

OPTIMUM PLANNING OF CONNECTIONS BETWEEN SUPPLIERS AND RECEIVERS UNDER CIRCUMSTANCES OF DEMAND-SUPPLY IMBALANCE AND EXISTING RESTRAINTS

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Abstract

Designing the connections between suppliers and receivers of a product is an important issue during the process of physical goods distribution. Selected solutions directly affect the level of costs expended for a transport process and indirectly the price of distributed goods, which determines the competitiveness of a given product. This study presents procedures making possible to plan the transport of goods under circumstances of imbalanced supply and demand taking into considerations existing restraints such as need to bring a part or a whole lot from a supplier (or suppliers), as well as necessity to deliver required quantity of ordered product to the receiver. The efficiency of the method was analyzed using the example of shifting products among three manufacturing enterprises and five wholesalers having the demands that suppliers cannot match. Additional factors considered in analyzed example were the requirements imposed by receivers, among which one needed to have 60% of declared order, while two others the complete declared order. Operations aiming at creating a preliminary flow matrix were made with a help of Minimum Matrix Element Method. The optimum solution was achieved applying Matrix Graph Method. The result is an optimum plan of connections among manufacturing enterprises and wholesalers. Meeting the requirements imposed by receivers indicates the effectiveness of discussed procedure.

Keywords: transport, optimization, flow restraints

1. Introduction

The free trade area including member countries of European Union and long distances between manufacturers and receivers of products are the cause for remarkable share of transportation works within process of goods distribution. Considerable capital-consumption of these works has negative effects on prices of transported products.

There are elements of production costs that can be influenced only to a small extent or cannot be subject of any impact at all; these are prices for raw material processed or energy utilized. Therefore, those types of economic activity that is associated with production and distribution, to which applying particular procedures can bring some savings, should be analyzed in details. Costs can be reduced by means of modernization of transportation means, which leads to lower costs for fuels, enhancing their loads [5], searching for alternative energy sources, or controlling the influence of transportation means exploitation degree on fuel utilization [6]. Among activities aiming at reducing costs for transport, the organization issues leading to the optimum planning of works are extremely important. Studies upon optimization of the raw material transport to processing facilities have been conducted for many years at The Department of Agricultural Machines and Devices, University of Life Sciences in Lublin [2, 3]. That type of operations includes activities, the subject of which is problem of connections between suppliers and receivers, which is called “*the transport issue*” in literature. Many various methods for finding a proper solution have been developed since the first formulation of the problem. A type of balance

between total supply of suppliers and summarized demand of receivers is a *sine qua non* condition for their appropriate application. Such situation is taken into consideration by so-called *classical formulation of a transport issue*. In practice, situations when suppliers are characterized by supply exceeding the receivers' demands, or receivers express their needs that cannot be met by suppliers, are more often found. Those situations are named *imbalanced issues* and are divided into cases without and with some restraints.

To work out an optimum solution for imbalanced issues containing restraints requires making particular operations, presenting of which is the aim of this study.

2. Methods

Condition to apply optimization methods in discussed issue (which is the need to exist the balance between demands and supplies) does not exclude them in situations, when such balance is absent. Before any activity contained in selected method, it is required to make some modifications aiming at balancing between demand and supply. Character of the operation depends on discussed case.

The case, in which suppliers offer more goods than receivers will or are able to take, or there is a need to withdraw the part or whole lot by one or many suppliers for some reasons such as limited storing space, can be described by following formulas:

$$Z_x = \sum_{i=1}^m \sum_{j=1}^n c_{ij} x_{ij}, \quad (1)$$

$$\sum_{i=1}^m x_{ij} = b_j, \quad \text{for } j = 1, 2, \dots, n, \quad (2)$$

$$\sum_{i=1}^m a_i > \sum_{j=1}^n b_j, \quad (3)$$

$$\sum_{j=1}^n x_{i_k j} = a_{i_k}, \quad i \in I_1 \text{ for } k = 1, \dots, s, \quad (4)$$

$$\sum_{j=1}^n x_{i_l j} \leq a_{i_l}, \quad i \in I_2 \text{ for } l = 1, \dots, r, \quad (5)$$

$$\sum_{i \in I_1} a_{i_k} \geq \sum_{j=1}^n b_j, \quad (6)$$

where:

m - number of suppliers,

n - number of receivers,

a_i - amount of the supply of i-th supplier,

b_j - amount of the demand of j-th receiver,

c_{ij} - cost for transport between i-th supplier and j-th receiver,

x_{ij} - quantity of load between i-th supplier and j-th receiver,

Z_x - purpose function, value of which includes cost for all planned transport operations,

I_1 - set of s suppliers marked as D_{i_k} for $k = 1, \dots, s$, from whose it is necessary to withdraw whole of offered lot,

I_2 - set of $r = m - s$ suppliers marked as D_{i_l} for $l = 1, \dots, r$, which are all suppliers not included in set I_1 .

Firstly, a procedure aiming at transforming the issues of that type to a form of a closed transport issue, needs to add an imaginary receiver, for which a demand (b_f) is attributed, and the value of which is defined applying the formula below:

$$b_f = \sum_{i=1}^m a_i - \sum_{j=1}^n b_j \quad (7)$$

Another operation consists in incorporating the existing restraints into the issue. In situation when there is a need to withdraw the whole offered lot from a supplier, some properly large number P should be introduced into the element of C, M system (matrix of transport costs C, as well as supplies and demands vector M), which can be found at the intersection corresponding to that supplier and column assigned to the imaginary receiver. The operation aims at making that element unattractive from a point of view of the optimization method, and it will result in excluding the possibility for that element to occur in final solution, hence assigning the whole supplier's lot to waiting receivers. During the calculations or encoding the software source for execution, it can be accepted that number P equals to triple value of the largest transport cost found within system C, M.

The procedure in situation when for some reason there is a need to withdraw only a part of offered lot from supplier (or suppliers), consists in attaching a new row to system C, M that is a twin referring to transport costs contained to the row corresponding to a supplier in question. The supply contained in newly added row has assigned some value equal to the goods quantity that is necessary to withdraw, which implies a need to decrease the supply by the same value within the row that was the original for the new one [1].

The case when receivers' demand exceeds suppliers' supply and supplying the whole or part of a lot to one or many receivers is necessary, is characterized by following formulas:

$$\sum_{i=1}^m a_i < \sum_{j=1}^n b_j \quad (8)$$

$$\sum_{j=1}^n x_{ij} = a_i, \text{ for } i = 1, 2, \dots, m, \quad (9)$$

$$\sum_{i=1}^m x_{ij_k} = b_{j_k}, \text{ } j \in J_1 \text{ for } k = 1, \dots, p, \quad (10)$$

$$\sum_{i=1}^m x_{ij_l} \leq b_{j_l}, \text{ } j \in J_2 \text{ for } l = 1, \dots, q, \quad (11)$$

$$\sum_{j \in J_1} b_{j_k} \geq \sum_{i=1}^m a_i, \quad (12)$$

where:

J_1 - is a set of p receivers marked as O_{j_k} for $k = 1, \dots, p$, to which supplying the whole lot is necessary,

J_2 - is a set of receivers $q = m - p$ marked as O_{j_l} for $l = 1, \dots, r$, which are all receivers not included in set J_1 .

The purpose function illustrating the total cost for all transport operations was described using formula (1).

Like for previous case, planning the connections between suppliers and receivers should be started from balancing the total demand with total supply values, which can be made by introducing the imaginary supplier D_f with a supply amounted to a_f to the system C, M.

$$a_f = \sum_{j=1}^n b_j - \sum_{i=1}^m a_i \quad (13)$$

Procedure aiming at taking into consideration existing restraints in a final transportation plan assumes various forms depending on whether there is a need to deliver the whole or only a part of a lot to the receiver.

Assuring the whole required lot of products to the receiver can be realized by means of introducing the number P, value of which is defined the same way as in situation of the surplus of supplies over demands, that should be placed into the cost matrix C at the intersection of a column representing a given receiver and row assigned to imaginary supplier.

The case, in which a receiver wants to get some established quantity of goods, that due to the surplus of demands over supply, is impossible to realize, and some factors make that it is necessary to arrange a situation when a receiver achieves particular part of a lot, requires incorporating additional column within C, M system. Elements of the column that correspond to the transport costs should be equal to those present in the column of discussed receiver. The demand level that should be assigned to the new column has to be equal to the quantity of product that has to be delivered to the receiver. Assigning the demand to a new column requires correcting its value in column corresponding to a given supplier, thus value that had been assigned to the new column should be subtracted from that value. The final operation to make is placing the number P at the intersection of newly added column with the row assigned to the imaginary supplier [1, 4].

3. Example

The method was analyzed using the example of shifting goods among manufacturing enterprises localized in Lublin, Lubartów, and Chełm, and wholesalers in Łęczna, Krasnystaw, Bychawa, Parczew, and Włodawa.

Values of costs for realizing the transport of a single ton of a product between particular suppliers and receivers were calculated with a help of the formula below:

$$c_{ij} = \frac{2 \cdot k \cdot l}{\bar{l}}, \quad (14)$$

where:

$i = 1, 2, \dots, m,$

$j = 1, 2, \dots, n,$

k - rate for one kilometre [PLN/km],

l - route length [km],

\bar{l} - capacity of transportation means [t].

Transport costs, values of supplies of particular enterprises, as well as demand levels of the wholesalers were placed within C, M system presented in Tab. 1. Total suppliers' supply is 750 tons, while sum of receiver's demand 800 tons, thus discussed example comprises the case, in which receivers have the need that cannot be matched by suppliers. Additional factors that affect the final solution consist in particular requirements of three receivers: the receiver, the wholesale store is localized in Łęczna, due to orders of shop owners put, wants to get at least 60% of goods it needed; receivers from Bychawa and Parczew, due to risky profitability of their economic activity, request the whole lot they demanded.

Tab. 1. The C, M system

	Łęczna	Krasnystaw	Bychawa	Parczew	Włodawa	a_i
Lublin	13.55	29.28	17.07	32.96	52.27	400
Lubartów	14.93	42.08	30.45	19.2	43.73	200
Chełm	29.87	17.6	39.68	44.91	26.77	150
b_j	200	120	130	210	140	

Insufficient quantity of products offered by suppliers requires adding an imaginary supplier into the C, M system, the supply of which is calculated on a base of formula (13). Such operation results are presented in Tab. 2.

Tab. 2. The C, M system enhanced with the raw corresponding to imaginary supplier

	Łęczna	Krasnystaw	Bychawa	Parczew	Włodawa	a_i
Lublin	13.55	29.28	17.07	32.96	52.27	400
Lubartów	14.93	42.08	30.45	19.2	43.73	200
Chełm	29.87	17.6	39.68	44.91	26.77	150
D_f						50
b_j	200	120	130	210	140	

To assure meeting additional requirements put by receivers is realized by means of introducing new column and placing number P in appropriate location (according to previous procedure). Newly construed C, M system is presented in Tab. 3.

Tab. 3. The C, M system taking into consideration existing restraints

	Łęczna	Łęczna	Krasnystaw	Bychawa	Parczew	Włodawa	a_i
Lublin	13.55	13.55	29.28	17.07	32.96	52.27	400
Lubartów	14.93	14.93	42.08	30.45	19.2	43.73	200
Chełm	29.87	29.87	17.6	39.68	44.91	26.77	150
D_f	0	P	0	P	P	0	50
b_j	80	120	120	130	210	140	

According to the procedure, number P is assigned with value equal to 156.81 PLN/t.

Tab. 4. The C, M, system being a starting point to apply the optimization methods

	Łęczna	Łęczna	Krasnystaw	Bychawa	Parczew	Włodawa	a_i
Lublin	13.55	13.55	29.28	17.07	32.96	52.27	400
Lubartów	14.93	14.93	42.08	30.45	19.2	43.73	200
Chełm	29.87	29.87	17.6	39.68	44.91	26.77	150
D_f	0	156.81	0	156.81	156.81	0	50
b_j	80	120	120	130	210	140	

Achieving the preliminary flow matrix X was realized using The Method of Least Matrix Element described in [2]. Subsequent changes within system C, X from making a graph to the first iteration, are presented in Tab. 5-8.

Tab. 5. System consisting of cost matrix C and preliminary flow matrix X

	Łęczna	Łęczna	Krasnystaw	Bychawa	Parczew	Włodawa
Lublin	13.55^{30}	13.55^{120}	29.28	17.07^{130}	32.96^{10}	52.27^{110}
Lubartów	14.93	14.93	42.08	30.45	19.2^{200}	43.73
Chełm	29.87	29.87	17.6^{120}	39.68	44.91	26.77^{30}
D_f	0^{50}	156.81	0	156.81	156.81	0

Tab. 6. The C, X system containing graph

	Łęczna	Łęczna	Krasnystaw	Bychawa	Parczew	Włodawa
Lublin	13,55 ³⁰	13,55 ¹²⁰	29,28	17,07 ¹³⁰	32,96 ¹⁰	52,27 ¹¹⁰
Lubartów	14,93	14,93	42,08	30,45	19,2 ²⁰⁰	43,73
Chełm	29,87	29,87	17,6 ¹²⁰	39,68	44,91	26,77 ³⁰
D _f	0 ³⁰	156,81	0	156,81	156,81	0

The purpose function calculated for the preliminary solution according to formula (1) resulted in a value of 17 086 PLN.

Tab. 7. The C, X system after zeroing values of highlighted elements

	Łęczna	Łęczna	Krasnystaw	Bychawa	Parczew	Włodawa
Lublin	0 ³⁰	0 ¹²⁰	0,27	0 ¹³⁰	0 ¹⁰	0 ¹¹⁰
Lubartów	15,14	15,14	12,74	27,14	0 ²⁰⁰	5,22
Chełm	41,82	41,82	0 ¹²⁰	48,11	37,45	0 ³⁰
D _f	0 ³⁰	156,81	-29,55	153,29	137,4	-38,72 ⁰

Tab. 8. The C, X system after the first iteration

	Łęczna	Łęczna	Krasnystaw	Bychawa	Parczew	Włodawa
Lublin	0 ⁸⁰	0 ¹²⁰	0,27	0 ¹³⁰	0 ¹⁰	0 ¹¹⁰
Lubartów	15,14	15,14	12,74	27,14	0 ²⁰⁰	5,22
Chełm	41,82	41,82	0 ¹²⁰	48,11	37,45	0 ³⁰
D _f	0	156,81	-29,55	153,29	137,4	-38,72 ⁵⁰

Further procedure was omitted due to the fact that its course is the same. The final solution was achieved by means of Matrix Graph Method [4] that is a useful method for the second stage of the optimization activity.

Tab. 9. The C, X, system as a final plan of transport

	Łęczna	Łęczna	Krasnystaw	Bychawa	Parczew	Włodawa
Lublin	13,55 ⁸⁰	13,55 ¹²⁰	29,28 ⁶⁰	17,07 ¹³⁰	32,96 ¹⁰	52,27
Lubartów	14,93	14,93	42,08	30,45	19,2 ²⁰⁰	43,73
Chełm	29,87	29,87	17,6 ⁶⁰	39,68	44,91	26,77 ⁹⁰
D _f	0	156,81	0	156,81	156,81	0 ⁵⁰

Value of the purpose function calculated for solutions accepted in the final transport plan amounts to 14 320.8 PLN.

4. Conclusions

Performed operations allowed for achieving a final flow matrix being a plan of connections between suppliers with receivers. Quantities of assignments made on the routes between imaginary supplier and particular wholesalers reflect the amounts of goods that cannot be delivered. In discussed example, the receiver that will not get the whole needed lot is the wholesaler from Włodawa. Quantity of goods that will not be delivered is 50 tons.

The whole offered lot was withdrawn from every supplier. All receivers, except from the wholesaler from Włodawa, got the amount of products they required. Value of the purpose function resulting from the second stage of the optimization procedure decreased by 16% of the initial value. Meeting the demands and decreasing the purpose function value indicates the effectiveness of discussed optimization methods. This type of activity allows for achieving significant savings during products transport process, which makes an opportunity to regulate prices aiming at enhancing the competitiveness of produced goods.

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