Redesigning an Existing Recovery Logistics Network in Closed Loop Supply Chain

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Abstract: Closed loop supply chains (CLSC) can be both a forward supply chains and also reverse supply chains. Recently CLSCs are gaining much attention because of the growing need for environmental conservation. A CLSC has a number of features that distinguish it from simply a forward supply chain. One of them is requiring a large fixed cost because of the many facilities required to collect and disassemble products at the end of their service life. Another is the additional costs required for expanding capacity to handle the increase in remanufactured products and parts. In this paper, the problems of redesigning an existing logistics network in the CLSC is addressed. Redesigning an existing logistics network considers both opening new facilities and closing existing facilities. To reduce the fixed cost of facilities, opening hybrid facilities and decisions regarding the volume of products at each facility are considered. For the forward supply chain, redesign problems have been well researched, but this study is the first effort to consider redesigning an existing logistics network while considering profit from the sale of land property as part of the actual data in a CLSC. A new mathematical programming model is proposed. To validate the network redesign model proposed, it is applied to a real industrial case. Through the case study, it was found that the model proposed addresses redesigning an existing CLSC logistics network corresponding to recycling and resource savings, and validates the extent of economic efficiency.

Key words: closed loop supply chain, redesigning network, facility location, network design

1 INTRODUCTION

Many companies are moving away from mass production and mass consumption as they put their efforts into resource-saving recycling activities. There are many reasons for this change, such as exhaustion of natural resources, increasing environmental awareness, new business opportunities and regulatory trends, and so on. As a match in parallel to this environment protection activity, there is a high interest in closed loop supply chains (CLSCs) [1]. A CLSC considers not only the forward flow, but also the reverse flow, which is responsible for products collected after their useful service life ends.

Compared to only a forward supply chain, CLSCs composed of forward and reverse supply chains have some unique features. The first feature is requiring a large number of facilities, so a large fixed cost, which is the cost of renting land properties for products collected and maintaining buildings and checking machines for products collected are required. In the forward supply chain, there are suppliers, factories, distribution centers (warehouses) and customers. On the other hand in a CLSC, in addition to these facilities there are collection centers, which collect and inventory products collected, and remanufacturing centers, which disassemble products collected and produce remanufactured products. Therefore, in CLSCs, fixed costs tend to increase. As the second feature, with increasing production related remanufactured products, there is an additional expense to for expanding the capacity of facilities. Many companies have started increasing the production of remanufactured products, and they are expected to increase production in the future. Accordingly, additional expenses for capacity expansion of the facilities will become necessary.

In this study, the problem of redesigning an existing logistics network (which means elimination and consolidation of transportation network and facility) in a
CLSC is considered. Actually, Ballou [2] researched the redesigning problem, and he indicated that redesign could save up to 5-10% of the total supply chain costs. In this study, a hybrid facility, which has the functions of multiple facilities, is adopted for opening a facility because it can reduce fixed cost and transportation cost by integrating facilities with each function into one facility. Notably, the hybrid facility applied in this study has the functions of a reuse center, recycling center and warehouse. Hence, closing existing facilities is considered, as well as opening hybrid facilities. Addressing the redesign of the network, a CLSC which corresponds to increasing the production of remanufactured products is designed and the required operations in each facility are decided. Zeballos et al. [3] considered opening hybrid facilities. There are several studies for remanufacturing, recovery and ecological supply chains for copiers [4], [5]. But this study is the first effort to consider redesigning a network taking in to account the profit from selling property.

In this study, a mathematical programming model is proposed, and the total cost of the supply chain including opening a new facility and closing an existing facility is considered and compared with real data. Then, the validity of the model proposed is verified.

In terms of applicability, the model considers redesigning existing logistics networks in CLSCs from a long-term point of view. It considers supply chain operation cost and redesigning CLSCs by opening and closing facilities and selling the property on which the existing facilities that are to be closed are built. There are several assumptions such as the product can be collected from customers and can be remanufactured into other products or can be disassembled to reuse parts, like copy machines.

The remainder of the paper is organized as follows. Section 2 introduces the literature review about CLSCs. Section 3 shows the details of the model proposed and its formulation. Section 4 reports numerical results concerning our case study. In Section 5, the model development is shown. Finally, Section 6 introduces our main findings and future directions.

2 LITERATURE REVIEW

In the past, many studies on CLSCs have been conducted. Govindan et al. [1] said that the interest in CLSCs is rising very much and that CLSCs play a critical role. They reviewed papers about reverse logistics and CLSCs. In their paper, they reviewed 382 previous studies and classified various problems. One of these problems is a “designing and planning” problem. “Designing” means to determine strategic decision variables like locations and the capacity of all facilities. “Planning” means to determine tactical decision variables like the quantities of flows between supply chain network entities. The literature related to this problem is “designing and planning”, and these are indicated below.

As part of the establishment of green supply chain the attention is also given to designing the supply chain which considers the reduction of environmental load. Reducing the emissions of carbon dioxide during production and transportation is considered in the research of Fahimnia et al. [6]. Paksoy et al. [7] targets the reduction of greenhouse gases simultaneously.

Next, there are also studies that consider the supplier selection problem when designing CLSCs. Companies do not consider the procurement of inexpensive raw materials so much, rather they select suppliers considering environment-friendly elements such as reducing waste, pollution, and energy use (Amin and Zhang [8], Ramezani et al. [9], and Chaabane et al. [10]).

There is also much research about network design problems considering uncertainty. In the background, shorter product lifecycles and producing multiple products have led to intense changes, and it is no longer easy to predict market trends. Also, natural disasters and accidents may cause a loss of procurement capacity, and there is a difference in the quality and quantity of products collected. To handle these problems, Amin and Zhang [11] consider uncertain raw material supply and customer demand, Ashfari et al. [12] assumed the amount of products collected and demand are uncertain, Gomes et al. [13] addressed the uncertain quality of products collected, and researched the design of CLSCs.

Then there are some studies about designing a CLSC. Georgiadis and Athanasious [14] studied capacity planning in the reverse channel of CLSCs. Lundin [15] researched the Swedish cash supply chain, and the purpose of his research was to present a model that determines the effects caused by design changes in a cash supply chain. Kusumastui et al. [16] presented a case study of a Singapore-based company providing after-sales service instead of an American-based computer brand in the Asia-Pacific region, and a facility location-allocation model was developed for their model.
However, previous studies considered opening new facilities, but redesigning while considering the opening of new facilities and closing existing facilities was not considered. In this study, the cost merit of concentrating facilities is verified by considering the current state of the CLSC relocation.

Here, redesigning represents not capacity planning but elimination and consolidation of facilities. This study considers closing existing facilities and the profit of selling property, which calculates the revenue of selling property minus the removal cost. Contrary to the uncertainty model, this study it treated as a deterministic model. However, redesigned CLSCs must use a planning period. Details of the model proposed are given in the following section.

3 MODEL DESCRIPTION AND FORMULATION

3.1 Model Description

The CLSC taken up by this study is outlined as indicated in Fig. 1. There is the assumption that there are multiple sites for customers, branch offices, collection centers, “Reuse centers,” “Recycle centers,” warehouses and distribution centers. There are several assumptions that the products can be collected from customers and remanufactured into other products or can be disassembled for reusable parts, as is done with copy machines. Products collected from customers via branch offices are gathered at collection centers, and a quality verification is performed. Those products suitable for reuse or remanufacturing are transported to a facility, called “Reuse center” in this study. The products collected which are not suitable are transported to the “Recycle center” for recycling. In some cases, products collected pass through warehouses because they need to be stored before processing. At reuse centers, products collected are processed to enable remanufacturing as whole products and parts, and then they are transported to customers via distribution centers. The remaining products are transported to recycle centers where further disassembly and recycling are performed. Then each of the raw materials obtained is sent to the appropriate material market. Collection centers and distribution centers exist in the same facility.

In terms of environmental consideration, there is no intentional disposal of the products collected and remanufactured parts in this CLSC. All products collected become remanufactured products or are disassembled and recycled for materials. Thus, under this assumption, the objective of this model is minimize total cost.

In this model, the supply chain considered for redesign is the part inside the bold line in Fig. 1. The newly opened facilities are hybrid facilities (specifically, ones combining a reuse center, warehouse and recycle center). The existing facilities where closing is considered are the reuse centers, warehouses and recycle centers. Opening a collection center and closing the existing collection center are not considered.

3.2 Model Formulation

In this study, a model is proposed for redesigning a CLSC network. The definitions of sets, parameters, and decision variables are show in Sections 3.2.1, 3.2.2 and 3.2.3, respectively. In addition, the objective function and constraints are show in Section 3.2.4.

3.2.1 Definition of Sets

CC : Set of distribution centers and collection centers
F : Set of reuse centers \( \{F^E \cup P^E\} \)
GC : Set of warehouses \( \{GC^E \cup P^E\} \)
RC : Set of recycle centers \( \{RC^E \cup P^E\} \)
F^E : Set of existing reuse centers
GC^E : Set of existing warehouses
RC^E : Set of existing recycle centers
P^E : Set of existing reuse center, warehouse and recycle center \( \{F^E \cup GC^E \cup RC^E\} \)
P^W : Set of candidate hybrid facilities
SL : Set of properties that can be sold
P : Set of parts

3.2.2 Definition of Parameters

c^T_{ij} : Cost to transport between node i,j
c^E_i : Fixed cost of facility i
c^O_i : Cost of opening facility i
c^C_i : Cost of closing facility i

Figure 1 Outline of CLSC
\[ Z = B \left( \sum_{i \in F} \sum_{j \in CC} c_{ii}^W (y_{ij} + \sum_{p \in P} y_{ijp}) + \sum_{i \in CC, j \in F \cap GGCjRC} c_{ij}^T y_{ij} + \sum_{i \in CC, j \in F \cap JRC} c_{ij}^T y_{ij} + \sum_{i \in F, j \in RC} c_{ij}^T y_{ij} + \sum_{i \in CC, j \in F \cap GGCjRC} c_{ij}^W o_{ij} + \sum_{i \in F, j \in RC} c_{ij}^W o_{ij} \right) - \sum_{i \in F, j \in F \cap JRC} (c_{ij}^T + c_{ij}^W) + \sum_{i \in CC, j \in F \cap GGCjRC} c_{ij}^C \left( 1 - \omega_{ij}^F_k \right) - \sum_{i \in CC, j \in F \cap GGCjRC} c_{ij}^C \left( 1 - \omega_{ij}^F_k \right) \]

subject to

\[ A_i = a_i \quad \forall i \in CC \]  

\[ o_i = \sum_{j \in CC} x_{ij} \quad \forall j \in CC \]

\[ \sum_{j \in CC} x_{ij} = o_j \quad \forall j \in F \]

\[ \sum_{j \in CC} x_{ij} = o_j \quad \forall j \in RC \]

\[ D^{MR} = o_{i, j} \quad \forall i, j \]

\[ D^{PR} = o_{i, p} \quad \forall i \in F, p \in F \]

\[ x_{ij} \leq u^T y_{ij} \quad \forall i, j \]  

\[ x_{ij} \leq w_{ij}^K \quad \forall i \in F, p \in F \]

\[ w_{ij}^K = 0 \quad \forall j \in F \]

3.2.3 Definition of Decision Variables

- \( c_{ii}^W \): Profit on sale of property \( i \)
- \( c_{ii}^T \): Operating cost at facility \( i \)
- \( c_{ii}^W \): Cost to produce remanufactured product
- \( c_{ii}^F \): Cost to produce reused parts
- \( u^T \): Operating capacity of facility \( i \)
- \( A_i \): Amount of products collected at collection center \( i \)
- \( D_i \): Demand for product at distribution center \( i \in CC \)
- \( D_{ip} \): Demand for part \( p \) at distribution center \( i \in CC \)
- \( D^{MR} \): Demand for products collected as remanufactured product
- \( D^{PR} \): Demand for products collected as reused parts
- \( C_p \): Unit requirements for part \( p \) to produce one unit of product
- \( u^T \): Transport capacity for product
- \( u_p \): Transport capacity for part \( p \)
- \( M \): Large number
- \( B \): Planning period

3.2.4 Objective Function and Constraints

minimize \( Z \)
The objective function \( Z \) to be minimized is the total of the running cost for the planning period, the initial investment and the profit from selling the property (Eq. (1)). Because the model considers supply chain operation cost and considers redesigning the CLSC by opening and closing facilities, the total cost is composed of the transportation cost, the operating cost, the fixed cost of facilities, opening cost of new facility, closing cost of existing facilities and sell the property on which the facilities being closed are built. From the first term to fourth term represent the transportation cost and operating cost. In the fifth and sixth terms, the fixed cost of facilities (seventh term) is represented. The breakdowns of the initial investment are the opening cost (eighth term) and closing cost (ninth term). The tenth term is the profit from selling the property.

Equations (2) and (3) impose product flow balance at collection centers and distribution centers. Equations (4) and (5) impose product flow balance at warehouses. Equations (6) through Eq. (10) represent product and parts flow at reuse centers, and Eq. (11) is the same constraint at recycle centers. The amount of inflow is equal to the amount of outflow. Equations (12) through (15) enforce demand satisfaction for products collected as remanufactured products and parts. The transportation capacity for products and parts is described by Eqs. (16) and (17), respectively. Equations (18) through (20) limit the operating capacity of collection centers, reuse centers, warehouses and recycle centers. Eq. (21) forbids opening a facility. Eq. (22) forbids closing a facility. Finally, Equations (23) and (24) enforce the continuous and discrete restrictions on the associated decision variables.

4 NUMERICAL EXPERIMENT

In this section, a numerical experiment is presented to show the model proposed. The case study considered in this paper is a copy machine company in Japan, and actual data from past actual performance data is used. Thus, actual data is used for the parameters explained in sections 3.2.1 and 3.2.2 to decide optimal values of variables, which are explained in Section 3.2.3 and the model in Section 3.2.4.

In Section 4.1, the details of experimental settings are described. The results of the numerical experiment are provided in Section 4.2.

<table>
<thead>
<tr>
<th>Case</th>
<th>Constraint of operating capacity</th>
<th>Opening facility</th>
<th>Closing facility</th>
</tr>
</thead>
<tbody>
<tr>
<td>①</td>
<td>Not imposed</td>
<td>Not permitted</td>
<td>Not permitted</td>
</tr>
<tr>
<td>②</td>
<td>Imposed</td>
<td>Permitted</td>
<td>Not permitted</td>
</tr>
<tr>
<td>③</td>
<td>Imposed</td>
<td>Permitted</td>
<td>Permitted</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Facility</th>
<th>Number</th>
<th>Alphabet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing reuse center</td>
<td>4</td>
<td>A ~ D</td>
</tr>
<tr>
<td>Existing recycle center</td>
<td>8</td>
<td>E ~ L</td>
</tr>
<tr>
<td>Existing warehouse</td>
<td>2</td>
<td>M, N</td>
</tr>
<tr>
<td>Candidate of hybrid facility</td>
<td>6</td>
<td>O ~ T</td>
</tr>
</tbody>
</table>
The purpose of case ③ is that the cost merit by closing existing facilities is verified.

### 4.2 Data Set

The experimental environment used on Intel® Core™ i5-3570 CPU @ 3.40GHz, 8.00 GB. Gurobi optimizer version 6.0.0 is used for solving the mixed integer programming problem.

The numbers of existing facilities and candidates for hybrid facility are indicated in Table 2, and the names of facilities are expressed in alphabetical characters. The time period is 10 years. Production amounts of remanufactured products and parts are given preliminarily, and they are about 1.7 times the current amount. The descending order of capacity of each facility is F > I > G > N > K > J > E > A > D > H > M > B > C > L. The location of each facility ranges from the Tohoku district to Kyushu district.

### 4.3 Experimental Results

#### 4.3.1 Experimental Results of Case ①

In this section, the results of case ① are shown. The optimal operating quantity of each facility is shown in Fig. 2.

As shown in Fig. 2, when the production of remanufactured products is increased, the facilities which should be expanded are A, B and D. In particular, quadruple the quantity of the current capacity is needed for B, because the transportation cost is cheaper than the other reuse centers. Additionally, there are unnecessary facilities (C, M) that are not operating, and these facilities should be closed. The facilities of which the optimal quantity is less than the current capacity are the targets of capacity contraction or facilities that should be closed.

#### Table 3 Expense results breakdown of case ② (unit : yen)

<table>
<thead>
<tr>
<th>Opened facility</th>
<th>Total cost</th>
<th>Breakdown of running cost</th>
<th>Breakdown of initial investment cost</th>
<th>Profit from sale of property</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Transportation cost</td>
<td>Operating cost</td>
<td>Fixed cost</td>
</tr>
<tr>
<td>O</td>
<td>10.00[B]</td>
<td>3.80[B]</td>
<td>1367</td>
<td>5.40[B]</td>
</tr>
</tbody>
</table>

Table 4 Expense results breakdown of case ③ (unit : yen)

<table>
<thead>
<tr>
<th>Opened facility</th>
<th>Total cost</th>
<th>Breakdown of running cost</th>
<th>Breakdown of initial investment cost</th>
<th>Profit from sale of property</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Transportation cost</td>
<td>Operating cost</td>
<td>Fixed cost</td>
</tr>
<tr>
<td>O</td>
<td>6.38[B]</td>
<td>0.50[B]</td>
<td>1367</td>
<td>2.06[B]</td>
</tr>
<tr>
<td>Q</td>
<td>11.34[B]</td>
<td>0.60[B]</td>
<td>1481</td>
<td>1.45[B]</td>
</tr>
<tr>
<td>R</td>
<td>8.02[B]</td>
<td>0.69[B]</td>
<td>76879</td>
<td>2.06[B]</td>
</tr>
<tr>
<td>T</td>
<td>12.85[B]</td>
<td>0.53[B]</td>
<td>8087</td>
<td>2.06[B]</td>
</tr>
</tbody>
</table>
4.3.2 Experimental Results of Case ② and Case ③

In this section, the results of Case ② and Case ③ are shown. In case ②, because the operating capacities of existing reuse centers is insufficient, there is necessity of open hybrid facilities. As discussed later, in these cases, there is no limitation to opening hybrid facilities. However, the optimal solution is opening only one solution. Thus, when the opening hybrid facility is changed, each cost is compared.

The results of case ② when a hybrid facility is opened at each candidate site are shown in Table 3 (where the values indicated in Table 3 are based on setting the total cost in candidate hybrid facility O to 10 billion yen). Profit from the sale of property is not obtained, but candidate O is chosen because of the initial investment and transportation costs. (The reason that operating cost is extremely small is because the total income from the production of remanufactured products and parts is subtracted from the total operating expenditure.)

The results of case ③ when a hybrid facility is opened at each candidate site are shown in Table 4. Candidate O is chosen because of the initial investment and transportation costs without a large profit from the sale of property.

The results for the optimal networks of cases ② and ③ are shown in Table 5. For ③, six facilities should be closed to reduce the fixed cost, and these are responsible for most of the running cost in ②. It is possible for hybrid facility O to serve the functions of the facilities that are closed. In addition, as shown in Table 6, the profits from the sales of properties can be gained for the closed facilities. Due to the running cost, case ③ has a smaller total cost. In particular compared with case ②, case ③, in which closing facilities is considered, has an expected cost merit of about 3.6 billion yen, despite a higher initial investment cost.

### Table 5 Results for optimal network

<table>
<thead>
<tr>
<th>Case</th>
<th>Opened facilities</th>
<th>Closed facilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>②</td>
<td>O</td>
<td>—</td>
</tr>
<tr>
<td>③</td>
<td>O</td>
<td>Reuse center (A, C, D)</td>
</tr>
</tbody>
</table>

### Table 6 Comparison of case ② and ③ (unit : yen)

<table>
<thead>
<tr>
<th>Case</th>
<th>Total cost</th>
<th>Transportation cost</th>
<th>Operating cost</th>
<th>Fixed cost</th>
<th>Opening cost</th>
<th>Closing cost</th>
<th>Profit from sale of property</th>
</tr>
</thead>
<tbody>
<tr>
<td>②</td>
<td>10.00[B]</td>
<td>3.80[B]</td>
<td>1367</td>
<td>5.40[B]</td>
<td>0.80[B]</td>
<td>—</td>
<td>0</td>
</tr>
</tbody>
</table>

[B] : billion

### Table 7 Expense results breakdown of the priority of closing (unit : yen)

<table>
<thead>
<tr>
<th>Closed facility</th>
<th>Total cost</th>
<th>Transportation cost</th>
<th>Operating cost</th>
<th>Fixed cost</th>
<th>Opening cost</th>
<th>Closing cost</th>
<th>Profit from sale of property</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>10.00[B]</td>
<td>3.80[B]</td>
<td>1367</td>
<td>5.40[B]</td>
<td>0.80[B]</td>
<td>—</td>
<td>0</td>
</tr>
<tr>
<td>A</td>
<td>8.72[B]</td>
<td>4.33[B]</td>
<td>7289</td>
<td>5.28[B]</td>
<td>0.80[B]</td>
<td>0.07[B]</td>
<td>1.78[B]</td>
</tr>
<tr>
<td>N</td>
<td>8.72[B]</td>
<td>3.83[B]</td>
<td>18565</td>
<td>4.10[B]</td>
<td>0.80[B]</td>
<td>0.02[B]</td>
<td>0</td>
</tr>
<tr>
<td>D</td>
<td>9.43[B]</td>
<td>4.39[B]</td>
<td>0</td>
<td>4.24[B]</td>
<td>0.80[B]</td>
<td>0.07[B]</td>
<td>0</td>
</tr>
<tr>
<td>F</td>
<td>9.59[B]</td>
<td>3.83[B]</td>
<td>14351</td>
<td>4.87[B]</td>
<td>0.80[B]</td>
<td>0.11[B]</td>
<td>0</td>
</tr>
<tr>
<td>C</td>
<td>9.89[B]</td>
<td>3.80[B]</td>
<td>9112</td>
<td>5.26[B]</td>
<td>0.80[B]</td>
<td>0.02[B]</td>
<td>0</td>
</tr>
<tr>
<td>M</td>
<td>9.91[B]</td>
<td>3.80[B]</td>
<td>1367</td>
<td>5.28[B]</td>
<td>0.80[B]</td>
<td>0.02[B]</td>
<td>0</td>
</tr>
</tbody>
</table>

[B] : billion
the result is the same as the results of case ②. The facility prioritized to be closed most is reuse center A because of the profit from the sale of property. It is also possible to produce remanufactured products and parts at the hybrid facility opened, O. The fixed cost is so high that the second facility is warehouse N. From the third facility, the fixed cost is the main reason for closing.

5 MODEL DEVELOPMENT

In this section, model development from disassembling and transporting parts at collection centers is considered. In Section 5.1, the details of model development are described. The formulation is shown in Section 5.2, and the results are shown in Section 5.3.

5.1 Details of Development

In this section, another model is proposed. The first model (cases ① to ③) is that processing products collected to allow their reuse as whole remanufactured products and reused parts can only be done in reuse centers. In case ④, reusable parts processing is possible at collection centers. Parts obtained by the process held in the distribution center, and products collected and processed for reusable parts are transported to recycle centers.

Using this model, installation of equipment for reusable parts processing at each reuse center can be considered. In addition, comparisons as to which is profitable, building hybrid facility or installing equipment at each reuse center and land sale profit, can be made.

5.2 Model Formulation of Case ④

In this section, a model for redesigning a CLSC network considering reusable parts at collection centers (case ④) is proposed. In 5.2.1, decision variables are defined, and the objective function and constraints are shown in 5.2.2.

5.2.1 Definition of Decision Variable

\[ x_{PRij} \] : Quantity of remaining products for reusable parts transported between node \( i \in CC \), \( j \in RC \)

5.2.2 Objective Function and Constraints

minimize \( Z \)

subject to

\[
A_i = o_i + o_{iPR} \quad \forall i \in CC
\]

\[
C_{pi}o_{iPR} = \sum_{j \in CC} x_{ijp} \quad \forall j \in CC, p \in P
\]

\[
C_{pi}o_{iPR} = \sum_{j \in PR} x_{ijPR} \quad \forall j \in CC
\]

\[
o_i = \sum_{j \in RC} x_{ij} \quad \forall j \in CC
\]

\[
\sum_{j \in CC} x_{ij} = o_j \quad \forall j \in F
\]

\[
\sum_{j \in CC} x_{ij} = o_j \quad \forall j \in F
\]

\[
o_i = o_{iMR} + o_{iPR} \quad \forall j \in F
\]

\[
o_{ijMR} = \sum_{j \in CC} x_{ij} \quad \forall i \in F, p \in P
\]

\[
C_{pi}o_{iPR} = \sum_{j \in CC} x_{ijp} \quad \forall j \in RC
\]

\[
o_{ijPR} = \sum_{j \in PR} x_{ij} \quad \forall i \in CC
\]

\[
\sum_{j \in CC} x_{ij} + \sum_{j \in RC} x_{ijPR} = o_j \quad \forall j \in RC
\]

\[
\sum_{i \in CC} o_{iPR} + \sum_{i \in P} o_{iPR} = D_{PR}
\]

\[
\sum_{i \in CC} x_{ij} = D_j \quad \forall j \in CC
\]

\[
\sum_{i \in CC} x_{ijp} + \sum_{i \in F} x_{ijp} = D_{ijp} \quad \forall j(p \neq i) \in CC, p \in P
\]

\[
x_{ijp} \leq u_{ijp} y_{ijp} \quad \forall i \in CC, j \in CC, p \in P
\]

\[
\sum_{j \in CC} x_{ij} \leq M_{w_i} \quad \forall i \in CC \cup F \cup GC \cup RC
\]

\[
\sum_{j \in CC} x_{ijp} \leq u_{ijp} M_{w_i} \quad \forall j(p \neq i) \in CC \cup F \cup GC \cup RC
\]

\[
\sum_{j \in CC} x_{ijp} \leq M_{w_i} \quad \forall i \in CC \cup F, p \in P
\]
\[ w_i^K = 0 \quad \forall i \in I^N \]  
(21)
\[ w_i^k = 1 \quad \forall i \in I^E \]  
(22)
\[ x_{ij}, x_{ijr}, x_{ijp}, y_{ij}, y_{ijp}, o_{ij}, o_{ijr}, o_{ijp}^R \geq 0 \]  
(23)
\[ w_i^K \in \{0,1\} \]  
(24)

The objective function \( Z \) to be minimized is the total of the running cost for the planning period, the initial investment and profit from the sale of property (Eq. (25)). When it’s compared with Eq. (1), the transportation cost for reused parts between the collection center and distribution centers (first term) and operating cost for reuse at collection centers (eighth term) are different. The remaining terms are the same as Eq. (1).

Equation. (2)' represents the amount of products collected equaling the summation quantity of usual operation and the quantity of parts reused. Equation (26) imposes the amount of reused parts obtained by reusable parts processing. The remaining products made from reusable parts in collection centers are transported to recycle centers (Eq. (27)). Equation. (11)' represents product and parts flow at recycle centers. Equation (13)' enforces demand satisfaction for reused parts at collection centers and reuse centers, and Eq. (28) also imposes demand satisfaction at distribution centers. Transport capacity for remaining products for reusable parts is represented in Eq. (29). Equation (17)' represents transportation capacity for parts. The other equations show the same meanings as cases ① to ③.

### 5.3. Experimental Results of Case ④

In this section, the results of case ④ are shown. The optimal network is shown in Table 8.

Under the assumption of cases ② and ③, facilities need to be opened because of lack of operating capacity in reuse centers. But in case ④, no facility is opened. This is because processing of products for reusable parts is allowed in collection centers and processing of products collected can be covered by the capacities of the existing reuse centers. The reasons of opening cost and profit from the sale of property are also included. If reuse center C is not closed, fixed cost increases. Additionally, whenever one recycle center is closed, fixed cost decreases but transportation cost increases.

A comparison of expense results of cases ③ and ④ is shown in Table 9. The total cost of case ④ will be one-third the total cost of case ③.

### 6 CONCLUSIONS

Nowadays, with the increase in environmental conservation activities, companies need to improve their capacity to increase production of remanufactured products. With regard to the tendency to increase capacities for reuse activities, companies need to consider the optimal network in order to decrease network costs. In this study, a model for redesigning an existing logistics CLSC network in which hybrid facilities are opened and existing facilities closed, is considered.

The formulation relevance was evaluated by an example based on an industrial case that involves the CLSC of a Japanese copy machine company. Through numerical experiments, the impact of redesigning a network was analyzed, and it was found that the model is effective for maximizing total profit and verifying scale of economy.

In this study, two models are proposed and verified. The first model is processing products collected to allow remanufacturing and reuse only in reuse centers. In the other model, processing reusable parts is possible at collection centers. Parts obtained by the process are held in a distribution center, and products collected to be processed for reusable parts are transported to recycle centers.

### Table 8 Results for optimal network

<table>
<thead>
<tr>
<th>Opened facilities</th>
<th>Closed facilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>Reuse center (C)</td>
</tr>
<tr>
<td></td>
<td>Recycle center (None)</td>
</tr>
<tr>
<td></td>
<td>Warehouse (M, N)</td>
</tr>
</tbody>
</table>

### Table 9 Expense results breakdown of case ③ and ④ (unit : yen)

<table>
<thead>
<tr>
<th>Case</th>
<th>Total cost</th>
<th>Breakdown of running cost</th>
<th>Breakdown of initial investment cost</th>
<th>Profit from sale of property</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Transportation cost</td>
<td>Operating cost</td>
<td>Fixed cost</td>
</tr>
<tr>
<td>④</td>
<td>2.04[B]</td>
<td>2.82[B]</td>
<td>25060</td>
<td>3.10[B]</td>
</tr>
</tbody>
</table>

[B] : billion
Comparing those two models, besides some of the fixed costs of facilities being high, it is valuable to process reusable parts not only at reuse centers, but also at collection centers.

There are some potential future studies. The model developed here is a single-period and single product example. Considering multiple periods and multiple products can contribute to a more practical situation. Additionally, considering a quantity discount problem about operating cost is an important aspect. To reduce the environmental load, green procurement should be investigated. In order to treat uncertainty, which is usual in the world, the model should be expanded to a stochastic model.

REFERENCES


