Case Study on Optimal Routing in Logistics Network by Priority-based Genetic Algorithm

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Keywords: Logistics network design, Genetic algorithm, Fixed-charged Transportation Problem

The definition of logistics adopted by the Council of Logistics Management is "the process of planning, implementing, and controlling the efficient, effective flow and storage of goods, services, and related information from point of origin to point of consumption for the purpose of conforming to customer requirements". Recently, the research on logistics caught more and more attention, and numerous theoretical models have been developed.

However, most of the problems are much more practically intricate than that in theory. Since logistics includes almost all of the activities involved in securing, the right type of material, in the right quantity, to the right locations, at the right time, and at the right cost, also delivered with the right tailored services required by the buyer organization. It needs the expertises and experiences in business, management science, mathematics, information science and other techoniques for different industries to overcome kinds of difficulties and to succeed in logistical practices for that reason. Due to the diversity and complexity of the practical problems, the existing models are usually not very satisfying to find the solutions efficiently and conveniently.

In the domain of logistics, the transportation problem (TP) is a well-known basic network problem. In general it is concerned with distributing commodities from the group of sources to the group of destinations, in such a way as to minize the total distribution cost. In practices, fixed cost, independent of the amount transported, is very common in TP. Involving the fixed cost, TP converts to fixed charged transportation problem (fcTP). Hultberg and Cardoso had proved that an equivalent formulation for a special case of fcTP is NP-hard. An optimal solution may occur at an extreme point of the feasible region is a local minimum. Because of the complexity involved in examining and escaping from many local minima of objective functions, it requires excessive computational effort to solve fcTP, and the existing analytical algorithms for solving fcTPs are useful only for small problems.

Earlier attempts have been made to solve this problem consisted of finding an approximate solution. Balinski observed that there exists an optimal solution to the relaxed version of fcTP formed by ignoring the integer restriction, i.e. the value of the fcTP follows closely the value of its corresponding reduced TP (rTP). Other well-known heuristic approaches are the ones by Cooper and Drebos, and Diaby, while some others have offered techniques based on ranking the extreme points. Sun et al. proposed a Tabu search method. Gray has attempted to provide an exact solution to this problem by decomposing it into a master integer program and a series of transportation sub-programs. Whereas Palekar et al. attempted to provide exact algorithms based on the branch-and-bound method for the solutions of small, fixed-charge problems.

Genetic algorithm (GA) is a guided random search methods where elements (called population) are randomly combined until some termination condition is achieved. Ever since GA was introduced by Holland to tackle linear and nonlinear optimization problems, it has emerged as one of the most efficient stochastic solution search procedures for solving various network design problems in supply chains and other fields. Gen et al. have applied spanning tree based GA to TP and fcTP successfully. In this paper, we consider the real-world case of ABC Co., Ltd. (ABC hereafter) as fcTP and solve it by using priority-based genetic algorithm (pGA) approach, sporting excellent ability to get out of local minima.

In this paper we consider a real world case of ABC Co., Ltd., as an extension of TP and fcTP corresponding to the different condition seperately. In this case, ABC hope to reduce its logistics cost in one of two alternative ways. One is to continue its old contract with the third party logistic provider (3PLs) just rearranging its monthly transportation plan. The other is to sign a new contract to adjust the transprotation cost involving a fixed cost in one of two alternative ways. One is to continue its old contract with the third party logistic provider (3PLs) just rearranging its monthly transportation plan. The other is to sign a new contract to adjust the transprotation cost involving a fixed cost in one of two alternative ways. One is to continue its old contract with the third party logistic provider (3PLs) just rearranging its monthly transportation plan. The other is to sign a new contract to adjust the transprotation cost involving a fixed cost. In order to make appreciate decision, we formulate the two subproblem using LP model and mixed integer programming (MIP) model correspondingly.

In order to lighten the computational burden and to increase the accuracy of solutions we propose a priority-based GA with two-stage path decoding method. We apply proposed pGA approach to this case and some other larger scaled test problems to prove that it can cansolve both TP and fcTP with higher speed and more ideal accuracy compared with existing software (LINDO and CPLEX).
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Recently, research on logistics caught more and more attention. One of the important issues on logistics system is to find optimal delivery routes with the least cost for products delivery. Numerous models have been developed for that reason. However, due to the diversity and complexity of practical problem, the existing models are usually not very satisfying to find the solution efficiently and convincingly.

In this paper, we treat a real-world logistics case with a company named ABC Co. Ltd., in Kitakyusyu Japan. Firstly, based on the natures of this conveyance routing problem, as an extension of transportation problem (TP) and fixed charge transportation problem (fcTP) we formulate the problem as a minimum cost flow (MCF) model. Due to the complexity of fcTP, we proposed a priority-based genetic algorithm (pGA) approach to find the most acceptable solution to this problem. In this pGA approach, a two-stage path decoding method is adopted to develop delivery paths from a chromosome. We also apply the pGA approach to this problem, and compare our results with the current logistics network situation, and calculate the improvement of logistics cost to help the management to make decisions. Finally, in order to check the effectiveness of the proposed method, the results acquired are compared with those come from the two methods/ software, such as LINDO and CPLEX.

Keywords: Logistics network design; Genetic algorithm; Fixed-charged Transportation Problem

1. Introduction

We have never lacked successful cases on logistics obtained mostly in books since 1960’s, especially in the 21st century and beyond. However, in spite that we do not want to be critical our practices in logistics are far from satisfying in any industry. What standing in our way to success in the optimization of logistics system might be ① In stead of logistics the management of many enterprises usually chronically pay much more attention to the sales, research and development (R&D) and other ‘traditional’ aspects in running their business. Although the total logistics cost in 1998 was striking 47 trillion Yen, 9.47% in GDP of Japan(1), logistic management has not received as much attentions as it deserves in many companies. ② Because of the dissimilitude of practical problems, many logistics problems are inextricable with other phenomena, and easily get veiled by other problems and overlooked. It is quite hard to identify the factors which need to be optimized and quantified for that reason. ③ Even in problems that have been treated, the complicated nature of them is very difficult to be expressed using mathematical words. ④ What’s more, up to now there has not existed a method, which is effective to all problems, even to some simple cases. Therefore, many of the problems, which can be formulated as mathematical model, are still irresoluble. The last three are what we are to overcome in this study, and hope to shed light on in logistical practices.

In the domain of logistics, the transportation problem (TP) is a well-known basic network problem. In general it is concerned with distributing commodities from the group of sources to the group of destinations, in such a way as to minimize the total distribution cost. In today’s business world, an elaborately designed logistics network and an optimal transporting strategy are key issues for many companies. Statistically, the transportation cost amounts up to a greater part than the sum of all the other costs in logistics in 2000 Japan(2).

In practice, fixed cost, independent of the amount transported, is quite common in TP. In this paper we consider a real world case as an extension of TP and fixed charged transportation problem (fcTP) corresponding to the different condition separately. Although TP can be solved by linear programming (LP), there exist many kinds of constraints in practical problem, which cannot be handled well by LP in most the cases. Besides, as its complexity increases, LP becomes time costly and asks for a large memory spaces. All of above bar it from wide application to these problems and its further extension. Moreover, Hultberg and Cardoso(3) proved that an equivalent formulation for a special case of fcTP is NP-hard. An optimal solution may occur at an extreme point of the constraint set and, for a non-degenerate fcTP with all positive fixed costs, every extreme point of the feasible region is a local minimum. Because of the complexity involved in examining and escaping from many local minima of objective functions, it requires excessive computational effort to solve fcTP, and the existing analytical algorithms for solving fcTPs such as branch and bound are useful only for small size problems(4). In order to overcome that we develop a priority-based genetic algorithm (pGA) approach with two-stage path decoding process to solve them.

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Earlier attempts have been made to solve this problem consisted of finding an approximate solution. The earliest one was proposed by Balinski(13), who observed that there exists an optimal solution to the relaxed version of fTCP formed by ignoring the integer restriction. Adlakha and Kowalski(19)(20) have made a pioneer attempt on this problem by using concepts of absolute points and the phenomenon discovered by Balinski. However, absolute points may not be present in many problems and the process becomes cumbersome as the problem size increases. Other well-known heuristic approaches are the ones by Cooper and Drebes(8), and Diaby(9), while some others have offered techniques based on ranking the extreme points.(10)(11) Sun et al(12) proposed a Tabu search method. Whereas Palekar et al.(13) attempted to provide exact algorithms based on the branch-and-bound method, Adlakha, V. and K. Kowalski(14) presents a simple algorithm for the solution of small, fixed-charge problems.

Ever since the genetic algorithms (GAs) was introduced by Holland(15) to tackle linear and nonlinear optimization problems, it has emerged as one of the most efficient stochastic solution search procedures for solving various network design problems in supply chains and other fields(16). Gen et al.(17) have applied spanning tree based GA to TP and fTCP successfully. In this paper, we consider the real-world case of ABC Co., Ltd. (ABC) as fTCP and solve it by using priority-based genetic algorithm (pGA) approach, sporting excellent ability to get out of local minima.

The rest of the paper is organized as following: First, we describe the problem and analyze it in detail. After that, in Section 3 we make some assumptions, based on which we formulate the problem by using a new mixed integer programming mathematical model. Then, in Section 4 a pGA approach is proposed for solving this problem. In Section 5, we study the case using the proposed approaches to this case and the improvement is calculated. Furthermore we apply the pGA approach to some larger scaled problems, and compare the results with those of other methods to check its effectiveness. Finally, in Section 6 some conclusive remarks are presented.

2. Problem Description

Our goals are to cut down the transportation cost by rearranging the transportation plan of ABC. A key point of this study or even a key point of dealing with any practical cases is to find out the inefficient factors of operations and quantify it. What’s more, it is sometimes one of the most difficult parts in practical case study.

ABC deals mainly with the business of steelmaking-related industry, domestic and international logistics. In its domestic logistics network, there are 6 distribution centers (DCs) located in cities of Saga, Fukuoka, Okayama, Shiga, Saitama, and Tochigi (we assign the No. 1-6 each corresponding) in Japan, in which the products are deposited, then transported from one DC to another, and waiting to be delivered to customers there. Fig. 1 & 2 shows the current delivery network of ABC and the monthly transportation flow among DCs.

Usually, ABC makes a contract with some third party logistic provider (3PLs), who provide logistics service of trucks, trains etc. when needed. According to the contract, if the 3PLs provides a truck to transport some products from one DC to another, and the truck returns without any load, ABC still needs to pay the truck returns without any load, ABC still needs to pay the additional operation fee as much as 0.3 times of the total normal transportation fee from the terminate DC to the original one(18). For example, the normal transportation price from DC 1 to DC 2 is 2,600 yen per ton. If ABC rents a truck to send 10 tons products from DC 1 to DC 2, and carries back products of the same weight, the total delivery cost is 2*10*2,600 = 52,000 [yen]. If there are no products that needs to be delivered from DC 2 to DC 1, which means the truck should return DC 1 with four wheels empty, the total delivery cost will become 1*10*2,600 + 0.3*10*2,600 = 33,800 [yen]. It is clear that additional fee of 0.3*10*2,600 = 7,800 [yen] is paid to the 3PLs. In this way the actual average transportation cost ABC paid becomes 33,800/10= 3,380 [yen/ton].

This operation of vacant conveyance gives rise to low efficiency to logistics network. The reason why it happens is shown in the example mentioned above, in which the truck that starts from DC 1 to DC 2 with 10 tons products, delivers no products when it returns. The transportation capacity of 10 tons is wasted.

Now to ABC is discussing making a new contract with its 3PLs. With a view to the profit of both sides, when some conveyance starts with a certain DC, some fixed cost is required. The fixed cost is irrespective of the transportation amount but varies with the starting node. As an exchanging condition for that, ABC’s products will be delivered at some preferential price. The inherent fixed cost in transportation converts the case from a simple TP to a fTCP, which is much more difficult to be solved.

Thereby, in this study we want know which is more cost-effective for them, to continue the old contract just rearranging its transportation plan, or to sign a new one?

3. Mathematical Formulation

Another key point in this study is to formulate the problem as a mathematical model. The objective of this problem is to determine the delivery flow with minimum cost in a network to satisfy
supply and demand requirements. The solution to the standard TP or fTCP has a network structure characterized as spanning tree\(^1\), while solution to this problem consists of several delivery paths and some cycles may be included. We consider the case as extensions of TP and fTCP. As Gen et al.\(^1\) proved the minimum cost flow (MCF) model can be applied to both TP and fTCP successfully.

Despite of the diversity in the nature of this problem, we just focus this study on improving the efficiency of the logistics network by optimizing the delivery routing to reduce fixed cost and the cost of the inefficient operations of vacant conveyance. We thus give some assumptions, based on which we formulate this problem.

A1: There is only one kind of products delivered in the network.

A2: The sum of the delivery flow into each DC must equal the sum of the delivery flow out of the DC (flow conservation requirement). This assumption implicates that considering the vacant conveyance, all the conveyance should return where it started.

A3: The operation of vacant conveyance can be taken as dummy delivery flow, the unit cost of which is equal to some certain times of the normal delivery. Assumption 3 and 4 are made to calculate the cost of the vacant conveyance operations, or the cost of unused transportation capacity.

A4: The amount of deliveries to DC \(i\) is not less than the amount of demand \(d_i\), the amount of deliveries from DC \(i\) is not less than the amount of supply \(b_i\).

Then, we define the notations used in this study as following:

**Notations:**

**Indices**

\(i, j, k\) : index of DC \((i, j, k = 1, 2, \ldots, N)\)

**Parameters**

\(c_{ij}\) : delivery cost between DC \(i\) and DC \(j\)

\(f_i\) : fixed cost of conveyance starting with DC \(i\)

\(\beta\) : coefficient of empty conveyance operating cost

\(d_i\) : amount of demand of DC \(i\)

\(b_i\) : amount of supply of DC \(i\)

\(\text{suc}(i)\): set of all successors of DC \(i\)

\(\text{pre}(i)\): set of all predecessors of DC \(i\)

\(N\) : total number of DC (in this study \(N = 6\))

\(E\) : set of nodes

\(V\) : set of arcs

**Decision Variables**

\(x_{ij}\) : delivery amount from DC \(i\) to DC \(j\)

\(y_{ij}\) : dummy delivery flow from DC \(i\) to DC \(j\)

\(z_i\) = \(\begin{cases} 1, \text{if conveyance starts with DC } i \\ 0, \text{otherwise} \end{cases}\)

3.1 Linear Programming Model

We firstly study a case involving no fixed cost. In a MCF model for simple TP, the total delivery cost is usually used as the objective function. In order to measure the vacant conveyance operations, we add one term of cost of dummy delivery flow to the mathematical model. Based on the assumptions mentioned above, we formulate this problem using linear programming (LP) model as follows:

\[
\begin{align*}
\min \quad & c_f = \sum_{i=1}^{N} \sum_{j=1}^{N} (c_{ij}x_{ij} + \beta \cdot c_{ij}y_{ij}) \\
\text{s. t.} \quad & \sum_{j=1}^{N} (x_{ij} + y_{ij}) - \sum_{k=1}^{N} (x_{kj} + y_{kj}) = 0, \forall i \\
& x_{ij} \geq d_i, \forall i \\
& y_{ij} \geq 0, \forall i, j
\end{align*}
\]

3.2 Mixed Integer Programming Model

By introducing a fixed cost, the mathematical model becomes:

\[
\begin{align*}
\min \quad & c_f = \sum_{i=1}^{N} \sum_{j=1}^{N} (c_{ij}x_{ij} + \beta \cdot c_{ij}y_{ij}) + \sum_{i=1}^{N} f_i z_i \\
\text{s. t.} \quad & \sum_{j=1}^{N} (x_{ij} + y_{ij}) - \sum_{k=1}^{N} (x_{kj} + y_{kj}) = 0, \forall i \\
& x_{ij} \geq d_i, \forall i \\
& y_{ij} \geq 0, \forall i, j \\
& z_i = \begin{cases} 1, \text{if } x_{ii} > 0, \forall i \\ 0, \text{otherwise} \end{cases} \\
& x_{ij}, y_{ij} \geq 0, \forall i, j \\
& z_i \in \{0,1\}, \forall i
\end{align*}
\]

A different point of this model from the standard fTCP is that as described in section 2, a fixed cost occurs when conveyance starts off with delivering products, while in standard fTCP model if \(x_{ii} > 0\), a fixed cost occurs. As a result, the total cost is affected not only by the delivery paths but also the starting node. Fox example, the total cost in the path 1→2→1 is different from that of the path 2→1→2 when delivering the same amount of products. Therefore, in this model we use a dummy starting node (node 0) to record the starting node. As specified, constraint (9) makes sure that no dummy flow appears at the dummy starting node. Constraint (10) shows that a fixed cost steps from the point when conveyance starts off node \(i\). Compared with the LP model, this one is significantly harder to solve because of the discontinuity in the
objective function introduced by 0-1 integer decision variables $z_i$, which represents the fixed costs.

4. Genetic Algorithm Approach

GA can be defined as meta-heuristics based on the evolutionary process of natural systems\(^{19}\). Since their inception, they have been applied to numerous optimization problems with greatly acceptable results.

4.1 Representation of the Chromosome

Prior to the application of GA, we need to design suitable chromosomes representing the candidate solutions. We here adopted the priority-based encoding method, which can escape the repair mechanisms in the searching process of GA, developed by Gen and Cheng\(^{16\&17}\). The priority-based encoding method is an indirect approach: encode some guiding information for constructing a path, but not a path itself, in a chromosome. In this method, a gene contains two kinds of information: the locus, the position of a gene located within the structure of a chromosome, and the allele, the value taken by the gene. The position of a gene (ID of locus) is also used to represent node ID in a graph and its value is used to represent the priority of the node for constructing a path among candidates. When forming transportation paths among DCs, only one arc with the highest priority within a chromosome is selected at each time. In this way, a path can be uniquely determined from this encoding. Fig. 3 shows the representation of the delivery path among 6 DCs, and we can get an alternative solution to the problem from this chromosome.

4.2 Initialization

In the initial population, we generate a population size of chromosomes. Each chromosome in the initial population is a candidate solution to the problem. We use the complete random method to generate the initial population.

**procedure 1:** Initialization by priority-based encoding

**input:** number of DC $N$

**output:** the chromosome $v_k$

**step 0:** for $i=1$ to $N$

$v_k[i] \leftarrow i$;

**step 1:** for $i=1$ to $[N/2]$

repeat

$j \leftarrow \text{random}(1,N)$;

$l \leftarrow \text{random}(1,N)$;

if $i \neq j$ then

swap $(v_k[j], v_k[l])$;

end if

end repeat

**step 2:** output the chromosome $v_k$;

Fig. 3. Sample representation of chromosome by priority-based encoding

<table>
<thead>
<tr>
<th>node ID ($i$)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>priority $v_k(i)$</td>
<td>6</td>
<td>5</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>

**Table 1.** Data of sample chromosome

<table>
<thead>
<tr>
<th>#</th>
<th>Path</th>
<th>Flow on the path</th>
<th>Dummy flow on the path</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>[1-5-4-3-1]</td>
<td>11.8</td>
<td>11.8</td>
</tr>
<tr>
<td>2</td>
<td>[1-5-4-1]</td>
<td>81.5</td>
<td>81.5</td>
</tr>
<tr>
<td>3</td>
<td>[1-5-1]</td>
<td>995.9</td>
<td>995.9</td>
</tr>
<tr>
<td>4</td>
<td>[1-4-1]</td>
<td>150.8</td>
<td>150.8</td>
</tr>
<tr>
<td>5</td>
<td>[2-1-2]</td>
<td>251.7</td>
<td>2517</td>
</tr>
<tr>
<td>6</td>
<td>[6-1-6]</td>
<td>73.1</td>
<td>73.1</td>
</tr>
<tr>
<td>7</td>
<td>[6-4-6]</td>
<td>717.9</td>
<td>717.9</td>
</tr>
<tr>
<td>8</td>
<td>[6-3-6]</td>
<td>697.1</td>
<td>697.1</td>
</tr>
</tbody>
</table>

4.3 Two-stage Path decoding Process

Decoding is the process of mapping from chromosomes to solutions. In this problem, we need to adopt a two-stage path decoding method, as described in procedure 2 and procedure 3. In the first stage, we obtain one path based on the priority from the chromosome corresponding to the constraints of this problem. Firstly, select a node, node $i$ for instance, with the highest priority and non-zero supply from node set $S_i$, and start a path with it, then moves it into another node set $P_i$. Next selects the node $j$ with the highest priority and non-zero demand from $S_j$, and move it into $P_j$ as done previously. Then we add arc $(i, j)$ to the path. After that if the supply of node $j$ is more than zero, set it as a new starting node, go on to search for another terminal node by repeating the steps above till no new terminal can be found. If the supply of node $j$ is zero, stop searching and return to the original node. In the second stage, repeat the processes in the first stage, until all constraints are satisfied to get all the transportation paths. By using this two-stage path decoding method we can obtain the data of network flow described in Table 1 from the chromosome shown in Fig. 3.

**procedure 2:** One-path Growth

**input:** problem data, chromosome $v_k$

**output:** path $P_i$, flow $f_i$, dummy flow $f_d$

**step 0:** select node $i$ as start node,

if $i$ has the highest priority and $b_i > 0$.

**step 1:** if $S_i = \emptyset$, go to step 3;

else continue.

**step 2:** select node $j$ as the destination node from $S_i$ with the highest priority and $d_j > 0$;

$P_i = P_i \cup \{ l \}$;

$S_i = S_i - \{ l \}$;

$i \leftarrow l$;

go back to step 1.

**step 3:** $l$-ID of start node of $P_i$;

$j$-ID of the predecessor of $i$ in $P_i$;

for $i = 1$ to $P_i$ do

tempFlow = $\min\{b_i, d_j\}$;

if tempFlow = 0 then

if tempFlow < $f_i$

$f_i = \text{tempFlow}$

$f_d = 0$

else

$f_i = \text{max}\{b_i, d_j\}$

$f_d = f_d$

$i \leftarrow j$;

$j$-ID of the predecessor of $j$ in $P_i$;

**step 4:** output the complete path $P_i$, flow $f_i$, dummy flow $f_d$;

**procedure 3:** Overall-path Growth

**input:** problem data, chromosome $v_k$

**output:** total delivery flow $x_{i}^k$ and dummy flow $y_{i}^k$

**step 0:** while $\sum_{j \in P_i} x_{ij}^k \leq b_i$ and $\sum_{j \in P_i} x_{ji}^k \leq d_j$

repeat procedure 2;

$x_{ij}^k = x_{ij}^k + f_i$;

$y_{ij}^k = y_{ij}^k + f_d$;

**step 1:** output total flow $x_{i}^k$ and dummy flow $y_{i}^k$ the network;

4.4 Genetic Operators

**Crossover:** Generally, crossover is used as the primary operator and the performance of a genetic algorithm is affected greatly by it. It generates offspring combined...
both parents’ features by exchange the information of the parents. In this study, we adopt Order crossover (OX), which can escape from the complex repairing procedure. The procedure is illustrated in Fig. 4. First, select a substring from parent 1 randomly. Second, produce a proto-child by copying the substring. Third, fill the blank loci of proto-child with the unsigned alleles from parent 2 sequentially. Then, we can get an offspring ə.

**Mutation:** Used as a background operator, mutation creates new individual to increase the variability of population by modifying one or more of the gene values of existing individuals. We use swap mutation operation, which select two positions of an individual randomly, and change the alleles they contain.

### 4.5 Evaluation and Selection

**Evaluation:** After decoding, we can get a candidate solution. The goodness of the chromosome should be measured, with respect to the objective function. The reciprocal of total delivery cost is used for evaluation.

**Selection:** Selection provides driving mechanism for better individuals to survive. It means the higher fitness value an individual has, the greater its chance to survive to next generation. We use roulette wheel selection in this study.

### 5. Case study

We apply the proposed pGA approach to this case to investigate its effectiveness. The original data are given in Table 2-5, including the transportation amount in current practical logistics network, unit transportation cost, fixed cost and favorable unit transportation cost including the transportation amount in current practical logistics network.

In the second step, pGA is used to find the solution to the MIP model in the case involving a fixed charge. As the reciprocal of total delivery cost is used for evaluation, we can find that the efficiency of the logistics is improved more as it costs less by 19.07%. Over 6 million yen can be saved. Another phenomenon is that the flows with small quantity become "extinct", which implicates that long path delivery with large quantity is more economic.

Additionally, in order to investigate the effectiveness of the proposed pGA approach, we consider some other problems of the same like with larger scale. The comparison on computational results with CPLEX is shown in Table 9. For small-scale problems, pGA can get the same results as CPLEX does with much less time. For the problem with 20 and more input nodes, the CPLEX costs over 1 hour, while the computation time of pGA stays still over 1 hour, while the computation time of pGA stays still.

**Table 2.** Transportation amount between each DC in current practical logistics network (ton)

<table>
<thead>
<tr>
<th>DC</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0</td>
<td>0.0</td>
<td>563.2</td>
<td>500.9</td>
<td>259.3</td>
<td>68.8</td>
</tr>
<tr>
<td>2</td>
<td>251.7</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>3</td>
<td>21.1</td>
<td>0.0</td>
<td>0.0</td>
<td>83.0</td>
<td>50.2</td>
<td>28.7</td>
</tr>
<tr>
<td>4</td>
<td>25.8</td>
<td>0.0</td>
<td>20.1</td>
<td>0.0</td>
<td>157.4</td>
<td>47.7</td>
</tr>
<tr>
<td>5</td>
<td>36.7</td>
<td>0.0</td>
<td>26.6</td>
<td>87.4</td>
<td>0.0</td>
<td>84.4</td>
</tr>
<tr>
<td>6</td>
<td>141.9</td>
<td>0.0</td>
<td>136.2</td>
<td>419.9</td>
<td>950.8</td>
<td>0.0</td>
</tr>
</tbody>
</table>

**Table 3.** Unit transportation cost between each DC in current practical logistics network (yen/ton)

<table>
<thead>
<tr>
<th>DC</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>- 2600</td>
<td>6400</td>
<td>8500</td>
<td>15600</td>
<td>16300</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>- 9200</td>
<td>7500</td>
<td>14600</td>
<td>15600</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>- 6000</td>
<td>13200</td>
<td>10700</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>- 9200</td>
<td>9100</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>- 5800</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 4.** Fixed cost for conveyance

<table>
<thead>
<tr>
<th>DC</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2340</td>
<td>5200</td>
<td>7600</td>
<td>11040</td>
<td>14670</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>7280</td>
<td>6870</td>
<td>13140</td>
<td>14040</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>4900</td>
<td>11880</td>
<td>9630</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>8200</td>
<td>8050</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>5000</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
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<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 5.** Favorable unit transportation cost

<table>
<thead>
<tr>
<th>DC</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0</td>
<td>542.9</td>
<td>718.2</td>
<td>0.0</td>
<td>36.7</td>
<td>68.8</td>
</tr>
<tr>
<td>2</td>
<td>324.8</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>3</td>
<td>21.1</td>
<td>0.0</td>
<td>0.0</td>
<td>478.1</td>
<td>5.0</td>
<td>2.8</td>
</tr>
<tr>
<td>4</td>
<td>25.8</td>
<td>0.0</td>
<td>0.0</td>
<td>157.9</td>
<td>47.7</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>36.7</td>
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<td>50.0</td>
<td>109.0</td>
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</tr>
<tr>
<td>6</td>
<td>68.8</td>
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<td>2.8</td>
<td>403.0</td>
<td>1173.6</td>
<td>0.0</td>
</tr>
</tbody>
</table>

**Table 6.** Delivery amounts between each DC in logistics network optimized by pGA for LP model (ton)

<table>
<thead>
<tr>
<th>DC</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0</td>
<td>0.0</td>
<td>679.8</td>
<td>712.6</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>2</td>
<td>0.0</td>
<td>0.0</td>
<td>251.7</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>3</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>37.2</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>4</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>66.3</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>5</td>
<td>74.39</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>160.7</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>402.8</td>
<td>0.0</td>
<td>52.19</td>
<td>1193.8</td>
<td>0.0</td>
<td></td>
</tr>
</tbody>
</table>

**Table 7.** Delivery amount between each DC in logistics network optimized by pGA (ton) for MIP model

<table>
<thead>
<tr>
<th>DC</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0</td>
<td>0.0</td>
<td>679.8</td>
<td>712.6</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>2</td>
<td>0.0</td>
<td>0.0</td>
<td>251.7</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>3</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>37.2</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>4</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>66.3</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>5</td>
<td>74.39</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>160.7</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>402.8</td>
<td>0.0</td>
<td>52.19</td>
<td>1193.8</td>
<td>0.0</td>
<td></td>
</tr>
</tbody>
</table>

**Table 8.** Comparison of results for case studied

<table>
<thead>
<tr>
<th>Total logistics cost</th>
<th>Total logistics cost optimized by LP and pGA</th>
<th>Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>37,040,120</td>
<td>31,928,012</td>
<td>16.23%</td>
</tr>
<tr>
<td>30,382,341</td>
<td>38,284,120</td>
<td>19.07%</td>
</tr>
</tbody>
</table>
In this step and the previous one, parameters are set as following: popSize = 50, maxGen = 1000, pc = 0.5 and pm = 0.6. All the applications are implemented in Java language and run on PC with Intel Pentium-4 2.4G Hz CPU.

6. Conclusion

In this study, we treat the real-world case of ABC Co. Ltd. In Kitakyusyu Japan. This case is related to a logistics network with DCs, in which products are delivered. The existence of a fixed cost for using conveyance and the operations of vacant conveyance causes low efficiency with current practice. The objective of this study is to minimize total logistics cost in the network by optimizing transportation routing. To obtain the ideal delivery routing, we consider the case as an extension of TP and fcTP corresponding to different conditions separately, and formulate them as two MCF models by using LP and MIP model correspondingly. We then propose a pGA approach with two-stage path decoding method to solve this problem. As a result, comparing to the result of LP method, we obtained an optimal solution to the first model-LP model by using the proposed approach. Unlike LINDO, the proposed pGA approach is also powerful to the second model-MIP model. From the results of both models, we can draw a conclusion that it is advantageous for ABC to make a new contract involving in the fixed cost, and monthly maximum 19.07% of the total cost (i.e. over 6 million yen) could be saved. Finally, we try to apply the pGA approach on some larger scaled problems, compared with CPLEX, pGA approach is proved to be effective and efficient to them.

Acknowledgements


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References


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