Analyzing and Mathematical Formulation of Two of Supply Chain Integration Models

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Abstract:
Nowadays simulation models use in supply chain as the main methodology. But there is limit or no effort on model that link warehousing and transportation processes together. In this paper we will consider two of linear programming models: transportation warehouse (TW) *model and manufacturing transportation warehouse* (MTW) *model that will help to solve this problem and improve supply chain management. We will analyze mathematical formulation of these models and determine the scheme of creation of* MTW *model. Genetic algorithm for the last model will be described. Computational example will show how to increase income and decrease total cost of logistics process.*

Key words: *integration models, genetic algorithm, manufacturing, supply chain, transportation, warehouse.*

1. Introduction:

Supply chain management is increasingly being recognized as the integration of key business processes across the supply chain. A lot of practical problems in supply chain can be solved by linear programming. According to the scientists, linear programming is a procedure for finding the maximum or minimum value of a function in two variables, subject to given conditions on the variables called constraints. Models of linear programming simulation have a significant role in management of supply chain.

Transportation warehouse (TW) and *manufacturing transportation warehouse* (MTW) models are created by construction of a set of sub-models. That is why these models are classified as integration models of supply chain. In the process of creation and optimization of this kind of models some problems arise, such as mathematical formulation, choosing the proper criteria of optimization and methods for solving the problem. According to the special literature, the integration models of supply chain use separate mathematical tasks. In the present paper the general transportation-warehouse and manufacturing-transportation-warehouse problems are analyzed.

Most researches still focus on one part of the warehouse or transportation service providers. There is limit or no effort on model that link warehousing and transportation processes together. Thus, such system is needed. There are still not enough attention to the cooperation of warehouse and transportation. Some theoretical and methodological problems with modeling process and integration planning of supply chain need furthermore research. In order to better supply chain management, we propose to develop an integrated new models that considers the corporation.

Purpose of this paper is: to improve the methodological principles of modeling and integration planning of supply chain; determine the updating MT and MTW models, which connect three of the most important bases in supply chain and logistics in general: manufacturing, transportation and warehousing; create the algorithm for MTW model and show a computational example that helps to increase total income and decrease cost during the whole logistics process.

As the result it was achieved the next innovations: formulated the supply chain integration MT and MTW models which link manufacturing, transportation and warehouse problem together; improved setting of the mathematical problem of MT and MTW types; described the genetic algorithm for MTW model. All these achievements will help to overpass computational problems that appeared during these problems solving.

Usefulness of the results in this study is that proposed models and algorithm help to develop and make the grounded and rational solutions in supply chain. The usage of these models and algorithms in the strategic and operational logistics planning will reduce logistics costs and improve the efficiency of business processes.

The subsequent sections of the paper are organized in the following way. In Section 2 the literature review will be done. In Section 3 will be considering TW and MTW problems, will give the description of mathematical formulation and possible constraints of these models; determined the scheme of creation MTW model. Than, will be shown the mathematical programming model and it constraints that probably can be appear. Genetic algorithm of solving MTW problem will be described in Section 4. And Section 5 will be containing the computational example and conclusion of this paper.

2. Literature review:

According to the January-February 2009 Statement of the Editor-in-Chief of Operations Research Journal, a high percentage of submissions to the journal use either simulation or stochastic models as their main methodology. This indicates an increased interest in solving more relevant problems and modeling the behavior of various systems more precisely. Theoretical and methodological tasks connected with this problem have been studied by several authors in the past, either as a separate problem or as a sub problem of more complex models.

Simulation models use mathematical or logical constructs and calculate the final solution. Simulation in itself does not optimize the solution for the problem, it is simply runs the model according to the specifications (Robinson). In a recent paper, Chen and Sarker have studied integrated model of procurement-production system under shared transportation for multi-vendor and single manufacturer. Van den Berg suggests to use a heuristic ranking algorithm to determine a near optimal class allocation. He shows that the algorithm works well and may be applied to a wide variety of warehousing systems with different demand curves, travel time measurements, warehouse layouts. One of the first efforts to integrate procurement, production and distribution decisions belongs to Cohen and Lee who developed a detailed model for logistics network design in a global (i.e., international) context. The model considers a single planning period with deterministic demand and is solved by a hierarchical approach in which integer variables associated with the design of the network are first assigned values so as to obtain a simple linear program. An interesting example is the work of Pirkul and Jayaraman on integrated production, transportation and distribution planning.

However, as can be seen from the recent reviews by Geoffrion and Powers, Thomas and Griffin and Vidal and Goetschalckx, most location models do not incorporate at least some aspects of the problem such as supplier or transportation mode selection. Kamath proposed a stochastic dynamic inventory model programming model and solution algorithm under uncertain environment. Harkness dealt with a new type of facility location model, which unit production costs were increasing when the scale of output exceeded its capacity. Nozick and Turnquist tried to integrate inventory, transportation and location functions of a supply chain. The proposed model has been confined to a single period, single echelon problem with no capacity constraint. Xie Zhongqing has examined the total cost benefits that can be achieved by suppliers and warehouses through the increased global visibility provided by an integrated system. A discrete event simulation model of a multi-product supply chain was developed by him to examine the potential benefits to be gained from global inventory visibility and trailer yard dispatching and sequencing techniques. Park proposes a bi-criteria-saving heuristic algorithm and an interactive scheduling computer system to deal with the bi-criteria vehicle scheduling problem (VSP) with time and area-dependent travel speeds. Schrage and Winston contain broad treatments of mathematical programming.

Tan describe a hybrid genetic algorithm (HGA) that complements the simple genetic algorithm with two search heuristics for solving the VRPTW. The algorithm was tested via simulation with a result that outperformed many existed heuristics. Neves; Ma and Davidrajuh proposed distribution channels planning model. Authors explored the use of an iterative approach for designing distribution chain in an agile virtual environment; and proved that quick adaptation to changing market situation and automation of supply chain management processes are essential.

Researches on problems such as the shortest paths problem, pick-up & delivery problem, location-routing problem, segmentation of delivery region and others can be found in Modesti and Sciomachen, A.A.Bochkarev, Desaulniers and Villeneuve, Dias and Climaco Mosheiov, G. Desaulniers, Swihart and Papastavrou, Fagerholt and Christiansen, Renaud, Nanry and Barnes, Irnich, Jayaraman and Srivastava, Tuzun and Burke; Novaes and Graciolli; Toth and Vigo.

3. Problem definition:

TW is a process of distribution centers allocation which is presented as simulative programming model.

Let's consider mathematical formulation of the problem.

Let y_j be a variable solution, then $y_j = 1$ in case if the warehouse is rented and $y_j = 0$ - if it is not, $\forall j \in \{1,\ldots,n\}$.

Let's introduce the following coefficients of linear programming variable model:

R_j – rental price of warehouse j (monthly) ;

$x_{i,j}$ – quantity of cabs sent from warehouse j to region *i*;

$c_{i,j}$ – average transportation fee of sending one cab from warehouse *j* to region *i*;

S_j – capacity of warehouse *j*;

D_i – demand of region *i*.

Mathematical formulation of this problem can be shown as:

$$\sum_{i=1}^{m}\sum_{j=1}^{n} c_{i,j} x_{i,j} + \sum_{j=1}^{n} R_j y_j \to \min; \qquad (1)$$

To find the minimum of criterion function we can consider the next constraints:

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$$\begin{cases} \sum_{i=1}^{n} x_{i,j} \le \sum_{i=1}^{n} S_j y_j, \ j = 1,\ldots,n; \\ \sum_{j=1}^{n} x_{i,j} = D_i, \ i = 1,\ldots,m; \\ x_{i,j} \ge 0; \\ x_{i,j} \in N \cup \{0\}, \ i = 1,\ldots,m, \ j = 1,\ldots,n; \\ y_j \in \{0,1\}, \ j = 1,\ldots,n. \end{cases} \tag{2}$$

The first line in the constraint system (2) is the constraint of carrying capacity of the warehouse. If $y_j = 0$, it means that any cabs can't be sent from warehouse *j*. The second line in (2) guarantees meeting demand in region *i*.
Third and fourth constraints are traditional classic transportation problem constraints of nonnegative of $x_{i,j}$ variables. The last constraint point is that variable y_j has to be binary. So it is obvious that the presented model is related with supply chain of integration model and contains two sub-models: model of transportation and warehouse model.

MTW problem is the problem of supply chain network structure of optimization presented as simulation programming model. Delivery network in big companies is a complex of systems described as a huge amount of elements and types of communication between them. For distribution channels analysis of such systems needs some extra information about process, resources, capacity and expenses. This information can be getting from optimization modeling of delivery network. The scheme of creation MTW model is described at the Fig.1.

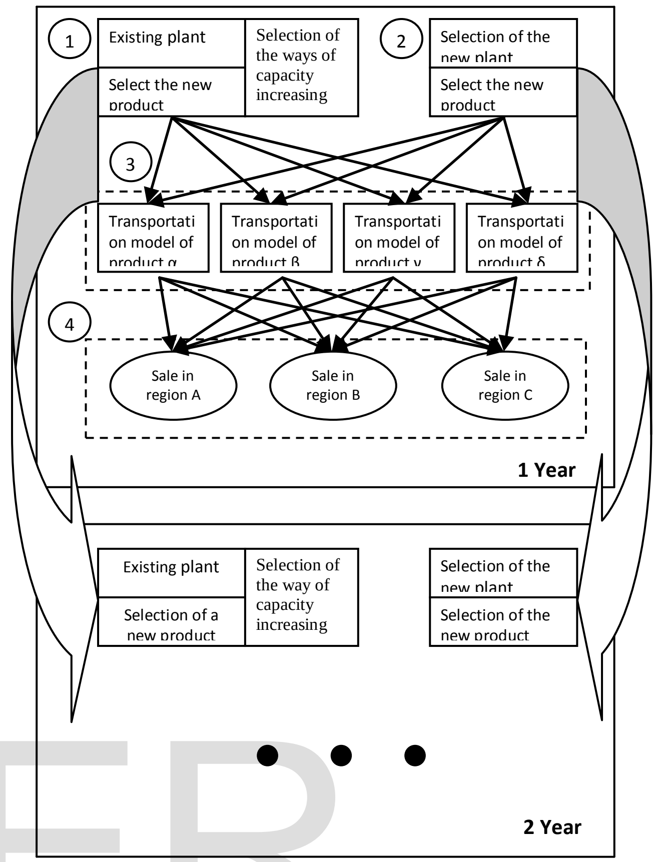

Fig. 1. The scheme of creation of MTW model

This picture presents the next sub-models:

- production of the existing factory model;
- production of a new factory model;
- transportation model;
- sale model.

Let's introduce the following coefficients and symbols of mathematical programming model:

$i \in I$ –indexing set of sales market;

$j \in J$ –indexing set of products variety;

$k \in K$ –indexing set of plants;

$l \in L$ –indexing set of using manufacturing recourses;

$t \in T$ –indexing set of planning periods;

$c_{j,k}$ – expenses of a unit of product *j* at the plant *k;*

$x_{j,k}$ – manufacturing volume of product *j* at the plant *k* during the year;

$c^*_{i,j,k}$ – transportation cost of delivery of the product *j* from the plant *k* to the market *i*;

$x^*_{i,j,k}$ – delivery value of product *j* from the plant *k* to the market *i* during the year;

p_j – the price of a unit of product j ;

$b_{k,l}$ – quantity of resources l at the plant k;

$\Delta b_{k,l}$ – additional quantity of resources l at the plant k during factory extension;

$d_j = \sum_{i=1}^{m} d_{i,j}$ – total value of sales of product j on the whole markets;

$d_{i,j}$ – sales of product j at the market i;

$d_{i,j}^{\max}$ – maximal volume of sales of product j at the market i;

$I_{k,t}^{+}$ – investment into the extension of the plant, during the year t;

$I_{k,t}$ – investment into construction of a new plant, during the year t;

I_k^{δ} – investment into the creation of a new product δ;

$y_{k,t}$ – variables conforming the chosen variants of investment into the extension of existent plant or construction of a new one;

u_k – variables, conforming the chosen variants of investment into the creation of a new product.

Now the manufacturing-transportation-warehouse model can be represented as:

$$Z = \sum_{t \in T} Z_t^p = \sum_{t \in T} \frac{Z_t}{(1+r)^t} \to \max, \tag{3}$$

where Z is the sum of discounted net income; Z_t^p is the discounted net income during the year t; Z_t is the net income during the year t; r is the annual percentage rate.

Function of the net income Z_t in criterion function (3) represents the next model:

$$Z_t = \sum_{j \in J} p_j d_j - \sum_{k \in K} \Big(\sum_{j \in J} c_{j,k} x_{j,k} + \sum_{i \in I} \sum_{j \in J} c_{i,j,k}^{*} x_{i,j,k}^{*} + \\ + I_{k,t}^{+} y_{k,t} + I_{k,t} y_{k,t} + I_k^{\delta} u_k \Big), \tag{4}$$

In the case of the next restriction:

$$\begin{cases} \sum_{j \in J} x_{j,k} u_k \le b_{k,l} + \Delta b_{k,l} y_k, \ \forall k \in K, l \in L; \\ \sum_{i \in I} x_{i,j,k}^{*} = x_{j,k}, \ \forall j \in J, k \in K; \\ \sum_{k \in K} x_{i,j,k}^{*} \le d_{i,j}^{\max}, \ \forall i \in I, j \in J; \\ x_{j,k} \ge 0, \ x_{j,k} \in N \cup \{0\}, \ \forall j \in J, \ k \in K; \\ x_{i,j,k}^{*} \ge 0, \ x_{i,j,k}^{*} \in N \cup \{0\}, \ i \in I, \ j \in J, \ k \in K; \end{cases} \tag{5}$$

…

$$\begin{cases} \sum_{t \in T} y_{k,t} \le 1, \ \forall k \in K, t \in T; \\ \sum_{k \in K} u_k \le 1, \ \forall k \in K; \\ y_{k,t} \in \{0,1\}, \ \forall k \in K, \ t \in T; \\ u_k \in \{0,1\}, \ k \in K. \end{cases} \tag{6}$$

The function (4) is the year net income t, which is calculated by deducting from the sales gross income:

- production costs;
- the cost of transportation from factories to markets;
- investment costs in the extension of the existing plant;
- the construction of a new plant
- the creation of a new product.

System of constraints (5) is local, i.e. variables and constants are defined within a specific year t in the reporting period of planning. The first group of restrictions in the system (5) is the restriction for the model of production. If the value of a variable is $y_k = 0$, the available resources are in quantity $b_{k,l}$. If the value of the variable is $y_k = 1$, i.e. the investment into the extension of the existing or construction of a new plant is made in the given year, then additional resources are available in the amount of $\Delta b_{k,l}$.

The second and the third group of restrictions in the system (5) are the restrictions for the model of transportation. The first of these restrictions is the restriction on the proposition, which is equal to the amount $x_{j,k}$ of manufacturing of the product j at plant k. The second restriction for the model of transportation means that the value of delivery of the products to the

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relevant market should not exceed the forecast of maximum sales of the product *j* at the market *i* - $d_{i,j}^{\max}$. Restrictions on the non-negative and integer variables $x_{j,k}$ and $x_{i,j,k}^{*}$ complete the system (5). The system (6) are restrictions for globally definite variables $y_{k,t}$ and u_k.

The first restriction in (6) indicates that the investment into the extension of the existing plant and the construction of a new plant can be made only once during the given period of planning. The second restriction (6) indicates that the investment into a new product δ may be implemented either at the existing or at a new plant. The last two restrictions (6) indicate that the variables $y_{k,t}$ and u_k are Boolean.

A number of computational problems arise while finding the numerical solution of this problem. First, the models (3) - (6) belong to a class of mixed programming models as the objective function and restrictions include integer variables $x_{j,k}$ and $x_{i,j,k}^{*}$, along with Boolean variables $y_{k,t}$ and u_k. Secondly, the model is dynamic, spanning several time periods. Third, it is a model of strategic planning designed to analyze solutions for different scenarios, and therefore, it is stochastic.

4. Genetic algorithm for MTW model:

One of the best heuristic approaches is genetic algorithm (GA) because of ability to find the solutions without limiting the problems.

Since the integrated model, that has been analyzed is a non-linear integer programming type, GA has proposed to overcome the limitations of the model problem.

The problem is to determine the manufacturing lot sizes policy, delivery quantities, number of shipments and as a result higher income. Genetic algorithm will be presented to efficiently solve the problem given in equation (3). GA is based on natural selection and the fittest principle. GA begins from an initial population (*N*). Each individual in the population is called chromosome which represents a solution. This chromosome is regenerated through iteration sequence, called generation. During regeneration, a chromosome is evaluated using a measurement called fitness value. The best chromosome will be selected as parents to generate offspring. To produce offspring, the parents operate crossover and mutation. Termination of generation is conducted when the optimal solution or near optimal solution is obtained. Before illustrating the searching process of GA, each chromosome must be represented. The chromosome represents manufacturing lot sizes policy, delivery quantities, number of shipments and higher income as a result. Figure 2 shows the structure of a chromosome.

$$\begin{array}{c} X \\ x_i \\ m \end{array} \begin{bmatrix} X_1, X_1 \ldots X_n \\ x_1, x_2 \ldots x_n \\ m_1, m_2 \ldots m_n \end{bmatrix}$$

Fig. 2. Structure of chromosome

The next GA's steps are helped to solve the model in equation (7) as shown in Fig. 3 and followed by description in followed section.

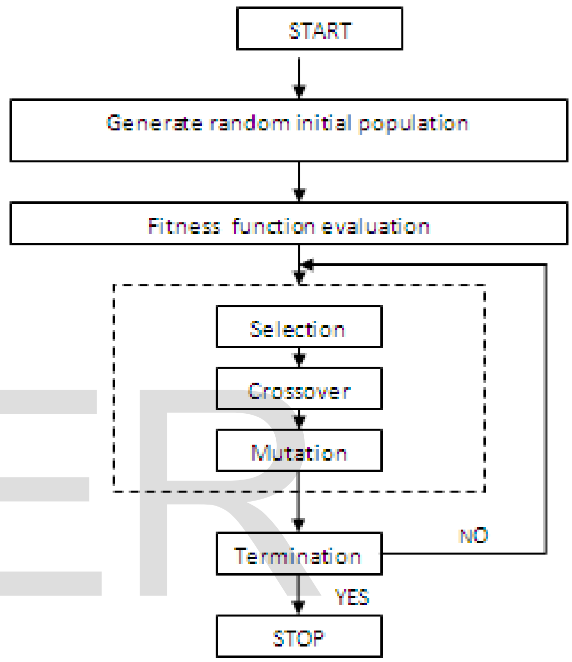

Fig. 3. Flowchart of genetic algorithm

1. Initial Population

The initial population (N) here is randomly generated by a number of chromosomes. So, the search space can be limited to find optimal solution if the population size is small. If the population size is large it will make more complex.

2. Fitness Evaluation

The fitness function is evaluated through calculation of total income of the system for each chromosome. The total income of the system is obtained based on equation (7).

3. Selection

In this step, the best individual chromosome will be selected from the current generation. Then the best chromosome becomes the parent of the next generation. In this paper, selection process uses Roulette Wheel Operation technique. In this technique selection probability for each individual, is in direct proportion to its fitness function.

4. Crossover

The aim of any crossover is to pairs the chromosomes in order for creation child chromosomes (offspring). These chromosomes selected from the current population with the crossover rate (C_r).

Crossover rate (C_r) is the probability of performing a crossover in GA.
This paper uses two cut point crossover. In Fig. 4 showed the example of this crossover.

Two Cut Point Crossover

Parents	[803 946 582 699 750 444 760 973 865 899 490 600]
Offspring	[(801 956 532) 699 750 444 760 973 865 (788 401 637)]
Offspring	[(803 946 582) 666 710 464 731 967 845 (899 490 600)]
Parents	[801 956 532 666 710 464 731 967 845 788 401 637]

Fig. 4. Example of crossover

5. Mutation

The mutation operator helps the GA process to find the global optimal solution by randomly changing the value of each element of chromosome based on mutation rate (M_r). The example of mutation is shown in Fig. 5.

[803 (946) 582 699 750 444 760 973 (865) 899 490 600]

↓

[803 (865) 582 699 750 444 760 973 (946) 899 490 600]

Fig. 5. Example of mutation operation

6. Termination

In case when solution is satisfied generation for new chromosome will be terminated. According to Niaki and Pasandideh,, the criteria to stop the generation are; (1) the process can be stopped after a fixed number of generations, or (2) any significant improvement in the solution is obtained. In this paper conducts a fixed 300 generations to search the solution.

5. Computational example and Conclusion:

The model solution process is illustrated by follow numerical example.

Data of The System

The data of the system include the manufacturing lot sizes policy, delivery quantities and number of shipments. The data used in Table I is obtained from work of Chen and Sarker. And it is used to test the model in equation (7). Using Microsoft Excel to model the formula in equation (7) by using those data below.

TABLE 1

DATA FOR NUMERICAL EXAMPLE

Cost Unit		P_i	D_i	S_i	C_i^V	H_i^V	H_i^M	d_i	w_i
Supplier	1	1200	10000	500	32	12	25	20	15
	2	7000	5000	800	24	23	25	15	10
	3	18000	15000	900	15	20	25	25	18
Manufacturer		C_D	C_S	D	ρ	H_M			
		50	1000	5000	8000	50			
Transportation		F_D	F_X	W_X	α				
		100	0,0005	45000	0,2				

Experiment Results

GA is helped to determine a solution for finding the optimal value of *X*, x_i and *m* so that income can be achieved. To find the solution procedures by using GA, the problem that already formulated in *Microsoft Excel* is connected to software by using generator GA NLI-gen.

The experiment was conducted based on comparison among population (N), probability of crossover (C_r) and probability of mutation (M_r). The results are summarized in Table II. Based on the results, the best solution was obtained when population (N) is 50 with C_r and M_r is 0.8 and 0.01 respectively, where the maximum income of the system is achieved. The generation of new chromosome is terminated by fixing at 300 generations.

TABLE II. EXPERIMENT RESULT

Row	N	C_r	M_r	x_1	x_2	x_3	m	X	Total Income/ Fitness
1	20	0.7	0.03	159	72	183	15	730	970656.356
2	30	0.7	0.04	156	73	185	15	732	970653.329
3	40	0.8	0.02	150	74	190	15	739	970660.650
4	50	0.8	0.01	179	66	175	16	731	970754.971
5	60	0.9	0.05	156	73	185	15	728	970653.360

In this paper, genetic algorithm (GA) is applied to optimize efficiently the integrated inventory model of MTW problem by searching optimal batch production lot size, delivery quantities, and number of shipments from supplier and manufacturer.

By using GA, the optimal decision for the integrated inventory model with delivery quantity from 4 vendors are 179, 66 and 175, the number of shipments for all vendors is 16 shipments, and the batch production lot size for manufacturer is 731. Then the maximum income can be achieved at $970754.971.

Conclusion

This study were analyzed two models of linear programming TW and MTW that linked three the most important bases in logistics: manufacturing-transportation-warehouse. During this work the relation between presented models and supply chain of integration models, that containing two or more sub-models was shown. As the result, it was determined that computational problems of these linear programming models lie in the theory of mathematical programming, because the solutions of problems of mixed programming are not currently developed sufficiently. At present time new area of strategic analysis is actively developing. It is planning scenarios. The paper proposes use the MTW model algorithm for finding optimal solutions of manufacturing-transportation- warehousing tasks. The usage of these models and algorithm in the strategic and operational logistics planning will reduce logistics costs and improve the efficiency of business processes.

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