CLOSED-LOOP SUPPLY CHAIN NETWORK OPTIMIZATION FOR HONG KONG CARTRIDGE RECYCLING INDUSTRY

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ABSTRACT
Environmental issues caused by improper abandoned cartridges increase obviously nowadays. Producers are perceived to be responsible for recycling products they have produced. In Hong Kong, due to abundant quantity of used cartridges, producers have to optimize their forward and reverse networks to maximize the recycling rate and their profits. In this paper, a comprehensive Closed-Loop Supply Chain (CLSC) model is established. This model contains eight partners in CLSC and describes the cartridge recycling situation in Hong Kong. In the literatures, many CLSC models were established and studied, but few of them analyzed the delivery activity for different kinds of materials extracted from used products, and also few papers studied the situation that used products are classified. In this model, delivery activities of different materials are considered and the used cartridges are classified into good
quality ones and poor quality ones. Producers will have different methods to process them. Furthermore, this model structures a simplified VRP to express the real situation that collection points onsite pick up used cartridges from customers. This problem is formulated into a linear programming model. Since both delivery routes and delivery quantities all over the CLSC network have to be optimized, the problem, which is NP-hard, becomes complex to calculate. To deal with it, a modified two-stage Genetic Algorithm (GA) is implemented. The two-stage encoding in this GA reinforces the genetic searching ability in solving this kind of problem. This algorithm optimizes the CLSC network and the results show a near optimal solution which provide producers the maximum profits.

Keyword: Closed-loop supply chain, Genetic algorithm, E-waste recycling, Reverse distribution

INTRODUCTION

In recent years, economy with electronic products gains a prosperity development, and the life cycle of electronic devices turn out to be shorter and shorter, making electronic waste the fastest growing part among garbage stream. The environmental and health risks of Waste Electric and Electronic Equipment (WEEE) become high, among which, used cartridges play an important role. Most of the used cartridges are improperly disposed to landfill or incineration. A toner cartridge tossed into landfill will take 450 years or more to decompose and the toxic materials in it such as lead and mercury will leak out to cause a great damage to the earth. Although a recycled toner cartridge can save nearly 1 kg of raw materials like plastic and metal to reduce the environment burden efficiently, it turned out that used cartridges at the end of their lifespan still been disposed improperly and the quantity of them has grown exponentially. Every year, about 1.2 trillion inkjet cartridges are used globally, but less than 30% of them being recycled. This terrible situation has been last for many years until the mandatory legislation of Extended Producer Responsibility (EPR) gain more and more popular around the world. Producers are perceived to be responsible for the recycling of products they have produced and sold. Due to the expensive cost of third party recycling companies, many cartridge producers choose to establish their own recycling factories, and producers also have to design product recycling networks along with product delivery networks according to specific customer regions. In Hong Kong, many companies start recycling of ink cartridge and toner cartridge several years ago, for example, Epson HK set up some collection points and collected used cartridges from 2007, Canon HK launched the recycling program of ink cartridge from 2009. Because of the abundant quantity of used products and the pressure of
environment, producers have to optimize their forward and reverse networks to maximize the recycling rate and also maximize their profits.

In recent years, many studies address the issue of WEEE recycling. Tsai and Hung (2009) focused on the treatment and recycling process of the system, they proposed a two-stage decision framework which include treatment stage and recycling stage. Although suppliers selection was added in this framework, it is not the optimization of the whole Closed-Loop Supply Chain (CLSC) network. Veenstra et al. (2010) suggested a Markov chain model analyzing the flow of WEEE through the reverse chain. Gamberini et al. (2010) established a transportation network in Italy which contained vehicle routing problem. An integrated solution approach was used to solve it. Mar-Ortiz et al. (2011) optimized the design of reverse chain for the collection of WEEE. In this network, a mixed integer linear programming was formulated to address the facility location problem, a new integer programming was established to solve the vehicle routing problem and a simulation study is implemented to assess the performance of the recovery system. Dwivedy and Mittal (2012) investigated into the WEEE flows in India and used a Markov chain to model the business sector of WEEE trade, which including the informal recycling of WEEE in developing countries. Alumur et al. (2012) proposed a multi-period reverse logistics network which formulated into a mixed-integer linear programming model. A real case of washing machines in Germany was implemented to justify this model. Wang and Huang (2013) established a two-stage robust programming model to decide the recycling volume and time in a CLSC. From the literature, it can be found that the focus of research about WEEE is the reverse network design and optimization, lacking the research of integrate both forward and reverse network.

In this paper, a comprehensive CLSC model based on the real situation of cartridge recycling in Hong Kong is established. It integrates both forward chain of product procedure and reverse chain of product recycling. This proposed model contains eight partners in CLSC and describes the cartridge recycling situation in Hong Kong.

In the literatures, many CLSC models were established and studied. Olugu and Wong (2012) proposed a CLSC performance evaluation system to a company from the automotive industry which reduces the cost of the whole CLSC network prominently. Ozkir and Basligil (2012) addressed a mixed integer linear program model to describe a CLCS network considering three ways of recovery process. Amin and Zhang (2012) established a three-stage multi-objective mixed-integer linear programming model designing the configuration and selection process of CLSC simultaneously.
Although many CLSC models were studied, few of them analyzed the delivery activity for different kinds of materials extracted from used products, and also few papers studied the situation that collected used products are classified. In this model, delivery activities of several kinds of materials are considered and the collected used cartridges are classified into two categories: good quality ones and poor quality ones. Producers will have different methods to process them. Furthermore, this model structures a simplified Vehicle Routing Problem (VRP) to express the real situation that collection points onsite pick up used cartridges from customers. This problem is formulated into a linear programming model. Since both delivery routes and delivery quantities all over the CLSC network have to be optimized, the problem, which is NP-hard, becomes complex to calculate. To deal with this complex calculation, a modified two-stage Genetic Algorithm (GA) is implemented. The two-stage encoding in this GA reinforces the genetic searching ability in solving this kind of problem. This algorithm optimizes the CLSC network and the results show a near optimal solution which provide producers the maximum profits.

MODELLING

This model is based on the real case study of ink and toner cartridge delivering and recycling in Hong Kong. The proposed model contains eight partners in the CLSC network: suppliers (S), manufacturers (M), warehouses (W), retailers (R), customers (Cu), collection points (Co), recycling companies (RC) and waste disposal plant (WDP). Figure 1 displays the whole CLSC network of this proposed model.

In this model, the demands of customers are preset. In order to fulfill the demand, manufacturers have two choices, one is to produce brand new products using raw materials, and the other one is to remanufacture the collected used products with good condition/quality. As for the raw materials, manufacturers have two acquisition channels: one is from suppliers and the other is from recycling companies. In the proposed model, it considers that manufacturers purchase several kinds of raw materials from suppliers and recycling companies to produce brand new products, which means multi-products is considered.

In this model, it is assumed that manufactures can make sure that remanufactured products have the same quality as brand new products, and also sale prices in the market are same.

After producing new products and remanufacturing used products as brand new ones, manufacturers deliver the products oversea to their warehouses in Hong Kong. Then, from warehouses, products are transported to retailers, and, finally, the retailers sell them to customers. Since retailers not belong to manufacturers, this part of revenue and cost is excluded from consideration in the CLSC network optimization.
Therefore, the demand of each retailer also has to be preset, and the sum of all the retailers demand must be equal to the sum of all the customer demand.

Customers always discard the used ink and toner cartridge at the end of their lifecycle in the corner. In HK situation, collection points will pick used products up from patron. In each customer area, managers of the cartridge company have to consider the vehicle routing problem of one or more collection points, which will make the CLSC network too complex to solve as whole. For simplicity, it is assumed that collection points will have a round trip in each customer areas to fetch used products. The transportation cost for a round trip is proportional to the quantity of used products collected in this round trip. The unit transportation cost for each used products are preset as a parameter.

No matter which method is used to collect, collection points will pay for the used products to the customer. In this model, it is assumed that the price collection points paid for either good quality used products or poor quality used products are the same. After collection, collection points deliver all the used products to recycling companies.
In the recycling company, all the used products are cleaned and classified according to two categories: good quality used products and poor quality used products. The good quality ones will be packaged and transported to manufacturers. For the poor quality ones, recycling company will disassemble and smash them and extract raw materials through further process. During the whole process, most of the substance can be recycled as raw materials. The remaining parts need to be disposed by the waste disposal plant using method of burn or landfill. The maximal disposal rate is preset in this model. The recycled raw material will finally be delivered to manufacturers for producing new products. The indices, parameters and decision variables are shown as below.

Indices

- \( I_t \) the number of suppliers supplying material \( t \) with \( i=1,2,...,I \)
- \( J \) the number of manufacturers with \( j=1,2,...,J \)
- \( K \) the number of warehouses with \( k=1,2,...,K \)
- \( L \) the number of retailers with \( l=1,2,...,L \)
- \( V \) the number of customers with \( v=1,2,...,V \)
- \( M \) the number of collection points with \( m=1,2,...,M \)
- \( N \) the number of recycling companies with \( n=1,2,...,N \)
- \( T \) the number of raw materials with \( t=1,2,...,T \)

Parameters

- \( c'_i \) capacity of supplier \( i \)
- \( c''_j \) capacity of manufacturer \( j \)
- \( c'''_k \) capacity of warehouse \( k \)
- \( d_l \) demand of retailer \( l \)
- \( d_v \) demand of customer area \( v \)
- \( c_{mc} \) capacity of collection point \( m \)
- \( s_{ij} \) unit cost of transportation of raw material \( t \) from each supplier \( i \) to each manufacturer \( j \)
- \( m_{jk} \) unit cost of transportation from each manufacturer \( j \) to each warehouse \( k \)
- \( w_{kl} \) unit cost of transportation from warehouse \( k \) to retailer \( l \)
- \( cu_{vm} \) unit cost of round trip transportation for collection point \( m \) taking back used products from customer area \( v \)
- \( co_{mn} \) unit cost of transportation from collection point \( m \) to recycling company \( n \)
- \( r_{nj} \) unit cost of transportation of raw material \( t \) from recycling company \( n \) to manufacturer \( j \)
- \( r_{nj0} \) unit cost of transportation of used product with good quality from
recycling company $n$ to manufacturer $j$

$f_j^m$ fixed cost for operating manufacturer $j$

$f_k^w$ fixed cost for operating warehouse $k$

$f_m^c$ fixed cost for operating collection point $m$

$f_p^n$ fixed cost for operating recycling company $n$

$s$ unit sorting cost for the used product

$x_0$ unit producing cost of new products using raw materials

$x_1$ unit processing cost for the used product with good quality

$x_2$ unit processing cost for the used product with poor quality

$x_3$ unit dispose cost for the material which cannot be recycled

$p_1$ the price of new products

$p_2$ unit cost that collection point pay to customers for the used product

$\lambda$ the percentage of good quality used products in all the recycling products

$\eta$ the required quantity of raw material $t$ to produce one new product

$\delta$ the recycled percentage of material $t$ in one used product

$\mu$ the recycling rate of customer area $v$

$\varphi$ the maximal disposal rate

$\varepsilon$ unit weight per used product

Decisions Variables

$q_{ij}^t$ Amount of raw material $t$ shipped from supplier $i$ to manufacturer $j$

$q_{jk}^w$ Amount shipped from manufacturer $j$ to warehouse $k$

$q_{km}^w$ Amount shipped from warehouse $k$ to retailer $l$

$q_{vm}^c$ Amount shipped from customer $v$ to collection point $m$

$q_{nm}^c$ Amount shipped from collection point $m$ to recycling company $n$

$q_{njt}$ Amount of raw material $t$ shipped from recycling company $n$ to manufacturer $j$

$q_{njt}$ Amount of used product with good quality shipped from recycling company $n$ to manufacturer $j$

$q_{nc}^c$ Amount of disposed materials from recycling company $n$

$q_j^m$ Amount of new produced products in manufacturer $j$

$$\alpha_j = \begin{cases} 1 & \text{if production takes place at manufacturer } j \\ 0 & \text{otherwise} \end{cases}$$

$$\beta_k = \begin{cases} 1 & \text{if warehouse } k \text{ is opened} \\ 0 & \text{otherwise} \end{cases}$$

$$\delta_m = \begin{cases} 1 & \text{if collection point } m \text{ is opened} \\ 0 & \text{otherwise} \end{cases}$$
if recycling company \( n \) is opened

\[ \gamma_n = \begin{cases} 
1 & \text{if recycling company } n \text{ is opened} \\
0 & \text{otherwise} 
\end{cases} \]

Objective function:

\[
\text{max} \quad TP = TR - TC
\]  

(1)

\[
TR = p_i \sum_l d_i
\]  

(2)

\[
TC = TC_1 + TC_2 + TC_3
\]  

(3)

\[
TC_1 = \sum_{l} \sum_{j} s_{ij} p_j + \sum_{j} \sum_{k} m_{jk} q_{jk}^n + \sum_{j} w_{ij} q_{ij}^n + \sum_{j} \sum_{v} c_{mv} q_{mv}^n
\]

\[
+ \sum_{v} \sum_{v} c_{mv} q_{mv}^n + \sum_{l} \sum_{j} r_{ij} q_{ij}^n + \sum_{l} \sum_{j} r_{ij} q_{ij0}
\]  

(4)

\[
TC_2 = \sum_{i} f_{i}^{\alpha} \alpha_{i} + \sum_{i} f_{i}^{\beta} \beta_{i} + \sum_{m} f_{m}^{\delta} \delta_{m} + \sum_{n} f_{n}^{\gamma} \gamma_{n}
\]  

(5)

\[
TC_3 = p_3 \sum_{i} \sum_{m} q_{im}^{\omega} + \sum_{i} \sum_{m} q_{im}^{\omega} + x_i \sum_{v} q_{ij}^{n} + x_j (\sum_{m} q_{im}^{\omega} - \sum_{m} q_{ij0}) + x_j \sum_{m} q_{im}^{\omega} + x_u \sum_{j} q_{j}^{\omega}
\]  

(6)

The objective is to maximize the total profit which is the value of total revenue minus total cost as showed in the objective function (1). The total revenue is the revenue of sale the new product which is displayed in function (2). The total cost consists of the total transportation cost, total facility fixed cost and total processing cost as represented by function (3). Equation (4) shows the total transportation cost in the CLSC network, which consists of seven section costs in different stages shown as follow: raw material transportation cost from suppliers to manufacturers, new product transportation cost from manufacturers to warehouses, the cost of new products delivered from warehouses to retailers, and the round trip cost of collection points to fetch the used products from customers, also the delivery cost for collected used products from collection points to recycling companies, the recycled raw material transportation cost from recycling companies to manufacturers and the delivery cost of collected good quality used products from recycling companies to manufacturers. Equation (5) shows the total fixed costs of the manufacturers, warehouses, collection points and recycling companies. Equation (6) displays the sum of used products obtained costs paid by collection points to customers, used products sorting costs in recycling companies, good quality used products processing costs in manufacturers, and poor quality used products processing costs in recycling companies, disposed costs and the costs of newly produced products using raw materials in manufacturers.

Subject to

\[
\sum_{j} q_{ij}^n \leq c_{i}^{\omega}, \quad \forall i
\]  

(7)
\[ \sum q_{ji}^w \leq c_{ji}^w \alpha_j, \quad \forall j \] (8)
\[ \sum q_{ij}^u \leq c_{ij}^u \beta_i, \quad \forall k \] (9)
\[ \sum q_{im}^{co} \leq c_{im}^{co} \delta_m, \quad \forall m \] (10)
\[ \sum q_{im}^{co} \leq c_{im}^{co} \gamma_n, \quad \forall n \] (11)
\[ \sum q_{ji}^w \geq d_j, \quad \forall l \] (12)
\[ d_j, \mu_v = \sum q_{im}^v, \quad \forall v \] (13)
\[ \sum q_{ji}^u = \sum q_{ij}^v, \quad \forall k \] (14)
\[ \sum q_{im}^v = \sum q_{im}^{co}, \quad \forall m \] (15)
\[ \sum q_{ij}^t \leq \delta \sum q_{im}^{co}, \quad \forall n, \forall t \] (16)
\[ \sum q_{ij}^t + \sum q_{ij}^e = q_{jm}^{new}, \quad \forall j, \forall t \] (17)
\[ \sum q_{ij}^t + q_{ij}^e = \sum q_{ij}^m, \quad \forall j \] (18)
\[ \sum q_{ij}^e \leq \delta \sum q_{im}^{co}, \quad \forall n \] (19)
\[ q_{im}^e = \varepsilon \sum_{m} q_{im}^{co} - \varepsilon \sum_{j} q_{ij}^e \sum_{m} (\eta_j \sum_{j} q_{ij}^e) \quad \forall n \] (20)
\[ q_{im}^e \leq \varepsilon \cdot \varphi \cdot (\sum_{m} q_{im}^{co} - \sum_{j} q_{ij}^{co}) \quad \forall n \] (21)
\[ \alpha_j, \beta_i, \delta_m, \gamma_n \in \{0,1\}, \quad \forall j,k,m,n \] (22)
\[ q_{ij}^m, q_{ji}^u, q_{im}^v, q_{im}^{co}, q_{ij}^e, q_{ij}^t, q_{jm}^{new} \in N \cup \{0\} \quad \forall i,j,k,l,m,n,v \] (23)

Constraints (7) and (8) formulate the capacity limitation of suppliers and manufacturers. Constraint (9) represents the capacity limitation of DCs. Constraints (10) and (11) show the capacity limitation in reverse logistics for collection points and recycling companies. Constraint (12) restraints that the retailers' demand must be satisfied, which also means the customer demand must be satisfied. Constraint (13) explains the relationship between customer recovery and recovery rate. Constraints (14) and (15) guarantee the in-flow equal to out-flow in each warehouse and each collection point respectively. Constraint (16) guarantees the output recycled materials don't exceed the maximum value that each recycling company can extract from used products. Constraint (17) shows that for each material in each manufacturer, the sum of the raw material from both suppliers and recycling companies can meet the demand for producing and remanufacturing needed new products. Constraint (18) restricts that for each manufacturer, the quantity of the provided products are the sum of the newly produced ones and the remanufactured ones. Constraint (19) restricts that the percentage of good quality used products in each recycling company cannot exceed the maximum value preset. Constraint (20) represents that the disposed materials are
remaining materials after all of the recycling processes. Constraint (21) restricts that in each recycling company, the total quantity of disposed materials must under the acceptable value, the right item of this inequality displays the transformation from the quantity of collected bad quality products to the weight of the material needs to be disposed of. Constraint (22) represents the binary variables. Constraint (23) represents the integer variables.

**METHODOLOGY**

**A two-stage priority-based GA**

The objective of the proposed CLSC model is to minimize the total cost of transportation and facility operation by designing an appropriate delivery route and delivery flow. In this study, a two-stage priority-based GA is developed to solve the problem described above. The proposed GA implements a two-stage priority-based encoding to solve this problem, which are Stage 1 - "Route Decision" and Stage 2 - "Freight Volume Decision".

Firstly, Route Decision is applied to design the delivery route between each level of the supply chain network. And then, according to the results of stage 1, Freight Volume Decision is implemented to decide the freight volume in each decided route.

**Stage 1 –Route Decision**

In the first stage of encoding, the chromosome has nine sections to represent each level of CLSC respectively. In each section, the number of genes equals to the product of the number of suppliers and the number of demanders. Totally in a chromosome, the number of genes is $I \times J \times T + J \times K + K \times L + V \times M + N + N \times J \times (T + 1)$.

In this numerical example, $T=2$, $I_1=3$, $I_2=2$, $J=4$, $K=2$. Two kinds of materials are considered. $I_1=3$ means the number of suppliers supplying material one is three, $I_2=2$ means the number of suppliers supplying material two is two. Suppliers provide materials to four manufacturers, and this four manufacturers will deliver finished products to two warehouses.

Each gene contains a binary number, 1 means the delivery route is used and 0 means not. The chromosome at this stage is shown in Figure 2. Obviously, the first section of the chromosome has $3 \times 4 = 12$ genes, it represents the delivery route of material one: the first four genes represent the situation of supplier one providing material one to manufacturers two and four but not providing materials to manufacturers one and three. The second four genes represent supplier two with material one, and the third four genes represent supplier three with material one. The second section of the chromosome has also $2 \times 4 = 8$ genes, which represents the delivery route of material two. The principle is the same as the first section. The third
section of the chromosome has 4*2=8 genes: The first two genes represent the situation of manufacturer one providing finished products to neither of the two warehouses, the second two genes represent manufacturer two, and so on.

![Figure 2](image1.png) The first three sections of chromosome in stage one

**Stage 2 - Freight Volume Decision**

After the first stage, a chromosome representing the delivery route has been established. The second stage is to decide the freight volume of materials or products according to the generated route. It is called freight volume decision. Figure 3 shows the chromosome after the second stage of encoding.

![Figure 3](image2.png) The first three sections of chromosome in stage two

The structure of the chromosome remains the same as in stage one, but the content has been changed. Among the first four genes, the first gene means supplier one won't delivery any raw material one to manufacture one, the second gene represents that supplier one will deliver 50 units of raw material one to manufacture two. Other sections have the close principle. The last gene in Figure 3 represents that manufacturer four will deliver 150 units of products to warehouse two.

The process "Cost Rank" is implemented at the beginning of encoding to decide the priority in freight volume decision. In this process, the unit cost of each delivery route is ranked in ascending order. The results of the rank are prepared for the process of freight volume decision.

**Genetic operations**

Genetic operations play an important role in genetic algorithm. Considering the properties of chromosomes in this problem, one-point crossover and one-point mutation are implemented to avoid dramatic changes in the genetic structure and prevent random genetic search.
COMPUTATIONAL EXPERIMENTS

To demonstrate the applicability of the proposed model and the stability of the proposed GA, three computational experiments with different scales are implemented: basic, middle and large. Table 1 shows the scale of these three experiments.

<table>
<thead>
<tr>
<th>Suppliers (t=1)</th>
<th>Suppliers (t=2)</th>
<th>Manufacturers</th>
<th>Warehouses</th>
<th>Retailers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic Scale</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Middle Scale</td>
<td>6</td>
<td>6</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>Large Scale</td>
<td>12</td>
<td>12</td>
<td>16</td>
<td>12</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Customers</th>
<th>Collection Points</th>
<th>Recycling Centers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic Scale</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Middle Scale</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>Large Scale</td>
<td>12</td>
<td>16</td>
</tr>
</tbody>
</table>

The dataset of basic scale experiment is randomly generated. Other scales are doubled and redoubled of the basic one. Table 2 shows the capacity and fixed cost of each facility in the basic scale experiment. Table 3 shows the demand of retailers and the recycling quantities of customers. Table 4 shows the unit shipping cost ($) in the basic scale experiment.

<table>
<thead>
<tr>
<th>Manufacturers</th>
<th>Warehouses</th>
<th>Collection points</th>
<th>Recycling companies</th>
<th>Suppliers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity</td>
<td>Fixed cost</td>
<td>Capacity</td>
<td>Fixed cost</td>
<td>Capacity</td>
</tr>
<tr>
<td>500</td>
<td>1100</td>
<td>800</td>
<td>500</td>
<td>80</td>
</tr>
<tr>
<td>600</td>
<td>1400</td>
<td>900</td>
<td>650</td>
<td>100</td>
</tr>
<tr>
<td>600</td>
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<td>1000</td>
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</tr>
<tr>
<td>800</td>
<td>1800</td>
<td>1500</td>
<td>140</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Retailers</th>
<th>Demands</th>
<th>100</th>
<th>300</th>
<th>500</th>
<th>500</th>
<th>600</th>
</tr>
</thead>
<tbody>
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<td></td>
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</table>

<table>
<thead>
<tr>
<th>Customers</th>
<th>Demands</th>
<th>500</th>
<th>700</th>
<th>800</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recycling quantities</td>
<td>100</td>
<td>154</td>
<td>168</td>
<td></td>
</tr>
<tr>
<td>Recycling rate</td>
<td>0.20</td>
<td>0.22</td>
<td>0.21</td>
<td></td>
</tr>
</tbody>
</table>
Table 4 The unit shipping cost in the basic scale experiment

| Costs | M | | W | | R |
|-------|---|------|---|------|---|------|
| S     | 1.5 | 2.5 | 2 | 3 | 10 | 12 | 15 |
|       | 3 | 1.5 | 2.5 | 4 | 15 | 13 | 14 |
|       | 2 | 2.5 | 2.5 | 2 | 9 | 10 | 14 |
|       | 4.5 | 6 | 7.5 | 6.5 | 10 | 11 | 12 |
|       | 7 | 6 | 5.5 | 6.5 | | | |
|       | 5 | 6 | 6.5 | 6.5 | | | |
|       | | | | | | | |
| Cu    | | | | | | | |
| Co    | 9 | 8 | 10 | 8 | 10 | 13 |
|       | 7 | 9 | 10 | 12 | 12 | 12 |
|       | 9 | 10 | 12 | 10 | 13 | 14 |
|       | | | | | 10 | 15 |
|       | | | | | | |
| Co    | | | | | | |
| RC    | 9 | 8 | 7 | 9 | 8 | 6 | 10 | 8 |
|       | 5 | 6 | 7 | 4 | 6 | 7 | 4 |
|       | 10 | 13 | 12 | 15 | 10 | 15 |
|       | 12 | 14 | 13 | 10 | 12 | 14 | 13 | 10 |


The computational results with proposed GA of the basic scale experiment are the same as the results with Lingo. It can be verified by drawing the closed-loop supply chain out. The verification of the results is seen in Figure 4. The results provide the optimal delivery route and delivery flow decision in the CLSC network, and these also give out the decision of facilities operational state. This integrated optimization can provide a reliable decision support for the printer cartridge company.

The results of middle scale and large scale experiments are also verified. All the three experiments' results are displayed in Table 5 comparing with results of Lingo. These results worked out by the provided GA, using a PC with Intel(R) Core(TM) i7-2600 CPU @ 3.4GHz, 8.0G RAM.

Table 5 The results and comparison between the proposed GA and Lingo

<table>
<thead>
<tr>
<th>50 Times each problems</th>
<th>Scale</th>
<th>Numerical examples</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Lingo 11.0</td>
<td>Optimal (US$)</td>
<td>63709.5</td>
</tr>
<tr>
<td></td>
<td>Time (s)</td>
<td>1</td>
</tr>
<tr>
<td>Proposed GA</td>
<td>Min-cost (US$)</td>
<td>63709.5</td>
</tr>
<tr>
<td>(population size=100)</td>
<td>Absolute difference</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Percentage difference</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Average-time (s)</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td>Percentage of time</td>
<td>9%</td>
</tr>
</tbody>
</table>
Table 5 shows the comparison between Lingo 11.0 and the proposed GA with three scales. The row of "Absolute difference" expresses the value that results of Lingo minus results of proposed GA. The minus sign means disparity. Take Scale 2 for example, the value of absolute difference is -1236, and the percentage difference is -0.7%. That means the result of proposed GA is 0.7% disadvantage compare with that of Lingo. However, the average time of the proposed GA is 2.04 s, which is only 10.2% of the time with Lingo. In Scale 3, the result of proposed GA is 0.62% disadvantage compare with that of Lingo, the running time is only 8.83% of Lingo's.

Figure 4 Result of basic scale experiment
CONCLUSIONS

With the booming development of electronic industry, the exponential growth of e-waste has polluted the environment seriously. Producers are perceived to be responsible for the recycling of products they have produced. However, few manufacturers adopted proper measures to deal with this because of expensive costs. To solve this problem, a comprehensive CLSC model of cartridge recycling is established in this paper. This model, which based on the real situation of cartridge recycle in Hong Kong, integrates both forward and reverse flow of products and contains eight partners in CLSC. In this research area, although many researchers discuss CLSC models, few of the models analyze the delivery activity for different kinds of materials that extracted from used products, and also few studies classify the collected used products according to the quality. The model proposed in this paper can address these issues. Moreover, this problem is formulated into a linear programming model and solved with a modified two-stage priority-based encoding GA which enhances the genetic searching ability. The adopted algorithm optimizes the CLSC network and the results show a near optimal solution, which can provide producers a reliable decision support.

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