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Genetic Algorithm for Multimodal Transportation Problem

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Abstract

Multimodal transportation becomes more popular and developed rapidly due to the pattern of globalization. One of the most efficient ways to optimize delivery time and reduce costs in a supply chain is by implementing multimodal transportation. Shipments of products from factories to markets through distribution hubs (DHs) in a supply chain are modeled as a two-stage distribution problem. Previous studies solve the multimodal distribution problem using an exact solution that takes a longer time to execute and if the problem is larger, the solution space will be more complex. A genetic algorithm (GA) is suggested in this study to tackle a two-stage transportation issue incorporating multimodal transport. A multimodal distribution problem is solved using the proposed GA and the effectiveness of the algorithms is evaluated by comparing with the previous solution. The findings of the numerical experiments indicated that the proposed method outperforms previous studies in terms of maximizing the total supply chain profit due to its robustness.

Keywords: Multimodal transportation; Genetic Algorithm; distribution network problem; two-stage transportation

Introduction

Supply chain is a system that links a company and its suppliers in order to create and distribute products to the customers. The management of the supply chain is vital since it can reduce costs and shortens the manufacturing process when it is effectively organized. A multi-stage distribution issue is a common issue for supply chain network businesses [1]. Logistics management of a supply chain is the one that deals with organizing and handling the delivery and storage of products from the manufacturer to the customers. Effective logistics management ensures that shipments are not delayed and the items are delivered in perfect condition thus reducing the company's cost. Nowadays, researchers are interested to apply multimodal in logistic networks due to the pattern of globalization. Implementing multimodal transportation in logistic networks will greatly enhance transportation efficiency and minimize overall costs [2,3].

Multimodal transportation is known as the combination of two or more transportation modes to transfer products under a single contract in an efficient way [4]. Generally, multimodal transportation is similar to a single transportation mode but includes transfer parts that involve cost and transfer time. The transfer parts occur because of several geographical location factors where the transportation cannot be carried out directly from factories to markets. Some multimodal studies only focus on minimizing cost but do not consider transfer cost in their model [4-6]. This paper aims to maximize the supply chain profit by applying multimodal transportation in the distribution network. In order to achieve the objective, a genetic algorithm (GA) is proposed to solve the optimization problem. An improvement scheme that will be explained further in the next section is combined with the GA to obtain a better result. Lastly, the performances of the algorithms will be compared with the existing solutions. All of the computational experiments in this study are conducted using Microsoft Visual C++ Studio 2022.

Materials and methods

This study implements an optimization model discussed in [7] that introduced multimodal transportation in distribution network design which aims to maximize supply chain profits. All manufacturing costs, distribution hub rentals, selling prices and penalty costs will be considered in the model. Three types of transportation modes are used during the shipment and the transfer part only occurs at the distribution hubs. Hence, the transport cost and delays may vary according to its transport modes. As the model also considers the time window, there are penalty fees for any late entry and storage charges for early arrivals of products. The objective of the multimodal distribution network problem is to maximize the total supply chain profits, given by

$$\begin{aligned} Maximize\ Z = \sum_{i=1}^{I} h_i Q_i + \sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{m=1}^{M} (v_k + b_{jk}^{m})\alpha_{jk}^{m} x_{jk}^{m} \\ - \sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{m=1}^{M}\sum_{m'=1}^{M} \gamma_{jk}^{m,m'} l_j^{m,m'} \alpha_{jk}^{m} x_{jk}^{m} - \sum_{j=1}^{J} f_j \mu_j \\ - \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{m'=1}^{M} c_{ij}^{m'} \beta_{ij}^{m'} y_{ij}^{m'} - S' - \theta' \end{aligned} \quad (1)$$

subject to

$$\sum_{j=1}^{J}\sum_{m=1}^{M} \alpha_{jk}^{m} x_{jk}^{m} \le G_k, \qquad k \in K \quad (2)$$

$$\sum_{k=1}^{K}\sum_{m=1}^{M} \alpha_{jk}^{m} x_{jk}^{m} \le w_j \mu_j, \qquad j \in J \quad (3)$$

$$\sum_{k=1}^{K}\sum_{m=1}^{M} \alpha_{jk}^{m} x_{jk}^{m} = \sum_{i=1}^{I}\sum_{m'=1}^{M} \beta_{ij}^{m'} y_{ij}^{m'}, \qquad j \in J \quad (4)$$

$$\sum_{j=1}^{J}\sum_{m'=1}^{M} \beta_{ij}^{m'} y_{ij}^{m'} = Q_i, \qquad i \in I \quad (5)$$

$$\sum_{m=1}^{M}\sum_{m'=1}^{M} \left(\alpha_{jk}^{m} \underline{b}_{jk}^{m'} + \gamma_{jk}^{m,m'} d_j^{m,m'} + \beta_{ij}^{m'} \underline{c}_{ij}^{m'}\right) = t_i, \qquad k \in K, j \in J, i \in I \quad (6)$$

$$S' = \{(a - t_i)S, \quad t_i < a\ 0, \quad t_i \ge a\ , \qquad i \in I \quad (7)$$

$$\theta' = \{0, \quad t_i \le b\ (t_i - b)\theta, \quad t_i > b\ , \qquad i \in I \quad (8)$$

$$\sum_{m=1}^{M} \alpha_{jk}^{m} \le 1, \qquad k \in K, j \in J \quad (9)$$

$$\sum_{m'=1}^{M} \beta_{ij}^{m'} \le 1, \qquad j \in J, i \in I \quad (10)$$

$$\sum_{m=1}^{M}\sum_{m'=1}^{M} \gamma_{jk}^{m,m'} \le 1, \qquad k \in K, j \in J \quad (11)$$

$$x_{jk}^{m}, y_{ij}^{m'} \ge 0, \qquad x, y \in Z, k \in K, j \in J, m, m' \in M \quad (12)$$

Nomenclature:

I	Number of markets	$d_j^{m,m'}$	Time spent transferring from mode m to m' at DH j
J	Number of distribution hubs	$l_j^{m,m'}$	Cost of transfer from mode m to m' at DH j
K	Number of factories	b_{jk}^{m}	Cost of delivery mode m from factory k to DH j
M	Number of transportation modes	$c_{ij}^{m'}$	Cost of delivery mode m' from DH j to market i
h_i	Sale prices of market i	$\underline{b}_{jk}^{m}$	Delivery time of mode m from factory k to DH j
Q_i	Resources demand of market i	$\underline{c}_{ij}^{m'}$	Delivery time of mode m' from DH j to market i
t_i	The arrival time to market i	S, θ	Earliness and tardiness penalty rate
w_j	Distribution hub j storage capacity	S', θ'	Earliness and tardiness penalty costs
f_j	Distribution hub j rental cost	x_{jk}^{m}	Quantity of product from factory k to DH j by m
G_k	Factory k limit production quantity	$y_{ij}^{m'}$	Quantity of product from DH j to market i by m'
v_k	Factory k production costs		

Objective function (1) maximizes the total profits of the supply chain. Constraints (2) and (3) are to ensure the factory capacity demand and distribution hub storage capacity are matched. Constraints (4) and (5) are the product flow conservation. Constraint (6) represents the sum of shipment time and the actual arrival time. Constraints (7) and (8) are the penalty costs for earliness and tardiness. Constraints (9) and (10) represent the operation volume integral. Constraint (11) ensures that transfer only occurs once from factory k and distribution hub j. Constraint (12) assures that the decision variables cannot be negative.

Genetic algorithm (GA) is proposed to solve the optimization problem stated. GA has been widely used for supply chain problems and the existing studies validate that GA can achieve a better solution compared to other methods for the model. In general, there are five phases for GA which are initial population, fitness evaluation, selection, crossover and mutation. As this is a distribution network problem, there are two stages of transportation problems: shipments from factories to distribution hubs (DHs) known as Part A and shipment from DHs to markets known as Part B. The summarize of the procedure for the GA is shown below:

Step 1: Generation of chromosomes or solutions to initialize the population.
Step 2: Evaluate each chromosome then select the best 50 chromosomes.
Step 3: Choose two chromosomes using the roulette wheel selection for crossover based on the fitness value of the chromosomes.
Step 4: Performs the crossover procedure to generate one offspring.
Step 5: Deploy the improvement scheme on the offspring and evaluate it.
Step 6: Repeat step 2 for the next generation until stopping criteria is met.

Commonly, the chromosome representations used in GA are priority-based encoding procedure, permutation representation, and matrix representation. In our GA, the chromosome is represented in permutation form because it results in a better solution as it remains feasible even after applying genetic operators such as crossover and mutation [8]. Since the optimization problem is a two-stage distribution network, a chromosome is denoted by two sub-chromosomes: S-C B denotes the solution for transportation from DHs to markets (Part B) and S-C A denotes the solution for transportation from factories to DHs (Part A). For the whole optimization problem, both sub-chromosomes comprise one chromosome. Let assume the transportation plan for the distribution network as shown in Figure 1. S-C A for shipments from DH j to market k in permutation form is {1-5-2-4-6-3} and S-C B for shipments from factory k to DH j is {3-4-8-6-5-9-2-12-1-7-11-10}. The capacity that is displayed at each distribution hub are corresponding to the capacity used and market demands.

S-C A:
{1-5-2-4-6-3}

S-C B:
{3-4-8-6-5-9-2-12-1-7-11-10}

Factory (K) k / Distribution Hub (J) j

	J_1	J_2	J_3	
K_1	1000	1440		2440
K_2		500		500
	1000	1940		

Distribution Hub (J) j / Market (I) i

	I_1	I_2	I_3	I_4	
J_1			840	160	1000
J_2	700	770		470	1940
J_3					
	700	770	840	630	

Figure 1 Transportation route and its sub-chromosomes in permutation representation.

The initial solution (or population) is generated randomly according to the data sets available from a defined range of variables. The transportation modes for each route are also chosen randomly and since it is generated randomly, several runs are required before determining the best solution. Then, each chromosome is evaluated according to the objective function which is to maximize the total profit. The probability of selection for each chromosome determines its fitness level. The higher the value, the higher the chance to be selected for the next generation. For crossover, the parents (chromosomes) are chosen by using roulette-wheel selection based on the fitness function followed:

$$F_p = \frac{1}{Z_p} \; where \; p = 1,2, \dots, N \tag{13}$$

with $\boldsymbol{N}$ denotes the population size and $\boldsymbol{Z_p}$ is the maximum profit for population $\boldsymbol{p}$.

The crossover procedure is predicted on the assumption that the produced child would outperform the parents. Therefore, it is intended to preserve as many gene traits from the dominant parent (base chromosome) as from the poor parent (donor chromosome). Every gene in the base chromosome is allocated a random number r between [0, 1]. If $r \leq 0.90$, the associated gene is brought from the base chromosome to the child. Then, according to the order-based crossover operator, the child's empty genes are subsequently filled from the poor parent. Let Z_1 and Z_2 are the total profit for the both chromosomes chosen respectively. Consider the first sub-chromosome (S-C B) for both parent chromosomes, pick better sub-chromosome and denotes as SC_B^*. Similar to the second sub-chromosomes, we obtain SC_A^*.

Assume that $Z_1 = 40{,}759$, $Z(S - C\ A) = 45{,}248$ and $Z(S - C\ B) = 22{,}876$ for Parent 1 and let the chromosome permutation representation for S-C A is {2-3-1-4-5-6} and S-C B is {3-4-8-9-6-7-1-12-10-5-11-2}. Then, assume that $Z_2 = 44{,}204$, $Z(S - C\ A) = 45{,}938$ and $Z(S - C\ B) = 18{,}387$ for Parent 2 and let the chromosome permutation representation for S-C A is {1-4-5-2-3-6} and S-C B is {5-8-2-7-3-4-9-1-11-6-10-12}. Hence, SC_A^* from Parent 1 selected is {2-3-1-4-5-6} and SC_B^* from Parent 2 selected is {5-8-2-7-3-4-9-1-11-6-10-12}. First consider SC_A^*, assign 6 random numbers corresponding to 6 genes in SC_A^*. Maintain the genes with random numbers less than or equal to 0.90, as shown followed:

0.966	0.995	0.703	0.504	0.903	0.822

2	3	1	4	5	6

↓ (1, 4, 6)

		1	4		6

Then, inherit the unassigned cell 2, 3 and 5 in a similar order as in S-C A of Parent 2 based on order-based crossover operation and S-C A obtained for the child is {5-2-1-4-3-6}.

1	4	5	2	3	6

↓

5	2	1	4	3	6

Similarly, repeat the above procedure for SC_B^* and S-C B obtained for the child is {5-8-2-4-3-9-7-1-11-6-10-12}. Given the full chromosome S-C A and S-C B for the child are {5-2-1-4-3-6} and {5-8-2-4-3-9-7-1-11-6-10-12} respectively. Finally, assign the deliveries by checking child's S-C B from left to right, similar to S-C A. Every child generated is enhanced by improvement process and the mutation operator will not be applied since the crossover operator inherits 90% of gene traits from a better parent and only 10% from the donor chromosome as proven by [8].

All chromosomes produced will be improved through an improvement scheme with two phases. Phase I is by assigning the maximum permitted delivery amount for each route and the assigned delivery amount for Phase II is accomplished by applying the stepping stone approach. The offspring will be evaluated and selected for the next generation if better than the current generation. The procedure will be repeated until the stopping criteria is met which is the maximum generation number or 3600 CPU-time seconds, whichever comes first.

Results and discussion

Data sets from [7] are used to generate the initial solution. The suggested method's effectiveness is compared with the best current solutions. LINGO 9 software is used to solve the optimization problem in [7] and the best maximum profit they obtained is 52026. Since it is an exact solution, the computing time for the solution is quite long.

In our study, the best profit over 40 runs which are 10 runs with four different population sizes is 52832. The transportation modes changed every time the products reached the DHs from the factory. The computing time to obtain the best maximum profit is less than 3600 seconds which is very quick to obtain a best solution. It is obvious that the proposed method outperforms the current studies. Hence, to evaluate the performance of the method, further analysis will be made by using different settings of genetic parameters to identify the most optimized genetic parameters on maximizing the total supply chain profit.

Conclusion

In this study, we proposed a genetic algorithm to solve the multimodal distribution network problem by considering a two-stage distribution network. Several optimization techniques may be used to maximize the profit of a problem. However, because of its robustness to escape from local optima, a genetic algorithm is used in this study. An effective supply chain management can help any business to sustain from day to day, especially to survive the aftermath of Covid-19 pandemic. This proposed method has proven its efficiency to obtain an optimal cost for multimodal transportation problems. These findings are beneficial to solve broad multimodal distribution networks problems and can be used as part of the transportation planning for supply chain industries.

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