of the restriction have to be as follows:

- the quantity of products exported from point of departure i (i ϵ A) to points k must be equal to the total stock ai at this point and the volume of cargo entered at that point from neighboring points l Figure 2, a:

$$\sum_{1} x_{ik} = a_i + \sum_{l} x_{li}, \ i \in A; \quad (13)$$

- the quantity of cargo imported into the point of consumption j (j ϵ B) from the neighboring l points must be equal to the total volume of consumption at this point and the volume of cargo exported from this point to the neighboring k points Figure 2, b:

$$\sum_{1} x_{ij} = b_j + \sum_{k} x_{jk}, \ \ i \in B; \quad (14)$$

- the quantity of cargo imported into the transit point r(rϵT) from the neighboring l points must be equal to the volume of cargo exported from this point to the neighboring k points Figure 2:

$$A = \{a_1, a_2, ... a_m\} = \{a_i\}_{i=1}^{m} \quad \sum_{1} x_{ir} = \sum_{k} x_{rk}, \ \ r \in T\,; \quad (15)$$

- the amount of freight traffic on the edges (sections) of the network should not exceed their bandwidth:

$$ij \le d_{ij}\,; \quad (16)$$

- total production (stocks) of products should be equal to total consumption (needs), thats why the transportation problem should be balanced (closed):

$$\sum_{i \in A} a_i = \sum_{j \in B} b_j\,; \quad (17)$$

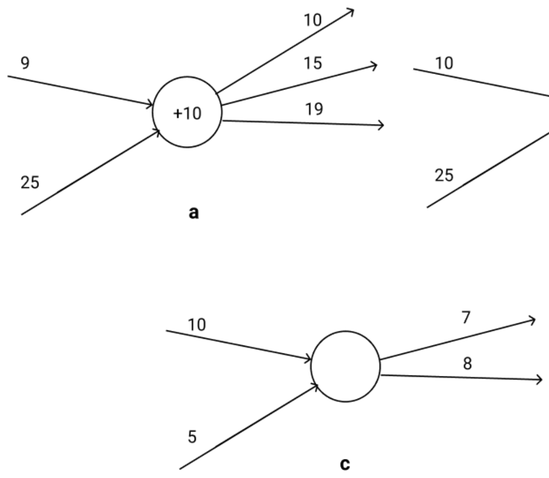

Fig. 2. Preparation of planning to achieve transportation for the tops of the transport network: (a)- for the return point; (b)- for the destination; (c)- for a transit point.

2. Modeling Results and Discussion.

The proposed methods we used for solving practical problems. The essence of the problem is in optimizing of process the transportation from producers to the consumer. For a detailed study of the intermediate stages taken into account during transportation.
Let's describe the problem of transportation in such form: the company has four factouries, which relate to manufacturers of products. Vector of stock products has such form: a = {100; 120; 150; 130}. Products provide to the use of customers. Vector of needs these products is make in such form : b = {140; 130; 90; 140}. Transporting products takes place from the supplier i to customers j. The cost of delivery of one unit of cargo from each point of departure to each appointment point is describe with matrix of tariffs. The matrix of tariffs has such form:

$$C = \begin{pmatrix} 4 & 5 & 5 & 7 \\ 8 & 7 & 5 & 4 \\ 9 & 6 & 4 & 5 \\ 3 & 2 & 9 & 3 \end{pmatrix}. \quad (18)$$

It is necessary to make the optimum plan of transportation. Cargo stocks are 100 + 120 + 150 + 130 = 500, consumer needs are 140 + 130 + 90 + 140 = 500, so we have a balanced transport problem.

2.1. The initial support plan

We construct the initial reference plan by the method of the north-western corner [2]. In the tabular view, it has the following view Figure 3:

2.2 Formation of the transport network

The transport network of the initial support plan has the form (Figure 4):

The support plan is not degenerate: the number of non-zero table cells are:

$$m + n - 1 = 4 + 4 - 1 = 7. \quad (19)$$

Plants	Customers				Stock of products
	B_1	B_2	B_3	B_4	
A_1	4; **100**	5; **0**	5; **0**	7; **0**	100
A_2	8; **40**	7; **80**	5; **0**	4; **0**	120
A_3	9; **0**	6; **50**	4; **90**	5; **10**	150
A_4	3; **0**	2; **0**	9; **0**	3; **130**	130
Needs	140	130	90	140	

Fig. 3. The initial support plan

The value of the objective function for the initial reference plan is equal to:

$$F(x) = 4 \cdot 100 + 8 \cdot 40 + 7 \cdot 80 + 6 \cdot 50 + \\ + 4 \cdot 90 + 5 \cdot 10 + 3 \cdot 130 = 2380 \quad (20)$$

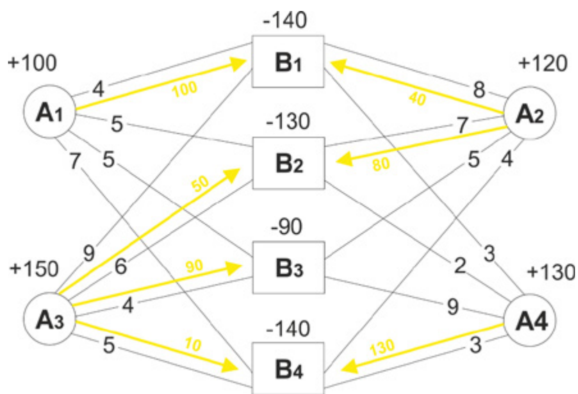

Fig. 4. The transport network of the initial support plan of transportation

Let's check the optimality of the reference plan using the method of potentials. We write the first condition of potentiality for non-zero cells $u_i + v_j = c_{ij}$, we find the value of potentials, assuming that $u_1 = 0$.

$$\begin{cases} u_1+v_1=4 \\ u_2+v_1=8 \\ u_2+v_2=7 \\ u_3+v_2=6 \\ u_3+v_3=4 \\ u_3+v_4=5 \\ u_4+v_4=3 \end{cases} \overset{u_1=0}{\Rightarrow} \begin{cases} v_1=4 \\ u_2=4 \\ v_2=3 \\ u_3=3 \\ v_3=1 \\ v_4=2 \\ u_4=1 \end{cases} \quad (21)$$

The support plan is not optimal because the second condition of potentiality is not execute for all zero cells $u_i+v_j \le c_{ij}$.

$$\begin{aligned} &(2;4): 4+2>4; \quad \Delta_{24}=4+2-4=2>0 \\ &(4;1): 1+4>3; \quad \Delta_{41}=1+4-3=2>0 \\ &(4;2): 1+3>2; \quad \Delta_{42}=1+3-2=2>0 \end{aligned} \quad (22)$$

The plan is improved until the potential conditions for all cells are met, and as a result, we get the following optimal plan (Fig.5):

Plants	Customers				Stock of products
	B_1	B_2	B_3	B_4	
A_1	4 **100**	5 **0**	5 **0**	7 **0**	100
A_2	8 **0**	7 **0**	5 **0**	4 **120**	120
A_3	9 **0**	6 **40**	4 **90**	5 **20**	150
A_4	3 **40**	2 **90**	9 **0**	3 **0**	130
Needs	140	130	90	140	

Fig. 5. The optimal support plan

The minimum costs will be:

$$\begin{aligned} F(x) &= 4\cdot100+4\cdot120+6\cdot40+ \\ &+4\cdot90+5\cdot20+3\cdot40+2\cdot90=1880 \end{aligned} \quad (23)$$

From optimal plan we have:

- from the first warehouse it is necessary to send all production to the first consumer;
-from the second warehouse it is necessary to send all production to the fourth consumer;
- from the third warehouse it is necessary to send production to the second consumer (40 units), to the third consumer (90 units) and to the fourth consumer (20 units);
- from the fourth warehouse it is necessary to send production to the first consumer (40 units), and to the second consumer (90 units).

The optimal support plan in network form is shown on Figure 6.

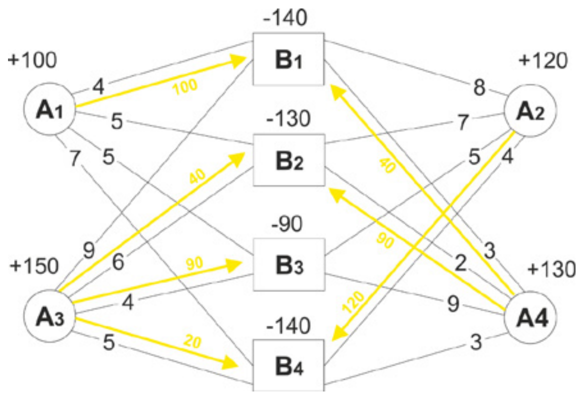

Fig. 6. The transport network of the optimal support plan of transportation.

The classic transport problem is one-stage in the sense that in it the products from suppliers come directly to consumers. However, in practice it is quite common for products from suppliers to first arrive at intermediate points (transport network nodes, distribution centers, warehouses), where, if necessary, they are reloaded or unloaded and stored for some time. That is, the final consumers do not receive products from suppliers, but from these intermediate points of transport networks.

If the transportation of products is not performed directly from the supplier to the consumer, but through some intermediate points, then a multi-stage transport task is used. We built several stages of such a problem in the following example (Figure 7).

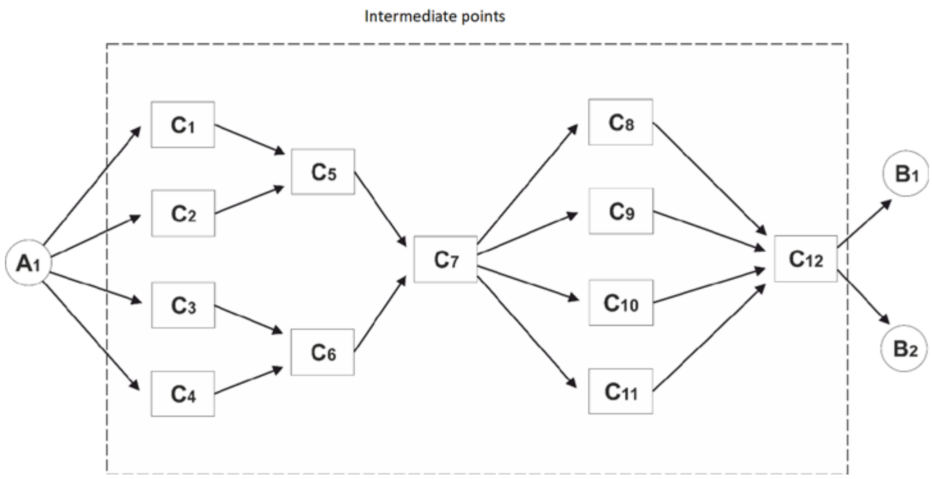

Fig. 7. The transport network of the several stages transport task

We consider FlexSim software tools as an effective software to analyze transport tasks. As FlexSim is useful tool for solving transport tasks and effective for different technical tasks [11-13] , economical tasks[21], industry tasks[9]. Principle of simulation modeling, gave as a chance to analyze every part of process. We used the transport network (Figure 7) for creating the simulation process in FlexSim (Figure 8). We can see all stages are connected between each other. We used basic elements: sources (Source), processes (Process) and queues (Queue). In our case, sources are the elements from which information or objects enter the product model it is point A_1 from Figure 7. Queues 1, 2, 3, 4, Conveyors, Separator, Racks 1, 2, 3, 4, 5, 6 Combiner in FlexSIM are intermediate stages of model (Figure 7). Sink 1 and Sink 2 we take as points B_1 and B_2 of our transport network. The algorithm of creating imitation model in FlexSim software is the next:

Step 1. Input, the first element is Source, where we specify the following logic:

Source1 – Source – FlowItemClass -Box.

Source1 – Flow – Send To Port – First Available.

Step 2. The next stage is the generation of products of different types (four types):

Triggers – On Creation – Set Item Type and Color- Item Type – duninform (1,4, get stream(current)).

Step 3. We have to divide each type of product into a different port.

We have four ports to each conveyor.

Separator – Flow – Send to Port – Port by Case.

Step 4. Create conveyors for distributing products to next stage.

Step 5. Create Racks and put the following logic for each rack:

Maximum content, Number of Bays, Number of Levels

Step 6. Create separator and combiner like intermediate points.

Step 7. Create Sink1 and Sink2 like points B_1 and B_2 (like destination points)

Step 8. Put connections between elements of the simulation model.

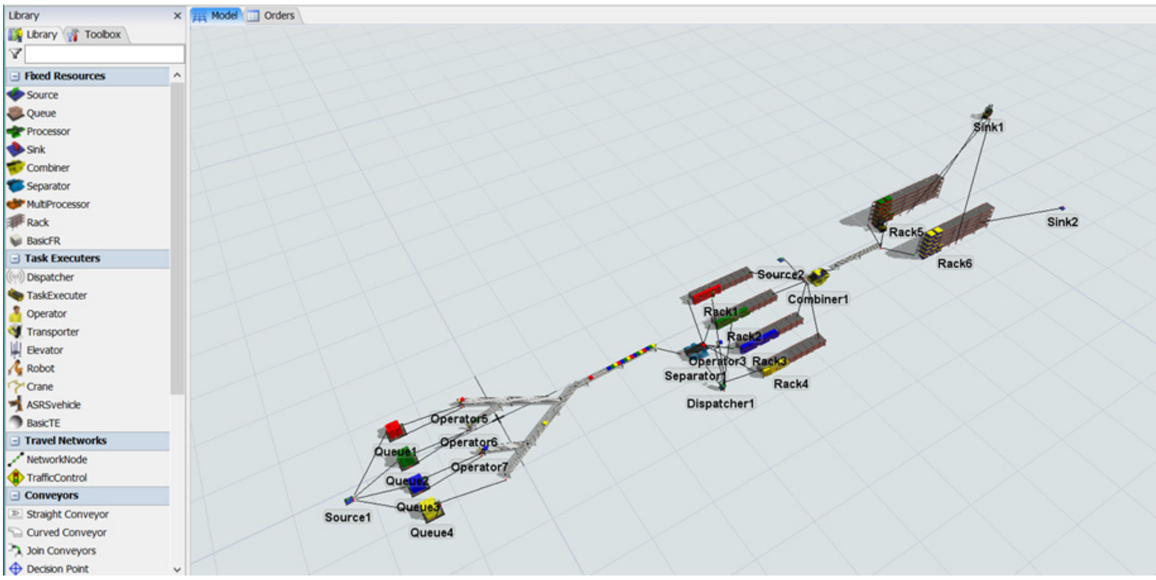

Fig. 8. The transport network of the several stages transport task

The developed simulation model in the FlexSim environment allowed seeing the process of transportation. The study allowed us to set the parameters of transportation, for example, the moving products through intermediate stages to destination points (B_1 and B_2) FlexSim tools allowed to visualize the transport network of the optimal support plan (Figure 6).

The analysis of the study conducted a mathematical analysis of the transport problem is the basic step of creation the simulation model of this process in FlexSim simulation software. The result is the optimal path of movement of products from the producer through intermediate points to the consumer. The model of process in the FlexSim environment is created allows to analyze each stage of delivery. For example, the number of each type of product delivered to the consumer, stops of products in warehouses (Rack 1, 2, 3, 4), the number of surplus products for each warehouses.

3. Conclusions

Based on the mathematic programing, an algorithm of universal transport problem has been presented. It helps to solve the transport problem for the supply of products to the customer from the supplier and present each step of solving algorithm. In this article we compere the classic transport problem is one-stage and real task that we meat in practice when it is quite common for products from suppliers to first arrive at intermediate points (it can be transport network nodes, distribution centers, warehouses). They are reloaded or unloaded and stored for some time. So as a result, the final consumers do not receive products from suppliers, but from these intermediate points of transport networks. We solve such the problem: the company has four factouries, which relate to manufacturers of products. The vector of stock products we built in such form: a = {100; 120; 150; 130}. Products provide to the use of customers. Vector of needs these products is make in such form : b = {140; 130; 90; 140}. We create the optimum plan of transportation. We construct the initial reference plan by the method of the north-western corner. The transport network of the initial support plan of transportation was built. From optimal plan, we have results what is optimal way of moving cargo: from the first warehouse, it is necessary to send all production to the first consumer; the next point will be from the second warehouse it is necessary to send all production to the fourth consumer. Then it will move from the third warehouse it is necessary to send production to the second consumer (40 units), to the third consumer (90 units) and to the fourth consumer (20 units) and the fourth warehouse it is necessary to send production to the first consumer (40 units), and to the second consumer (90 units). The FlexSim software toolswas used for creation the imitation model for transport task we solved. There will be further studies in which we will analyze the statistic of each stage for this transport task with using FlexSim environmental.

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