Cross-border logistics with fleet management: 
A goal programming approach

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Abstract

In this paper, we introduce the cross-border logistics problem with fleet management. A major phenomenon of implementation of open-door policy in China is the move of Hong Kong-based manufacturers’ production lines to China, crossing the border to take advantages of lower production costs, lower wages and lower rental costs. The finished products are then transshipped to Hong Kong, an efficient logistics hub well-equipped with reliable transportation facility, for exporting. We present a preemptive goal programming model for multi-objective cross-border logistics problem, in which three objectives are optimized hierarchically. We also describe a framework for incorporating decision-makers’ opinions for determination of goal priorities and target values. A set of Hong Kong data have been used to test the effectiveness and efficiency of the proposed model. Results demonstrate the decision-makers can find the flexibility and robustness of the proposed model by adjusting the goal priorities with respect to the importance of each objective.

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Keywords: Logistics; Goal programming; Vehicle composition; Multiple criteria decision making

1. Introduction

Since, the implementation of China’s open-door policy in 1979, many Hong Kong-based manufacturers’ have moved their production facilities over the border from Hong Kong to cities in Southern China including Shenzhen, Dongguan, Zhuhai, Huaizhou and Xiamen. By doing this, they have taken advantage of lower wages and lower rental costs. After receiving raw materials from suppliers, products are manufactured in China. To avoid numerous problems with delays, damages or delivery errors due to inefficient and bureaucratic Chinese intermediaries, Hong Kong manufacturers prefer for their finished and packed products to be exported to Hong Kong so that they can inspect the products before selling locally or shipping overseas using either private carriers or for-hire carriers.

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A unique characteristic of logistics problems experienced by Hong Kong manufacturers is the geographical separation of Hong Kong and China (Fig. 1). All vehicles traveling from Hong Kong to China or vice versa must cross the border at one of three custom checkpoints for executing cargo clearance procedures. These checkpoints are located in North-East Hong Kong at Sha Tau Kok, in North Hong Kong at Man Kam To, and in North-West Hong Kong at Lok Ma Chau.

### Notations

#### Parameters

<table>
<thead>
<tr>
<th>Notation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{DG}^0$</td>
<td>Initial volume of products stored in the Dongguan warehouse (units)</td>
</tr>
<tr>
<td>$V_{SZ}^0$</td>
<td>Initial volume of products stored in the Shenzhen warehouse (units)</td>
</tr>
<tr>
<td>$V_{HK}^0$</td>
<td>Initial volume of products stored in the Hong Kong warehouse (units)</td>
</tr>
<tr>
<td>$M$</td>
<td>Maximum amount of manufactured products produced in the factory in Dongguan (units)</td>
</tr>
<tr>
<td>$D_t^{min}$</td>
<td>Minimum known demand in Hong Kong on day $t$ (units)</td>
</tr>
<tr>
<td>$D_t^{max}$</td>
<td>Maximum forecast sales in Hong Kong on day $t$ (units)</td>
</tr>
<tr>
<td>$c_r$</td>
<td>Transportation cost associated with private truck choosing route $r$ ($/unit$)</td>
</tr>
<tr>
<td>$g_i$</td>
<td>Hiring cost of truck $i$, $i \in {2,3}$ ($/vehicle$)</td>
</tr>
<tr>
<td>$ac$</td>
<td>Allowance paid to a driver who makes more than one cross-border round-trip per day ($/trip$)</td>
</tr>
<tr>
<td>$h_{DG}$</td>
<td>Unit inventory cost for the Dongguan warehouse ($/unit$)</td>
</tr>
<tr>
<td>$h_{SZ}$</td>
<td>Unit inventory cost for the Shenzhen warehouse ($/unit$)</td>
</tr>
<tr>
<td>$h_{HK}$</td>
<td>Unit inventory cost for the Hong Kong warehouse ($/unit$)</td>
</tr>
<tr>
<td>$q_i$</td>
<td>Capacity of truck $i$ (units)</td>
</tr>
<tr>
<td>$FS$</td>
<td>Number of private trucks available (vehicles)</td>
</tr>
<tr>
<td>$t_r$</td>
<td>Time spent making a round-trip on route $r$ by private truck (hours)</td>
</tr>
<tr>
<td>$WT$</td>
<td>Driver’s maximum working hours (hour)</td>
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<tr>
<td>$b_f$</td>
<td>Aspiration level of ‘market fulfillment goal’ to be achieved</td>
</tr>
<tr>
<td>$b_c$</td>
<td>Aspiration level of ‘total cost goal’ to be achieved</td>
</tr>
<tr>
<td>$b_h$</td>
<td>Aspiration level of ‘hiring Hong Kong truck goal’ to be achieved</td>
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#### Decision variables

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<thead>
<tr>
<th>Notation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S_t'$</td>
<td>Volume of products delivered from the factory in Dongguan on day $t$ (units)</td>
</tr>
<tr>
<td>$D_t'$</td>
<td>Volume of products sold to the market on day $t$ (units)</td>
</tr>
<tr>
<td>$w_i^t$</td>
<td>Number of China trucks hired for Route 1 on day $t$</td>
</tr>
<tr>
<td>$y_2^t$</td>
<td>Number of private truck trips made on Route 2 on day $t$</td>
</tr>
<tr>
<td>$y_3^t$</td>
<td>Number of private truck trips made on Route 3 on day $t$</td>
</tr>
<tr>
<td>$z_3^t$</td>
<td>Number of Hong Kong trucks hired for Route 3 on day $t$</td>
</tr>
<tr>
<td>$x_r^t$</td>
<td>Volume of products loaded by truck choosing route $r$ on day $t$</td>
</tr>
<tr>
<td>$u_r^t$</td>
<td>Volume of products loaded by private truck choosing route $r$ on day $t$</td>
</tr>
<tr>
<td>$V_{DG}^t$</td>
<td>Volume of products stored in the Dongguan warehouse on day $t$</td>
</tr>
<tr>
<td>$V_{SZ}^t$</td>
<td>Volume of products stored in the Shenzhen warehouse on day $t$</td>
</tr>
<tr>
<td>$V_{HK}^t$</td>
<td>Volume of products stored in the Hong Kong warehouse on day $t$</td>
</tr>
<tr>
<td>$e_t$</td>
<td>Number of round-trips over 1 made by private truck on day $t$</td>
</tr>
</tbody>
</table>

#### Auxiliary variables

<table>
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<th>Notation</th>
<th>Description</th>
</tr>
</thead>
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<tr>
<td>$d_f^+$</td>
<td>Deviation of underachievement of $b_f$</td>
</tr>
<tr>
<td>$d_f^-$</td>
<td>Deviation of overachievement of $b_f$</td>
</tr>
<tr>
<td>$d_c^+$</td>
<td>Deviation of underachievement of $b_c$</td>
</tr>
<tr>
<td>$d_c^-$</td>
<td>Deviation of overachievement of $b_c$</td>
</tr>
<tr>
<td>$d_h^+$</td>
<td>Deviation of underachievement of $b_h$</td>
</tr>
<tr>
<td>$d_h^-$</td>
<td>Deviation of overachievement of $b_h$</td>
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</table>
This study focuses on a transportation management problem faced by a Hong Kong manufacturer. The company’s headquarters is in Hong Kong and the company’s factory is located in Dongguan in China. Every day finished products are transported from China to Hong Kong to fulfill daily sales orders and future demand. The company uses private trucks to transport products; these originate at the Hong Kong depot. These trucks are registered in Hong Kong and can operate on both sides of the border. If necessary, the company can hire more trucks from other logistics partners to handle excess demand. Two types of truck can be hired: (1) a Hong Kong truck, which has a larger capacity than private truck and can also operate on both sides of the border; (2) a China truck, which has the same capacity as private truck but can only operate in China. With the information presently available there are currently three alternatives:

1. to use private trucks to transport the products directly from Dongguan to Hong Kong;
2. to hire Hong Kong trucks to transport products directly from Dongguan to Hong Kong;
3. to hire China trucks to transport products from Dongguan to Shenzhen first, switching to private trucks for the trip between Shenzhen and Hong Kong. This enables more round-trips to be made so that more products can be delivered in a single day under a driving time regulation.

Moreover, apart from transportation costs based on the routes chosen and hiring costs of truck, other costs should be considered in this study. Firstly, inventory cost is incurred when the excess products are stored at three warehouses located in Dongguan, Shenzhen and Hong Kong. Secondly, each trip across the border also involves a complicated clearance procedure, including an inspection of the products, declaration of legal documents, etc. Therefore, besides their basic salary, drivers are provided with an allowance if they make more than one round-trip crossing the border each day.

The company currently adopts transportation strategy alternative 3. However, this strategy incurs higher expenditure and requires more storage space. The purpose of this paper is to propose a goal programming approach to cross-border logistics problem with multiple objectives such as maximization of market fulfillment, minimization of total cost and control of the use of Hong Kong trucks. By adjusting the goal priority with respect to the importance of each objective, decision-makers and management will find an optimal transportation strategy including optimal delivery routes and an optimal vehicle fleet composition for a weekly planning horizon. The aim is to provide an overview to the whole transportation management problem and suggest alternative transportation strategies. Additionally, the model may serve as a basis for the study of transportation problems in cross-border logistics systems. The simplicity of the implementation and operation of the model helps decision-makers manage the flow of products without having to learn complex operations and programming procedures.

2. Literature review

Transportation was one of the earliest problems in which linear programming was applied in the area of logistics. Developed by Hitchcock (1941) it is concerned with the allocation of homogeneous products from \( m \) sources to \( n \) destinations. The sources are production facilities with an available supply of goods, while
the destinations are sales outlets, warehouses, etc., with a certain demand. The classical transportation
problem is concerned with the transportation of homogeneous products from \( m \) sources to \( n \) destinations
with minimal transportation cost. The cost function comprises operating costs, the number of products
transported, delivery time, unfulfilled demand, etc. An extension of the transportation problem is the solid
transportation problem, in which the product can be carried by different modes of transport or conveyance
(Haley, 1962).

In the real world, however, many logistics problems are not defined as easily as the transportation
problem. In recent decades, a wide variety of models have been developed to solve different kinds of logistics
problems according to practical strategies. Slats, Bhola, Evers, and Dijkhuizen (1995) claimed that
operations research (OR) and management science (MS) techniques such as mathematical programming,
heuristics and simulation, are essential to support the innovation of logistics processes. Arntzenm, Brown,
Harrsion, and Trafton (1995) developed a Global Supply Chain Model (GSCM), which recommends a
production, distribution and vendor network. GSCM was formulated as a large mixed integer linear pro-
gramming that incorporates a global, multi-product bill of materials for supply chains with an arbitrary
echelon structure and a comprehensive model of integrated global manufacturing and distribution decis-
ions. Shih (1997) proposed a mixed integer programming model that provides planning and scheduling
of coal imports from multiple suppliers for Taiwan’s power company, which has more than one power
plant. Three objectives including total inventory cost, transportation cost and holding cost were minimized
subject to a set of constraints such as company procurement policy, power plant demand, harbor unload-
ing capacity, inventory balance equations, blending requirement and safety stock. Vidal and Goetschalckx
(1997) presented an extensive literature review of strategic production-distribution models. The review
mainly focuses on mixed integer programming models for strategic production-distribution problems.
The relevant factors were identified as the formulations and specific characteristics of solution methods
with computational experiences. Maturana and Contesse (1998) studied a mixed integer programming
model of the logistics associated with the production and distribution of sulfuric acid in Chile. Optimiza-
tion approaches are desirable for the sulfuric acid logistics because storing, shipping and disposing of sul-
furic acid is relatively expensive. Kim and Kim (2000) developed a mixed integer linear programming
model to formulate a multi-period inventory/distribution planning problem in a one-warehouse multi-re-
tailer distribution system where the products are transported from a warehouse to several retailers using a
fleet of heterogeneous vehicles. The problem was solved by a Lagrangian relaxation approach. Jayaraman
and Pirkul (2001) studied an integrated logistics model for planning and coordination of production and
distribution facilities in a multi-echelon environment. The integrated logistics consists of the product mix
at each plant, the shipments of raw material from vendors to manufacturing plants, and the distribution
of finished products from the plants to the different customer zones through a set of warehouses. A
mixed-integer programming of the integrated model was formulated and solved using an efficient heuristic
solution procedure.

3. A goal programming approach

Most of the real-world problems are formulated into single objective linear programming (LP) methodol-
gy or LP model. Researchers and practitioners are more and more aware of the presence of multiple criteria
in real-life problems of management and decision (Vincque, 1992; Tamiz, Jones, & Romero, 1998). Tzeng and
Chen (1999) defined multiple criteria decision making (MCDM) as a means to solving decision problems that
involve multiple (sometimes conflicting) objectives.

Goal programming (GP), which is an extension of LP and is a branch of MCDM, is commonly applied to
deal with the multi-objective problems (Rifai, 1994). Charnes and Cooper (1961) described that GP is used to
derive a set of conflict objectives as close as possible. Tamiz et al. (1998) reviewed the state-of-the-art current
developments in goal programming. With fast computational growth, both linear and non-linear GP can be
solved using well-developed software such as LINDO (linear interactive and discrete optimization) or meta-
heuristics such as simulated annealing, genetic algorithms, tabu search and so on (Jones, Mirrazavi, & Tamiz,
2002). Moreover, GP is more direct and flexible in manipulating different scenarios by adjusting either target
values or weights.
Basically, the structures of GP and LP are the same. The concept of GP is to introduce extra auxiliary variables called deviations, which do not act as the “decision maker” but the “facilitator” to formulate the model. These deviations represent the distance between the aspiration of goals (target values) and the realized results. Two kinds of deviations are considered which may be represented as under-achievement of the goal by negative deviation \((d^-)\) and over-achievement of the goal by positive deviation \((d^+)\). Each goal is expressed as a linear equation with deviation(s). As opposed to linear programming, which directly optimizes objectives, goal programming attempts to minimize the unwanted deviations between aspiration level of goal and the optimal solution. GP model consists of two sets of constraints, i.e., system constraints and goal constraints. System constraints are formulated following the concept of LP, whilst goal constraints are taken as the auxiliary constraints which determine the best possible solution with respect to a set of desired goals. The GP model used in this paper is called as preemptive GP, in which the unwanted deviations are minimized hierarchically according to the priority levels of the goals so that the goals of primary importance can receive first-priority attention, those of second importance can receive second-priority attention, and so forth. In other words, in the preemptive GP, the goals of first-priority is minimized in the first phrase. Using the obtained feasible solution result in the phrase, the goals of second priority is minimized, and so on. The preemptive GP model accepts implicitly infinite trade-offs among goals placed in different priority levels (Romero, 1991).

According to Romero (2004), the framework of preemptive goal programming model can be formulated as follows:

**Achievement function:**

\[
\text{Lex min } a = \left[ \sum_{k \in h_1} (a_k d^+_k + \beta_k d^-_k), \ldots, \sum_{k \in h_q} (a_k d^+_k + \beta_k d^-_k), \ldots, \sum_{k \in h_Q} (a_k d^+_k + \beta_k d^-_k) \right] \tag{1}
\]

s.t. **Goal and systems constraints:**

\[
f_i(x) \sim 0, \quad i = 1, 2, \ldots, q \tag{2}
\]

\[
g_k(x) - d^+_k + d^-_k = b_k, \quad k \in h_j, \quad j \in \{1, 2, \ldots, Q\} \tag{3}
\]

\[
d^+_k, d^-_k \geq 0, \quad k \in h_j, \quad j \in \{1, 2, \ldots, Q\} \tag{4}
\]

where the relational symbol \("\sim\"\) denotes =, \(\geq\) or \(\leq\); \(h_j\) is the index set of goals placed in the \(j\)th priority level; \(a_k\), is the weighting factor for positive deviation; \(\beta_k\), is the weighting factor for negative deviation;

\[
d^+_k = \begin{cases} 
  g_k(x) - b_k, & \text{if } g_k(x) > b_k, \\
  0, & \text{otherwise.}
\end{cases} \tag{positive deviation}
\]

\[
d^-_k = \begin{cases} 
  b_k - g_k(x), & \text{if } g_k(x) < b_k, \\
  0, & \text{otherwise.}
\end{cases} \tag{negative deviation}
\]

\(f_i(x)\), system constraint; \(g_k(x)\), goal constraint; \(b_k\), aspiration level of goal \(k\).

It is noted that, in optimization formulation, we have \(d^+_k \cdot d^-_k = 0\) for all \(k\). Moreover, in the achievement function, \(a_k = 0\) if \(d^+_k\) is not an unwanted deviation and \(\beta_k = 0\) if \(d^-_k\) is not an unwanted deviation. It implies that only unwanted deviations are included into the achievement function. For instance, if over-achievement to be minimized, then the negative deviation, \(d^-_k\), is not an unwanted deviation and \(\beta_k = 0\).

**4. Model formulation**

Under the company’s current logistics strategy, the road network consists of three routes: Route 1, connecting Dongguan and Shenzhen; Route 2, connecting Shenzhen and Hong Kong; and Route 3, connecting Dongguan and Hong Kong. As presented in Fig. 2, Routes 2 and 3 include a border crossing.

In this study, as with other Hong Kong-based manufacturers who have moved their production lines to China, the company may operate its private trucks \(i, i = 1\), hire trucks \(i, i = 2\) in China that can operate inside China, and/or hire trucks \(i, i = 3\) in Hong Kong that can operate both in Hong Kong and China. These trucks, according to the route and schedule plan, may choose route \(r, r \in R = \{1, 2, 3\}\). For cost effectiveness, the
route and schedule plan involves six working days, \( t, t \in T \), in which the decision-maker determines the daily volume of products delivered by various trucks to fulfill sales demand in Hong Kong.

4.1. Mathematical formulation

The goal programming model for a cross-border logistics problem is given as follows.

\[
\text{LEXMIN } \{d_f^+, d_c^+, d_h^+\} \tag{5}
\]

subject to

Goal constraints:

\[
\sum_{i=1}^{T} D_i^+ + d_f^+ - d_f^- = b_f \tag{6}
\]

\[
\sum_{i=1}^{T} \sum_{r=2}^{3} g_i y_i^r + \sum_{i=1}^{T} (g_3 w_i^1 + g_3 z_i^3) + \left( h_{DG} \sum_{r=1}^{T} V_{DG}^r + h_{SZ} \sum_{r=1}^{T} V_{SZ}^r + h_{HK} \sum_{r=1}^{T} V_{HK}^r \right) + ac \sum_{i=1}^{T} e_i^+ + d_i^- - d_i^+ = b_c \tag{7}
\]

\[
\sum_{i=1}^{T} z_i^3 + d_i^- - d_i^+ = b_h \tag{8}
\]

System constraints:

\[
x_i^1 \leq q_1 w_i^1, \quad t = 1, 2, \ldots, T \tag{9}
\]

\[
x_i^2 \leq q_3 y_i^2, \quad t = 1, 2, \ldots, T \tag{10}
\]

\[
x_i^3 \leq q_3 z_i^3 + q_3 z_i^3, \quad t = 1, 2, \ldots, T \tag{11}
\]

\[
S_i + V_{DG}^r = V_{DG}^r + x_i^1 + x_i^3, \quad t = 1, 2, \ldots, T \tag{12}
\]

\[
V_{SZ}^r + x_i^1 = V_{SZ}^r + x_i^3, \quad t = 1, 2, \ldots, T \tag{13}
\]

\[
V_{HK}^r + x_i^2 + x_i^3 = V_{HK}^r + D_i^+, \quad t = 1, 2, \ldots, T \tag{14}
\]

\[
S_i \leq M, \quad t = 1, 2, \ldots, T \tag{15}
\]

\[
D_{\text{min}}^f \leq D_i^f \leq D_{\text{max}}^f, \quad t = 1, 2, \ldots, T \tag{16}
\]

\[
u_i^3 = x_i^3, \quad t = 1, 2, \ldots, T \tag{17}
\]

\[
u_i^3 + q_3 z_i^3 \geq x_i^3, \quad t = 1, 2, \ldots, T \tag{18}
\]

\[
y_i^3 + y_i^3 - FS = e_i^-, \quad t = 1, 2, \ldots, T \tag{19}
\]

\[
\sum_{r=2}^{3} t_r y_i^r \leq WT, \quad t = 1, 2, \ldots, T \tag{20}
\]

\[
w_i^1, y_i^1, z_i^3, x_i^1, u_i^3, S_i, D_i^f, V_{DG}^r, V_{SZ}^r, V_{HK}^r, e_i^- \text{ are integer}, \quad r = 1, 2, 3, \quad t = 1, 2, \ldots, T \tag{21}
\]

All decision variables \( \geq 0 \) \tag{22}

In the mathematical modeling of cross-border logistics problem, objective functions are described as goal constraints. The purpose of optimization is to minimize the deviations from these goals by considering highly prioritized goals first. Eq. (5) represents the lexicographical order of deviational variables to be minimized.
Eq. (6) represents the ‘market fulfillment goal’ constraints to ensure that the total volume of products transported to Hong Kong can fulfill the market demand as far as possible. Eq. (7) represents the ‘total cost goal’ constraints to ensure that the total expenditure is as small as possible. The first term in Eq. (7) represents the transportation cost associated with transportation of products by private trucks on Routes 2 and 3; the second term represents the hiring cost associated with hiring a China truck to deliver products from Dongguan to Shenzhen (Route 1) and hiring a Hong Kong truck to deliver products directly from Dongguan to Hong Kong (Route 3); the third term represents the inventory cost associated with storing products in Dongguan, Shenzhen and Hong Kong warehouses; and the final term represents the allowance given to drivers who make more than one cross-border route trip. Eq. (8) represents the ‘hiring Hong Kong truck goal’ constraints to ensure that the number of Hong Kong trucks hired achieves an expected target value because the availability of Hong Kong trucks is subject to the terms of the leasing contract between the manufacturing company and the leasing firm. Eqs. (9)–(11) are capacity equations and assure that, for every route, the loading volume of products cannot exceed trucks’ capacity. Eq. (9) ensures that the volume of products transported by China truck cannot exceed the capacity of total China trucks which are hired to use Route 1. Eq. (10) ensures that the volume of products transshipped by private truck cannot exceed the capacity of total private trucks which are assigned to use Route 2. Eq. (11) ensures that the volume of products transported by private trucks and Hong Kong trucks cannot exceed the capacity of total private trucks and Hong Kong trucks which are assigned to use Route 3. Eq. (12) is a supply equation which ensures that, for a certain day $t$, the total volume of products supplied from the factory and currently stored in the Dongguan warehouse is equal to the total volume of products transported to Shenzhen and Hong Kong and stored in the Dongguan warehouse. Eq. (13) is transshipment equation which ensures that, for a certain day $t$, the total volume of products transported from Dongguan and currently stored in the Shenzhen warehouse is equal to the volume of products transported to Hong Kong and stored in the Shenzhen warehouse. Eq. (14) is demand equation which ensures that, for a certain day $t$, the total volume of products received from Dongguan and Shenzhen and currently stored in the Hong Kong warehouse is equal to the total volume of products sold to the market and stored in the Hong Kong warehouse. Eq. (15) ensures that the total volume of products delivered at period $t$ cannot exceed the maximum amount of manufactured products produced in the factory in Dongguan. Eq. (16) sets the upper and lower limits for the market demand. Eqs. (17 and 18) determine the number of products transported by private trucks using Routes 2 and 3. Eq. (19) is an extra trips equation and determines the number of round-trips over 1 for each truck. Eq. (20) is a time equation and ensures that the working hours for the private truck’s drivers cannot exceed their maximum working hours. Eq. (21) ensures integrality. Eq. (22) ensures that all decision variables are non-negative.

5. Computational results

Under the company’s current logistics strategy, three private trucks are used to deliver the products using Route 2 (SZ–HK) and Route 3 (DG–HK). The transportation costs incurred for a private truck using Routes 2 and 3 and the hiring costs incurred for the Hong Kong and China trucks using Routes 3 and 1 are shown in Table 1. The trucks’ capacity and travel time are also shown in Table 1. Experience suggests it takes approximately 5 and 8 h to make a round-trip on Routes 2 and 3 by private truck, respectively. Since, there is a maximum of 10 working hours in each day, a driver can only make two round-trips on Route 2 and one round-trip on Route 3 daily. The allowance for every extra cross-border round trip is $70. The inventory costs for the Dongguan, Shenzhen and Hong Kong warehouses are $0.1, $0.3 and $0.67, respectively.

<table>
<thead>
<tr>
<th>Type</th>
<th>Route used</th>
<th>Transportation cost</th>
<th>Hiring cost</th>
<th>Allowance</th>
<th>Travel time</th>
<th>Capacity (U)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Private</td>
<td>2</td>
<td>$2.18</td>
<td>–</td>
<td>$70</td>
<td>5 h</td>
<td>250</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>$3.18</td>
<td>–</td>
<td>$70</td>
<td>8 h</td>
<td>250</td>
</tr>
<tr>
<td>China</td>
<td>1</td>
<td>–</td>
<td>$350</td>
<td>–</td>
<td>–</td>
<td>250</td>
</tr>
<tr>
<td>HK</td>
<td>3</td>
<td>–</td>
<td>–</td>
<td>$1800</td>
<td>–</td>
<td>450</td>
</tr>
</tbody>
</table>
In the following, the managerial plan for six working days is considered. The maximum forecast demand (high scenario) and minimum known sales (low scenario) are shown in Table 2.

The present logistics strategy that the company adopts is to assign all private trucks to Route 2 in order that more products can be delivered (maximum $2 \times 3 = 500$ U a day by one private truck), and hiring six China trucks to transport the products from the factory to Shenzhen using Route 1. For each trip, the private truck will load a maximal volume of products (250 U). Excess products will be stored in the Hong Kong warehouse. The maximum volume of products that can be handled by the three private trucks is only 1500. Hence, Hong Kong trucks will be hired to deliver the remaining volume of products directly from Dongguan to Hong Kong. The solution under this strategy is given in Table 3.

It can be seen that under the present strategy, the total costs incurred for low scenario and high scenario are $38,260 and $57,358, respectively. Not surprisingly, the three private trucks would use Route 2 rather than Route 3 and, on average, two and three Hong Kong trucks are hired in the low and high scenarios, respectively.

In the goal programming formulation, it was not too difficult to state the target value because the ideal solutions were known a priori by optimizing each objective individually. The ideal solutions are shown in Table 4. After reviewing these ideal solutions and past experience, company’s management came up with the target values as shown in Table 5. The target value of ‘market fulfillment goal’, $b_{mf}$, is $12,000; the target value of ‘total cost goal’, $b_c$, is $35,200; and the target value of ‘hiring Hong Kong truck’ goal, $b_h$, is 6. After consulting the company’s management, the deviation variables to be minimized are prioritized as follows: first $d_{h}^{+}$, second $d_{c}^{+}$, and third $d_{f}^{-}$.

Using the data presented, the linear goal programming model was formulated as in Section 3, and the optimal solution can be easily obtained using the simplex method. Many other packages such as LINDO (linear interactive and discrete optimization) can also solve the problem efficiently (Evans, 1993). The results from the proposed model are shown in Table 6. The highest-priority goal is to minimize the overachievement of hiring

### Table 2
Three sets of demand data for six working days

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
<th>Day 4</th>
<th>Day 5</th>
<th>Day 6</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low ($D_{\text{min}}$)</td>
<td>1000</td>
<td>1200</td>
<td>2000</td>
<td>1700</td>
<td>1400</td>
<td>2300</td>
<td>9600</td>
</tr>
<tr>
<td>High ($D_{\text{max}}$)</td>
<td>1800</td>
<td>2000</td>
<td>2800</td>
<td>2500</td>
<td>2200</td>
<td>3100</td>
<td>14,400</td>
</tr>
</tbody>
</table>

### Table 3
Solution of present strategy

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Transportation costs</th>
<th>Hiring costs</th>
<th>Inventory costs</th>
<th>Allowance</th>
<th>Total costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>15,942</td>
<td>19,200</td>
<td>2278</td>
<td>840</td>
<td>38,260</td>
</tr>
<tr>
<td>High</td>
<td>19,620</td>
<td>34,200</td>
<td>2278</td>
<td>1260</td>
<td>57,358</td>
</tr>
</tbody>
</table>

- Average cost = total cost/total demand.
- Number of China trucks using Route 1.
- Number of private trucks using Route 2.
- Number of private trucks using Route 3.
- Number of HK trucks using Route 3.

### Table 4
Ideal solutions

<table>
<thead>
<tr>
<th>Market fulfillment (U)</th>
<th>Total costs ($)</th>
<th>Hiring HK-truck (vehicle)</th>
</tr>
</thead>
<tbody>
<tr>
<td>14,400</td>
<td>35,025</td>
<td>2</td>
</tr>
</tbody>
</table>
The positive deviation variable, $d^+$, is 0. The goal for hiring Hong Kong trucks has been achieved. The second-priority goal is to minimize the overachievement of total costs. The positive deviation variable, $d^+$, is 276. This shows that total cost is over-satisfied. The total cost including transportation cost, hiring cost, inventory cost and allowance is $35,476. Finally, the remaining priority goal is to minimize the underachievement of market fulfillment. The negative deviation variable, $d^-$, is 2400. This means that the realized logistics plan does not fully meet the marketing goal. The total volume of products needed to fulfill the market demand is 9600 U, which is a low scenario case. The average cost for each product is $3.70.

Under the current result, it is observed that the total volume of products needed to fulfill market demand is under-satisfied. It is reasonable to test when the ‘market fulfillment goal’ is the second-priority, whereas the ‘total cost goal’ is the lowest priority (Run 2). As can be seen in Table 6, the results in Run 2 show that the market fulfillment is increased by 22% (11,700 U), while increasing the total costs by 24% ($44,280). Six Hong Kong trucks are hired in both runs because ‘hiring Hong Kong truck goal’ is the highest priority in Runs 1 and 2. Although more products are transported, the average cost for each product is slightly higher than that in Run 1 ($3.78).

As can be seen, Runs 1 and 2 have the same set of target values but different priorities. It is of interest to test different sets of target values keeping the same priority structure for goals. In Run 3, the target value of ‘market fulfillment goal’, $b_f$, is $13,000, the target value of ‘total cost goal’, $b_c$, is $35,200, and the target value of ‘hiring Hong Kong truck goal’, $b_h$, is 12, and the priority structure of goals is the same as in Run 1. The results show that the number of Hong Kong trucks required in Run 3 is 11, which is less than the target value. Moreover, the ‘total cost goal’ is achieved. However, the total volume of products needed to fulfill the market is 9655 U. The average cost for each product in this run is $3.66, which is the smallest cost in all runs.

In order to increase the market fulfillment, the ‘market fulfillment goal’ is the highest priority, whilst the ‘total cost goal’ is the lowest priority (Run 4). The results show that the total volume of products needed to fulfill the market is 13,000 U, the number of Hong Kong trucks hired is 12 and the total cost incurred is $49,278. Finally, the average cost for each product in Run 4 is $3.79.

### Conclusions

In this paper, a goal programming model is proposed to deal with a cross-border logistics problem in Hong Kong in which three major objectives with target values are optimized hierarchically. The three objectives are the maximization of market fulfillment, the minimization of total costs, and the minimization of the number of Hong Kong trucks hired. The model can effectively find an optimal transportation strategy in terms of optimal
delivery routes and optimal vehicle fleet composition. It is also able to control inventory levels in the Dongguan, Shenzhen and Hong Kong warehouses. A real case in an existing Hong Kong-based manufacturing company is studied in this paper. Some useful findings are observed. The results of the runs illustrate the flexibility and robustness of the model so that management can estimate numerous scenarios regarding various strategic assumptions by changing priority rankings.

It is believed that logistics problems have increased with the implementation of China’s open-door policy and economic reforms in Hong Kong. It is high time that supply chain management was developed and more appropriate logistics tools studied to meet changing requirements. The proposed optimization model serves as a basic tool uniquely adapted to cross-border transportation management problems. This paper illustrates the effectiveness and efficiency of the proposed model. However, there is still much room for improvement and investigation for the proposed model with regard to its application to real-world situations. Real data from other logistics companies can be used to validate the model and to analyze its sensitivity to changes in transportation management strategies. It should be noted that the computation and analysis of the model under different scenarios would lead to different outcomes.

All in all, the computerized cross-border logistics problem for a global supply chain will be a critical part of the company’s management system. It is expected that the proposed model will bring about a significant improvement in the company’s global supply chain management in the future.

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References