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Global Logistics Road Planning: A Genetic Algorithm Approach

Yue Wu*

School of Management, University of Southampton,
University Road, Highfield, Southampton, SO17 1BJ, UK

Abstract Logistics transportation between two countries presents some special challenges and issues for business organizations, because of the cost differentials between two countries regarding transporting, staffing, warehousing, etc. In this study, we consider a logistics problem experienced by a producer of electrical equipment, which needs to transport their products, which are produced in Mainland China and stored in Mainland China's warehouse, to Hong Kong's warehouse by truck every day. The company has their own fleet with the limited capacity. Based on the strategic plan, the company has no any plan to purchase new trucks, and they would like to rent additional trucks from two countries for crossing-border transportation. The logistic company has to determine its fleet composition and route, as well as the inventory level in the two warehouses. A mixed 0-1 integer programming model is formulated. As the solution method, we propose a genetic algorithm. Computational results demonstrate the effectiveness of the proposed model and algorithm.

Keywords global logistics; transportation; warehousing; genetic algorithm

1 Introduction

This study is motivated by a global logistic transportation problem between Mainland China and Hong Kong. Because of China's booming economy, more and more companies have been establishing their production facilities in Mainland China. Hong Kong has been the largest source of foreign direct investment in Mainland China accounting for about 51% of the national total, with a cumulative value of US$157.7 Billion from 1979 to 1999. Taking the year 2002, 45% of Hong Kong's total exports to the Mainland China are for outward processing, reaching US$35.2 billion, representing an increase of 6% over 2001 (Hong Kong Census and Statistics Department). Hong Kong has been actively participating in the re-export trade with China, particularly through 'outward processing' activities. In outward processing, raw materials and components are shipped from Hong Kong to the cities in Southern China to be included in the manufacturing process. The finished products are then shipped back to Hong Kong for re-export to overseas countries. Hong Kong's outward processing activity includes the establishment of owned or joint-venture plants

*Corresponding author: Tel: +44 (0) 23 8059 3069. Fax: +44 (0) 23 8059 3844. E-mail: y.wu@soton.ac.uk

in China, as well as the subcontracting of parts of the production process to the plants in the Mainland China, particularly Southern China, which has been as an outward processing base for Hong Kong's manufacturers. This relocation of manufacturing activities also brought in capital and technology needed to accelerate China's modernization. The effect is so significant that Hong Kong become China's major source of foreign investment.

Logistics and transportation management is an important domain of human activities, and supports most other social and economic activities. Aneja and Nair (1979) consider two objectives in the transportation problem. Interactive algorithms have been proposed as ways of solving multi-objective transportation problems (Ringuest and Rinks 1987). Etezadi and Beasley (1983) built a mixed-stage linear programming model to find the optimal number of vehicles needed to supply a number of customers from a central point. Chanas *et al.* (1998) consider supply and demand in an imprecise rather than a crisp way. Denardo *et al.* (1988) solve the problem of finding the vehicle schedule that minimizes total inconvenience for travel along a fixed path, where service times schedule are constrained by time windows. Sun et al. (1998) present a tabu search approach for the fixed charge transportation problem. Their objective is to find the combination of routes that minimizes the total variable and fixed costs while satisfying the supply and demand requirements of each origin and destination pair. Liu and Shen (1999) describe several insertion-based savings heuristic algorithms for the fleet size and mixed vehicle routing problem with time window constraints.

2 Problem description and model formulation

In this paper, the company has its own truck i^0 $(i \in I^0)$ with two licenses, and the unit trip cost is denoted by h^0. The company has two warehouses located in Mainland China and Hong Kong, respectively. When demand in Hong Kong market is higher than the company's transportation capacity, the company may rent a truck i $(i \in I^1)$ with a Chinese driving license; rent a truck i $(i \in I^2)$ with a Hong Kong's driving license; and rent a truck can i $(i \in I^3)$ with two countries' licenses. Because the boundary restricts of two countries, only those truck with two countries' licenses can directly cross the border from Mainland China to Hong Kong. As a result, trucks with the Chinese driving licenses have to unload all shipments on the border, and trucks with Hong Kong's driving licenses then load the shipment into the trucks and go to the Hong Kong's warehouse. All trucks have their maximum loading capacity, represented by V_i $(i \in I^0 \cup I^1 \cup I^2 \cup I^3)$. Let h_1 represent the unit cost for renting a truck with a Chinese driving license, h_2 represent the unit cost for renting a truck with a Hong Kong's driving license, and h_3 represent the unit cost for renting a truck with two licenses from both countries. It is also assumed that the unit inventory cost in the Mainland China's warehouse is denoted by c^1, and the unit inventory cost in the Hong Kong's warehouse is c^2. In day t $(t \in T)$, s_t volumes of products are required to be transported by renting trucks from the Mainland China's warehouse, and d_t volumes of products are demanded from Hong Kong. If demand is not satisfied, the company suffer a shortage cost. The unit shortage cost is denoted by c^3. Let w_0^1 denote the initial volume of products stored in the Mainland China's warehouse, and w_0^2 denote the initial volume of products stored in the Hong Kong's warehouse. The company has three options for transporting products from Mainland China to Hong Kong:

1. use company-owed fleet, which can directly transport products from the Mainland China's warehouse to the Hong Kong's warehouse.
2. to rent trucks with two countries' licenses, which can directly transport products from Mainland China to Hong Kong; or
3. to rent trucks with Chinese licenses first, switching to trucks with Hong Kong's licenses. This option incurs a trans-shipment cost on the border point, because it involves unloading and loading process. The unit trans-shipment cost is denoted by c^0.

The company needs to determine an optimal logistics plan, aiming at minimizing the total logistics cost, consisting of trip cost for the company's own fleet, renting truck cost, warehousing cost, and trans-shipping cost. Decision variables include:

$$x_{it} = \begin{cases} 1 & \text{if truck } i \text{ is rented on day } t \\ 0 & \text{otherwise} \end{cases}, i \in I^0 \cup I^1 \cup I^2 \cup I^3, t \in T;$$

X_{it} = volume of products loaded by truck i on day t, $i \in I^0 \cup I^1 \cup I^2 \cup I^3$, $t \in T$;
w_t^1 = inventory of volume of products in the Mainland China's warehouse on day t, $t \in T$;
w_t^2 = inventory of volume of products in the Hong Kong's warehouse on day t, $t \in T$;
w_t^3 = shortage of volume of products in the Hong Kong's warehouse on day t, $t \in T$.

The logistics planning problem between two countries can be formulated as the following mixed 0-1 integer programming model:

$$\min \sum_{t\in T}\sum_{i\in I^0} h^0 x_{it} + \sum_{t\in T}\sum_{i\in I^1} h^1 x_{it} + \sum_{t\in T}\sum_{i\in I^{21}} h^2 x_{it} + \sum_{t\in T}\sum_{i\in I^3} h^3 x_{it} + \sum_{t\in T}\sum_{i\in I^2} c^0 * V_{it}^1 + \sum_{t\in T} c^1 w_t^1 + \sum_{t\in T} c^2 w_t^2 + \sum_{t\in T} c^3 w_t^3 \quad (1)$$

$$\text{s.t.} \quad V_{it} \le V_i x_{it}, \quad i \in I^1 \cup I^2 \cup I^3, t \in T \quad (2)$$

$$s_t + w_{t-1}^1 = \sum_{i\in I^0\cup I^1\cup I^3} X_{it} + w_t^1, \quad t \in T \quad (3)$$

$$\sum_{i\in I^1} X_{it} = \sum_{i\in I^2} X_{it}, \quad t \in T \quad (4)$$

$$\sum_{i\in I^0\cup I^1\cup I^3} X_{it} + w_{t-1}^2 = d_t + w_t^2 - w_t^3, \quad t \in T \quad (5)$$

$$x_{it} \in \{0,1\}, \quad X_{it} \ge 0, \quad i \in I^0 \cup I^1 \cup I^2 \cup I^3, \quad t \in T \quad (6)$$

$$w_t^1, w_t^2, w_t^3 \ge 0, \quad t \in T \quad (7)$$

The first term in objective function is the trip cost of the company-owned trucks. The second, third and fourth terms are the unit cost of hiring China's trucks, Hong Kong's trucks, and trucks with two licenses. The fifth term is the trans-shipment cost. The sixth term is the warehousing cost in the Mainland China's warehouse, and the seventh term is the warehousing cost in the Hong Kong's warehouse. The final term is the shortage cost. Constraint (2) ensures that, for every truck, the loading volume of products cannot exceed its capacity limit. Constraint (3) ensures that, on day t, the total volume of the products available to transport plus the initial products stored in the Mainland China warehouse is equal to the sum of volume of the products transported to the border by the trucks with Chinese license and volume of the products directly transported to Hong Kong by trucks with two licenses, minus the volume of stored in the Mainland China warehouse at the end of day. Constraint (4) ensures that, on day t, the total volume of the products transported from the Mainland China's warehouse to the border by the trucks hired from China will be equal to the total volume of products transported from the border to the Hong Kong's warehouse by the Hong Kong's trucks. No products are allowed to stay overnight on the border. Constraint (5) ensures that, on day t, the total volume of the products received plus the products already stored in the Hong Kong warehouse is equal to the total volume of the products required by the markets plus products stored in the Hong Kong's warehouse, minus shortage of volume of products in the Hong Kong's warehouse. Constraints (6) and (7) determine variable types.

3 An genetic algorithm

In recent year, there has been an increasing interest in using different artificial intelligence algorithms to solve hard optimization problems. However, genetic algorithms have been receiving great attention among them and have also been successfully applied in many research fields. Choosing an appropriate chromosome representation of candidate solutions for the problem is the foundation for applying a genetic algorithm to the optimization problems here. In our problem, we use a vector, $V=\{\{x_{01},x_{02},\cdots,x_{0n_0}\},\{x_{11},x_{12},\cdots,x_{1n_1}\},\{x_{21},x_{22},\cdots,x_{2n_2}\},\{x_{31},x_{32},\cdots,x_{3n_3}\}\}$, as a chromosome to present a solution. Let $x_0=\{x_{01},x_{02},\cdots,x_{0n_0}\}$, where n_0 represents the truck number of the company's fleet; $x_1=\{x_{11},x_{12},\cdots,x_{1n_1}\}$, where n_1 represents the truck number of the Chinese's trucks available; $x_2=\{x_{21},x_{22},\cdots,x_{2n_2}\}$, where n_2 represents the truck number of the Hong Kong's trucks available; and $x_3=\{x_{31},x_{32},\cdots,x_{3n_3}\}$, where n_3 represents the truck number of the Chinese's trucks available. All x_{ij} are binary variables.

We define an integer *popsize* as the number of chromosome. *popsize* chromosomes can be generated using the above approach.

3.1 Fitness Function

Let $fit(V_1)$, $fit(V_2)$, $\ldots$, $fit(V_{popsize})$ denote the fitness function at the current generation, which will assign a probability of reproduction to each chromosome. The chromosomes that have a higher fitness function will have a higher chance of producing children. In our study, we use the roulette wheel selection strategy. We assign rank relationship among the *popsize* chromosomes V_1, V_2, $\ldots$, $V_{popsize}$ such that current chromosomes will be rearranged in an ascending order relationship. If a chromosome has a smaller ordinal number, the chromosome is better. We define the fitness function as $fit(V_i) = a(1-a)^{i-1}$, where $i = 1, 2, \cdots, popsize$. According to the ranking criterion, we conclude that $i = 1$ is the best chromosome, and $i = popsize$ is the worst.

3.2 Selection

The selection process proceeds by spinning the roulette wheel *popsize* times. Thus, we select a chromosome to be a new population.

Begin
  q_0=0;
  for $i \leftarrow 1$ to *popsize* do

$$q_i = \sum_{k=1}^{i} fit(V_k)$$

  end
  for $i \leftarrow 1$ to *popsize* do
    generate a random number r in [0,1];
    if $(q_{i-1} < r \leq q_i)$ select the i-th chromosome V_i;
  end;
End.

3.3 Crossover Operation

Let p_c be the probability of crossover among chromosomes. This probability gives the expected number $p_c \cdot popsize$ of chromosomes during the crossover operation. We generate a random number r among [0,1]. Chromosome V_i is selected for the crossover operation if $r < p_c$. We repeat this processing for *popsize* times and generate $p_c \cdot popsize$ chromosomes for the crossover operation. We them randomly select two chromosomes (V_1 and V_2) as parents. V_1 and V_2 are denoted as follows: $V_1 = \{x_1^1, x_2^1, \cdots, x_n^1\}$, $V_2 = \{x_1^2, x_2^2, \cdots, x_n^2\}$. Select a random position i for vector V_1 and a random position j for vector V_2. Change these two variables (x_i^1 and x_j^2). The two children V_1' and V_2' are $V_1' = \{x_1^1, x_2^1, \cdots, x_{i-1}^1, x_j^2, x_{i+1}^1, \cdots, x_n^1\}$, and $V_2' = \{x_1^2, x_2^2, \cdots, x_{j-1}^2, x_i^1, x_{j+1}^2, \cdots, x_n^2\}$. If two children V_1' and V_2' are not feasible, we repeat the above process until both of children are feasible.

3.4 Mutation Operation

We define a parameter p_m as the probability of mutation operation. This probability gives the expected number $p_c \cdot popsize$ of chromosomes during the mutation operation. We generate a random number r among [0,1]. The chromosome V_i is selected for mutation operation if $r < p_m$. We repeat this processing *popsize* times and generate $p_c \cdot popsize$ chromosomes for mutation operation on average. Select two

Table 1: Supply and demand

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
Supply	2000	1800	2300	1600	2100	1500
Demand	1800	1700	2200	1500	1900	1400

random position i and position j for vector V, which is selected for mutation operation. Change the position of the two variables (x_i^1 and x_j^2). The child V' is obtained by mutation operation as follows:

$$V' = \{x_1, x_2, \cdots, x_{i-1}, x_j, x_{i+1}, \cdots, x_{j-1}, x_i, x_{j+1}, \cdots, x_n\}$$

If the child V' is not feasible, we repeat above process until both children are feasible or until a predetermined number of iterations are achieved.

4 Computational Results

Under the company's current logistics strategy, three company-own trucks ($V1$, $V2$, $V3$) are used to deliver the products between the Mainland China warehouse and Hong Kong warehouse; four China-hire trucks ($V4$, $V5$, $V6$, $V7$) operate between the Mainland China warehouse and the border; four Hong Kong-hire trucks ($V8$, $V9$, $V10$, $V11$) operate between the border and the Hong Kong's warehouse; and two Hong Kong trucks ($V12$, $V12$) operate between the Mainland China's warehouse and Hong Kong's warehouse. The unit trip cost for the company's owned trucks is \$200. However, the unit hiring cost for China's trucks, Hong Kong's trucks, and the trucks with two licenses are \$500, \$1200, and \$1500, respectively. It is also assumed that all trucks have the same loading capacity of 450. The unit inventory cost is \$1 in the Mainland China's warehouse and \$4 in the Hong Kong's warehouse. The unit shortage cost is \$12. The unit trans-shipment cost is \$0.6. Table 1 gives the supply in the Mainland China's warehouse and demand from Hong Kong for six days.

Using the genetics algorithm, we can obtain a logistics plan. Table 2 gives the computational results, including a loading plan for all trucks, a trans-shipping plan, and warehousing plan and a shortage plan. The related costs are also shown in Table 2. The total weekly logistics costs are \$15,775.

5 Conclusions

In this study, a mixed integer programming model is proposed to deal with the global logistics transportation problem between Mainland China and Hong Kong. By using the genetic algorithm proposed in this study, we can effectively find a logistics strategy in terms of fleet composition and inventory level, which involves two countries. It is believed that logistics problems have increased with the implementation of global supply chain management. It is high time that global logistic management is developed and more appropriate logistics tools studied to meet today's highly competitive business environment. The mixed integer programming model is formulated

Table 2: Loading plan for all vehicle

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Cost
Company-owned trucks	V1(450) V2(450) V3(450)	V1(350) V2(450) V3(450	V1(450) V2(450) V3(450)	V1(450) V2(450) V3(450)	V1(450) V2(450) V3(450)	V1(450) V2(450) V3(450)	$3,600
Hired trucks with China's license				V4(250)			$300
Hired trucks with China's license				V4(250)			$600
Hired trucks with two licenses	V14(450)	V12(450)	V12(450) V13(450)		V14(450)		$7,500
Inventory in the China's warehouse	200	300	350	650	800		$2,650
Inventory in the Hong Kong's warehouse			50	150	50		$1,000
Shortage in Hong Kong							

and the effectiveness and efficiency of the proposed genetic algorithm is presented. Future research may consider the changing information, and stochastic programming may be applied to solve the uncertain logistics problems.

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