역물류를 고려한 통합 물류망 구축에 대한 모델 및 해법에 관한 연구
Model and Algorithm for Logistics Network Integrating Forward and Reverse Flows

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ABSTRACT

As today's business environment has become more and more competitive, forward as well as backward flows of products among members belonging to a supply chain have been increased. The backward flows of products, which are common in most industries, result from increasing amount of products that are returned, recalled, or need to be repaired. Effective management for these backward flows of products has become an important issue for businesses because of opportunities for simultaneously enhancing profitability and customer satisfaction from returned products. Since third party logistics service providers (3PLs) are playing an important role in reverse logistics operations, the 3PLs should perform two simultaneous logistics operations for a number of different clients who want to improve their logistics operations for both forward and reverse flows. In this case, distribution networks have been independently designed with respect to either forward or backward flows so far. This paper proposes a mixed integer programming model for the design of network integrating both forward and reverse logistics. Since this network design problem belongs to a class of NP-hard problems, we present an efficient heuristic based on Lagrangean relaxation and apply it to numerical examples to test the validity of proposed heuristic.

Keywords: *third party logistics, reverse logistics, integrated distribution network; Lagrangean relaxation*

1. INTRODUCTION

The competitive business environment in today has resulted in increasing cooperation among individual companies as members of a supply chain. In other words, the success of a company will depend on its ability to achieve effective integration of worldwide organizational relationships within a supply chain [7]. Moreover, consumers now require high levels of customer service with a short life cycle. In such an environment, a growing number of companies are under pressure to be concerned with filling their customers' orders, keeping the deliveries of products up to speed, reducing inventory, and implementing reverse logistics. Consequently, the individual companies of a supply chain are frequently faced with the challenges of restructuring their distribution network with respect to global need and volatile market changes.

As a result, third party logistics service providers (3PLs) are playing an increasing role in supporting the design, management, and operation of supply chains. The market for 3PLs in U.S was estimated at more than $45 billion in 1999 and is growing by nearly 18 percent annually and the primary growth in 3PLs markets has been in warehousing and distribution. In addition, 74% of Fortune 500 companies in U.S used 3PLs' services during 2000. These services involved transportation management, freight payment, warehouse management, shipment tracking, and reverse logistics. Virtually, all of the companies reported positive cost reduction due to the avoidance of insurance and employee costs as well as material handling equipment and technology purchases [19].

Today, using 3PLs such as UPS, FedEx, GENCO, etc. is becoming the wave of the future and a major element in logistics. The main advantage of outsourcing services to 3PLs is that these 3PLs allow companies to get into a new business, a new market. In addition, 3PLs have also become important players in reverse logistics since the implementation of return operations requires a specialized infrastructure needing special information systems for tracking/capturing data, dedicated equipment for the processing of returns, and specialist trained non-standard manufacturing processes. In an integrated logistics network in 3PLs, some products are brought to the original customers through a forward supply chain whose structure may consist of suppliers, manufacturers, distribution centers, retailers, and original customers. After being sold to customers through a supply chain, the product might go back to a manufacturer from retailers/e-retailers or original customers. Finally, the products enter into a reverse logistic flow. In the first stage, the reverse process is collection, reclaiming returned products and transporting them to a particular location such as manufacturers or a repair center. To collect these products, there is a need in a transportation network where most companies are using distribution centers, central return centers, or hybrid warehouse-return facilities.

Therefore, this paper deals with the design of a distribution network, considering integrated forward and reverse flows. The network for 3PLs can consist of client's facilities, warehouses (or distribution centers), collection centers, and clients' market places. The collection center especially in this paper is assumed to perform the collection of returned product, minor repair operations, and shipment of the products to original clients. More specifically, the strategic decisions to be considered for 3PLs are related to:

1) Where to locate warehouse and collection centers?
2) How many warehouses and collection centers are established?
3) How to allocate appropriate space for each product in warehouses and collection centers?
4) How to allocate customers into appropriate warehouses and collection centers?

However, there have been few studies dealing with mathematical models for use by 3PLs. Thus, this paper proposes a mixed integer programming model for the design of network integrating both forward and reverse logistics. Unfortunately this network design problem belongs to a class of NP-hard problems. Hence, we present an efficient heuristic based on Lagrangean relaxation and apply it to numerical examples to test the validity of proposed heuristic.

2. LITERATURE REVIEW

The network design issues in 3PLs can be divided into two categories with respect to the material flows, and most studies of existing network models have involved in dealing with only a single flow such as forward flow or reverse flow. Here are some of studies. In forward logistics with respect to multi-commodity aspects, Elson [8] was perhaps the first to solve the multi-commodity capacitated version of the facility location problem, considering a single echelon of transshipment stocking points.

Geoffrion and Graves [10] developed a model to optimize commodity flows. Their model not only dealt with facility location and commodity flows but also with customer assignment. Later, Geoffrion, Graves, and Lee [11] refined Geoffrion and Graves' model [10] for practical applications in which they developed an optimization procedure by the use of the decomposition theory of Benders [6]. Akins [1] analyzed the capacitated facility location problem where the size of a plant to be established was bounded and presented a branch-and-bound algorithm as a solution method. Lee [16] developed a general model for a capacitated facility location problem that deals with a multi-product, multi-type facility model. He proposed an optimal solution algorithm based on Bender's decomposition. Lee [17] extended a standard capacitated facility location problem to generalization of multi-product, multi-type capacitated facility location problem with a choice of facility and presented an effective algorithm based on cross decomposition. The algorithm unifies Bender's decomposition and Lagrangean relaxation into a single framework. Finally, Pirkul et al. [20] developed an efficient heuristic procedure for solving the multi-commodity, multi-plant capacitated facility location problem.

In reverse flows, there has been relatively little attention on a reverse logistics network. However, for the last decades, increasing concerns over environmental degradation and increased opportunities for cost savings or high customer satisfaction from returned products prompted some researchers to develop reverse logistics models: reuse logistics, remanufacturing logistics, and recycling logistics models. For reuse logistics models, Kroon and Vrijens [15] reported a case study concerning the design of a logistics system for reusable transportation packages. The authors proposed a MILP, closely related to a classical uncapacitated warehouse location model. Spengler et al. [21] dealt with the recycling of industrial by-products in the German steel industry. They proposed a MILP model based on the modified multi-level warehouse location problem. The model was solved using a modified Benders decomposition. For recycling logistics models, Barros et al. [3] reported a case study addressing the design of a logistics network for the recycling of sand and presented a MILP model based on a multi-level capacitated warehouse location problem. Louwers et al. [18] considered the design of a recycling network for carpet waste. They proposed a continuous location model that used a linear approximation to the more accurate nonlinear model.

For remanufacturing logistics models, Kirkke et al. [14] described a case study, dealing with a reverse logistics network for the returns, processing, and recovery of discarded copiers. They presented a MILP model based on a multi-level uncapacitated warehouse location model. Jayaraman et al. [12] analyzed the logistics network of an electronic equipment remanufacturing company in the USA. They proposed a single period MILP model based on a multi-product capacitated warehouse location model.

3. MODELING A LOGISTICS NETWORK FOR 3PLs

The modeling approach for 3PLs in this paper belongs to a location-allocation location model. The main differences of this model compared to existing location models might lie in handling in forward and reverse flows simultaneously since 3PLs operate supply chains for a large number of different customers requiring various types of logistics

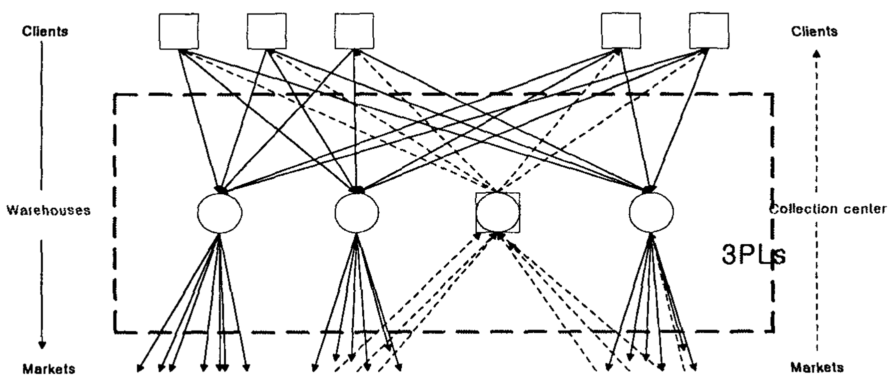


Figure 1. An Integrated Network Structure

services. The network structure of this model is illustrated in Figure 1. In this network, instead of dealing with separate warehouse or collection centers, we also considered a new type of a hybrid distribution-collection facility. Advantage of installing a hybrid facility might save costs as results of sharing material handling equipment, infrastructure, and so on. The problem in this paper assumes that the locations of clients' plants and the clients' customers, together with products to be shipped, are known.

3.1 Notations

(Indices and sets)

$P = \{1, \ldots, NP\}$, set of clients' forward/collection product types

$I = \{1, \ldots, NI\}$, set of clients' plant locations

$J = \{1, \ldots, NJ\}$, set of possible sites for warehouses

$L = \{1, \ldots, NL\}$, set of collection centers

$S = J \cap L$, set of the possible sites for hybrid warehouse-collection center

$K = \{1, \ldots, NK\}$, set of fixed customer locations

(Model parameters)

M_{ip} = maximum production capacity of product p in the client's plant i; $i \in I$, $p \in P$

M_j = maximum capacity of warehouse j; $j \in J$

M_l = maximum capacity of collection center l; $l \in L$

d_{pk} = demand of product p at customer k; $p \in P$, $k \in K$

r_{pk} = amount of returns of product p from customer k; $p \in P$, $k \in K$

α_p = weight factor of product p based on characteristics of the product type; $p \in P$

w_j = fixed cost of opening warehouse j; $j \in J$

v_j = unit variable cost for warehouse j; $j \in J$

r_l = fixed cost of opening collection center l; $l \in L$

u_l = unit variable cost for collection center l; $l \in L$

h_s = cost savings from opening hybrid warehouse-collection center s; $s \in S$

c^f_{pijk} = unit variable cost of serving demand of product p at customer k from plant i and warehouse j, including transportation and handling cost; $p \in P$, $i \in I$, $j \in J$, $k \in K$

c^r_{pkli} = unit variable cost of taking back returned product p from customer k via collection center l to plant i, including transportation and handling cost; $p \in P$, $k \in K$, $l \in L$, $i \in I$

(Decision variables)

X^f_{pijk} = 1, if demand of customer k for product p is served through warehouse j from client' plant i , $p \in P$, $i \in I$, $j \in J$, $k \in K$; Otherwise 0

X^{r}_{pkli} = 1, if demand of customer k for product p is serviced through collection center l to plant i, $p \in P$, $k \in K$, $l \in L$ $i \in I$; Otherwise 0

$Z_j = 1$, if warehouse j is open; $j \in J$; 0, otherwise

$G_l = 1$, if collection center l is open; $l \in L$; 0, otherwise

3.2 Mathematical formulation

P : Minimize

$$\sum_{j \in J} \left[w_j Z_j + v_j \sum_{p \in P} \sum_{i \in I} \sum_{k \in K} \alpha_p X^{f}_{pijk} \right] + \sum_{l \in L} \left[r_l G_l + u_l \sum_{p \in P} \sum_{i \in I} \sum_{k \in K} \alpha_p X^{r}_{pkli} \right] - \sum_{s \in S} h_s Z_s G_s + \sum_{p \in P} \sum_{i \in I} \sum_{j \in J} \sum_{k \in K} c^{f}_{pijk} X^{f}_{pijk} + \sum_{p \in P} \sum_{k \in K} \sum_{l \in L} \sum_{i \in I_0} c^{r}_{pkli} X^{r}_{pkli} \quad (1)$$

Subject to

$$\sum_{i \in I} \sum_{j \in J} X^{f}_{pijk} \geq d_{pk} \ , \ \forall p \in P, \ k \in K \quad (2)$$

$$\sum_{p \in P} \sum_{i \in I} \sum_{k \in K} \alpha_p X^{f}_{pijk} \leq M_j Z_j \quad \forall j \in J \quad (3)$$

$$\sum_{l \in L} \sum_{i \in I} X^{r}_{pkli} \geq r_{pk}, \ \forall k \in K, \ p \in P \quad (4)$$

$$\sum_{p \in P} \sum_{k \in K} \sum_{i \in I} \alpha_p X^{r}_{pkli} \leq M_l G_l \quad \forall l \in L \quad (5)$$

$$X^{f}_{pijk} \leq 0, \quad p \in P, \ \forall i \in I, \ \forall j \in J, \ k \in K \quad (6)$$

$$X^{r}_{pkli} \leq 0, \quad p \in P, \ \forall i \in I, \ \forall l \in L, \ k \in K \quad (7)$$

$$Z_j \in (0,1), \ \forall j \in J \quad (8)$$

$$G_l \in (0,1), \ \forall l \in L \quad (9)$$

This model has the objective (1) of minimizing the total cost of a distribution network that consists of the fixed and variable costs of warehouses and collection centers, transportation costs while maximizing cost savings from utilizing hybrid warehouse-collection centers. Constraint (2) guarantees that the total volume of products demanded by a client's customer should be satisfied. Constraint (3) assures that the total volume of products shipped to customers cannot exceed the capacity of the warehouse serving them. Constraint (4) ensures that the returned products are taken back to the plant of a client. Constraint (5) assures that the total number of returned products cannot exceed the capacity of a collection center. Constraints (6) and (7) preserve the non-negativity restrictions on the decision variables while constraints (8) and (9) ensure the binary integrality of decision variables.

The proposed mixed integer model has nonlinear components in the objective function (1), calculating cost savings from opening hybrid facilities so that after adding dummy variables (=Q_s) indicating whether incurring cost saving or not, we convert it into a linear model. The objective function can be rearranged using binary variable Q_s as follows:

P' : Minimize

$$\sum_{j \in J} \left[w_j Z_j + v_j \sum_{p \in P} \sum_{i \in I} \sum_{k \in K} \alpha_p X^{f}_{pijk} \right] +$$

$$\sum_{l\in L}\left[r_l G_l + u_l \sum_{p\in P}\sum_{i\in I}\sum_{k\in K}\alpha_p X^r_{pkli}\right] -$$

$$\sum_{s\in S} h_s Q_s + \sum_{p\in P}\sum_{i\in I}\sum_{j\in J}\sum_{k\in K} c^f_{pijk} X^f_{pijk} +$$

$$\sum_{p\in P}\sum_{k\in K}\sum_{l\in L}\sum_{i\in I_0} c^r_{pkli} X^r_{pkli} \tag{10}$$

Next, we add more constraints into the set of original constraints as follows:

$$Z_s + G_s - 2Q_s \geq 0, \quad \forall s \in S \tag{11}$$

$$Z_s + G_s - Q_s \leq 1, \quad \forall s \in S \tag{12}$$

Constraint (11) assures that if either a warehouse located in s ($=Z_s$) or a collection located in s ($=G_s$) is close, Q_s should be 0. Constraint (12) ensures that if both Z_s and G_s are open, Q_s should be 1.

4. LAGRANGEAN RELAXATION METHOD

The mathematical model belongs a class of multi-commodity distribution network design models which are known to be NP-hard problems[20]. Hence, the solution methodology involves the development of heuristic procedures for the large size problems. In this paper, Lagrangean relaxation method is applied to get good solutions. The Lagrangean relaxation methods have been widely applied to facility location problems. Some of works are done by Geoffrion [9], Trangantalerngsak et al.[22], Beasley[4,5], Klincewicz and Luss[14], Barcelo and Casanovas[2]

Lagrangean relaxation method relaxes a set of constraints from an original problem (e.g., relaxing integrality constraints) and then adds them to the objective function of the problem using Lagrangean multipliers. This transformation aims to make the relaxed problem easier to solve than the original problem. The solution of the relaxed problem with the suitable multipliers thus provides a lower bound to the original problem (in case of minimization). Then, the Lagrangian dual problem is to find the values of the multipliers for achieving the tightest possible lower bound progressively. The dual problems are solved by updating the multipliers which is generally done by a subgradient method. The solutions of Lagrangian dual problem thus provide information to find optimal feasible solution for an upper bound. To find an upper bound, a heuristic procedure is typically applied. The solution procedure by Lagrangean method is finally terminated by convergence criteria between an upper bound and a low bound.

4.1 Lower Bound

In this paper, the Lagrangian relaxation P' is obtained after the constraints (2) and (4) in the original problem, enforcing each customer to be served are relaxed using ϕ_{pk} and ω_{pk}. In addition, in order to produce tighter lower bonds and increase the chance of getting a feasible solution [32, 9], the surrogate constraint (13) and (14) are added for LR1 and LR2 respectively:

$$\sum_j M_j Z_j \geq \sum_p \sum_k d_{pk} \tag{13}$$

$$\sum_j M_l G_l \geq \sum_p \sum_k r_{pk} \tag{14}$$

Thus, the mathematical representation of P' is as follows:

P': $\text{LR}(\phi_{pk}, \omega_{pk}) =$

$$\text{Min} \sum_{j\in J}\left[w_j Z_j + v_j \sum_{p\in P}\sum_{i\in I}\sum_{k\in K}\alpha_p X^f_{pijk}\right]$$

$$+ \sum_{l\in L}\left[r_l G_l + u_l \sum_{p\in P}\sum_{i\in I}\sum_{k\in K}\alpha_p X^r_{pkli}\right]$$

$$- \sum_{s \in S} h_s Q_s + \sum_{p \in P} \sum_{i \in I} \sum_{j \in J} \sum_{k \in K} c^f_{pijk} X^f_{pijk}$$

$$+ \sum_{p \in P} \sum_{k \in K} \sum_{l \in L} \sum_{i \in I_0} c^r_{pkli} X^r_{pkli}$$

$$+ \phi_{pk} (d_{pk} - \sum_{i \in I} \sum_{j \in J} X^f_{pijk})$$

$$+ \omega_{pk} (r_{pk} - \sum_{l \in L} \sum_{i \in I} X^r_{pkli}) \qquad (15)$$

Subject to (3), (5), (6), (7). (13), and (14). Then, problem P' can be separated into three sub-problems, such as the relaxed forward problem (LR1), the relaxed backward problem (LR2), and the cost saving problem (LR3). In doing so, the sum of objective functions of the three subproblems provides a lower bound on the objective value of the original problem. The subproblems are mathematically expressed as follows:

LR1(ϕ_{pk}) : Minimize

$$\sum_{p \in P} \sum_{k \in K} \phi_{pk} d_{pk}$$

$$- [\text{Max} \sum_{p \in P} \sum_{i \in I} \sum_{k \in K} (\phi_{pk} - v_j \alpha_p - c^f_{pijk}) X^f_{pijk}$$

$$- \sum_{j \in J} w_j Z_j \ ] \qquad (16)$$

Subject to (3), (6), (8), and (13).

LR2(ω_{pk}) : Minimize

$$\sum_{p \in P} \sum_{k \in K} \omega_{pk} d_{pk}$$

$$- [\text{Max} \sum_{p \in P} \sum_{i \in I} \sum_{k \in K} (\omega_{pk} - u_l \alpha_p - c^r_{pkli}) X^r_{pkli}$$

$$- \sum_{l \in L} r_l G_l \ ] \qquad (17)$$

Subject to (5), (7), (9), and (14).

$$\text{LR3: Minimize} \ - \sum_{s \in S} h_s Q_s \qquad (18)$$

Subject to

$$Z_s + G_s - 2Q_s \geq 0, \quad \forall s \in S \qquad (19)$$

$$Z_s + G_s - Q_s \leq 1, \quad \forall s \in S \qquad (20)$$

Now, in order to solve the subproblems, LR 1(ϕ_{pk}) and LR 2(ω_{pk}) are all knapsack problems. Thus, Bitran et al.[7] show that LR1(ϕ_{pk}) and LR 2(ω_{pk})can be separated into independent knapsack problems for each $j \in J$ and $l \in L$ respectively in order to solve LR 1(ϕ_{pk}) for a given ϕ_{pk} and LR 2(ω_{pk}) for given ω_{pk}. Then, LR 1(ϕ_{pk}) and LR 2(ω_{pk}) can be redefined as follows:

$$\text{LR1}(\phi_{pk}) = \quad \text{Minimize} \sum_{p \in P} \sum_{k \in K} \phi_{pk} d_{pk}$$

$$- \sum_{j \in J} Sub_j [LR(\phi_{pk})] \ Z_j$$

Subject to (13) and (8)

where Sub_j [LR1(ϕ_{pk})] = $-w_j$

$$- \text{Max} \sum_{p \in P} \sum_{i \in I} \sum_{k \in K} (\phi_{pk} - v_j \alpha_p - c^f_{pijk}) X^f_{pijk}$$

subject to

$$\sum_{p \in P} \sum_{i \in I} \sum_{k \in K} \alpha_p X^f_{pijk} \leq M_j \ , \quad \forall j \in J$$

$$X^{f}_{pijk} \leq 0, \quad p \in P, \ \forall i \in I, \ \forall j \in J.$$

$$\text{LR 2}(\omega_{pk}) = \text{Minimize} \sum_{p \in P} \sum_{k \in K} \omega_{pk} d_{pk}$$

$$- \sum_{l \in L} Sub_l [LR(\omega_{pk})] G_l$$

Subject to (14) and (9)

$$\text{where} \quad Sub_l [\text{ LR } 2(\omega_{pk})] = - \ r_l$$

$$- \text{ Max} \sum_{p \in P} \sum_{i \in I} \sum_{k \in K} (\omega_{pk} - u_l \alpha_p - c^{r}_{pkli}) X^{r}_{pkli}$$

subject to

$$\sum_{p \in P} \sum_{k \in K} \sum_{i \in I} \alpha_p X^{r}_{pkli} \leq M_l$$

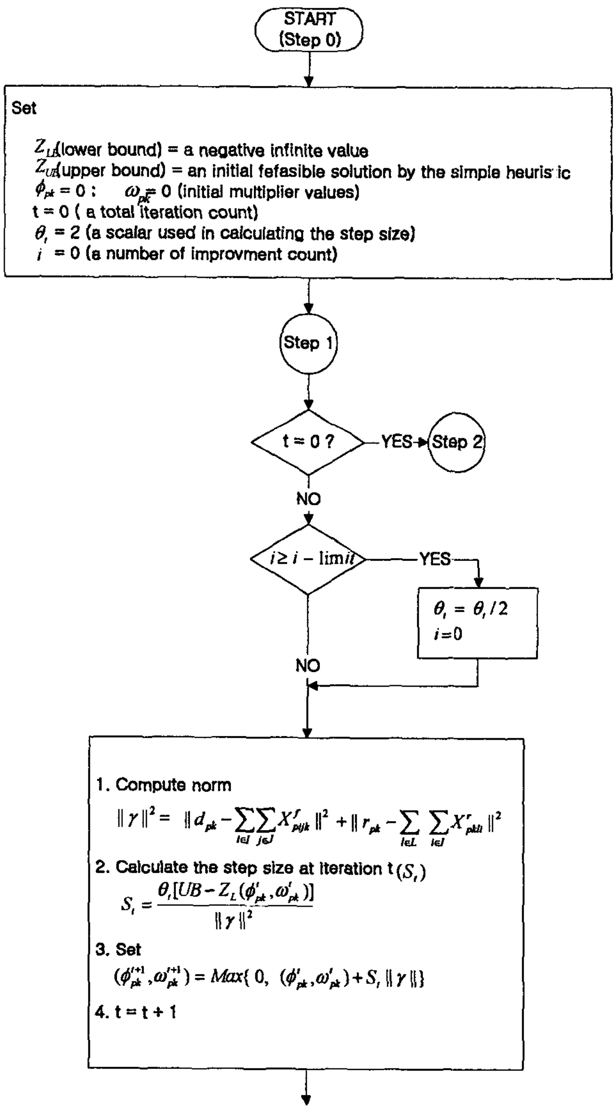
$$X^{r}_{pkli} \leq 0, \quad p \in P, \ \forall i \in I, \ k \in K.$$

Finally, LR3 is obtained based on the solutions of LR1(ϕ_{pk}) and LR 2(ω_{pk}) to calculate cost savings.

4.2 Upper Bound and Subgradient Method

The quality of the feasible solution on Lagrangian relaxation is important since the best solution obtained may be the optimal solution to the original solution. At the start, the feasible solution for an initial upper bound is needed. In this paper, it can be simply determined as follows: i) Opening minimum fixed cost candidate warehouses and repair centers while satisfying a total demand of customers. ii) Assigning closest customers to appropriate facilities until the total capacity of the facilities exceeds the total demand of the customers.

Next, the computation of upper bounds within a subgradient algorithm is carried out by the following steps: i) The opening/closing decision variables (Z_j and G_l) are obtained from the Lagrangean dual problem. ii) Based on the decision variables in i), assignment variables (X^{f}_{pijk} and X^{r}_{pkli}) are determined by a subalgorithm . This can be a transshipment algorithm by which the relaxed constraints are spontaneously satisfied. Finally, the objective of the subgradient optimization procedure is to find appropriate multipliers by updating the lower bound from the Lagrangean dual problem. The description of the subgradient procedure is showed in Figure 3.



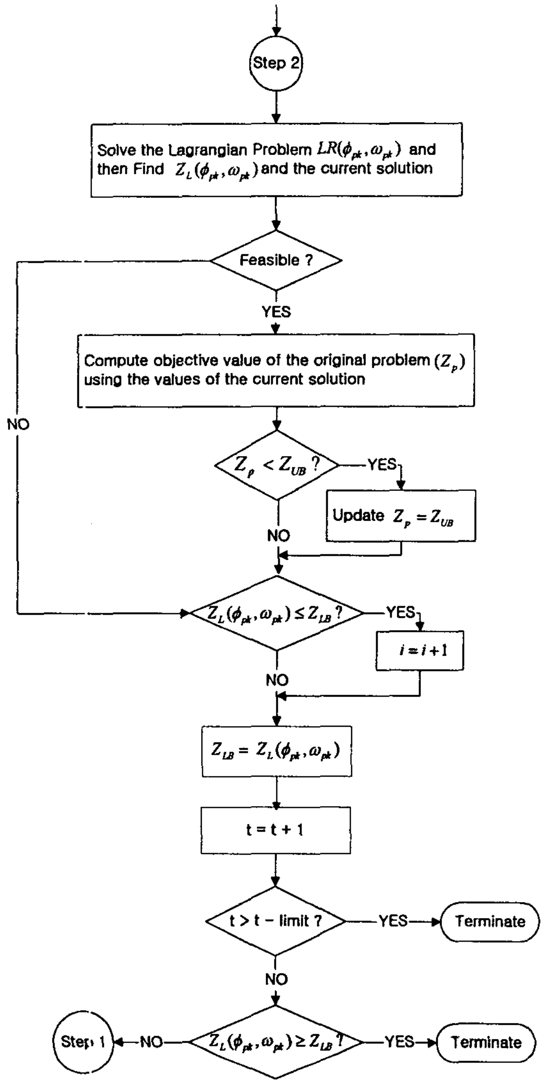


Figure 3. A Description of Subgradient Procedure

5. COMPUTATIONAL TESTING

The proposed algorithm was applied to a base-line model for a 3PL, facing to develop a distribution network for providing forward and reverse logistics services. There were two clients who made a contract with the 3PL, and each of them had ten customers to be served for forward and backward flows. Also, we assumed that plant locations of the clients, locations of their customers, and demands of the customers were known. Demands and returns in each client are assumed to be 10% of forward flow and is summarized in Table 1. The plant locations of the clients and the potential locations of warehouses as well as collection centers are shown in Table 3. Opening a hybrid warehouse-collection center is meant when a warehouse and a collection center are open in the same location. This hybrid facility thus achieves cost savings ($= h_s$) by sharing infrastructure, material handling equipment, transportation costs, etc, and five potential locations are considered as shown in Table 2. Additionally, Table 3 summarizes the parameter settings for this model.

Table 1. Customer Data for Forward and Reverse Flows in the Base-Line Model

	Client 1				Client 2			
Index	**X**	**Y**	**Demand**	**Return**	**x**	**y**	**Demand**	**Return**
1	126.32	109.07	100	10	122.24	107.40	200	20
2	100.13	57.31	100	10	114.20	189.92	200	20
3	23.51	109.17	100	10	49.04	68.38	200	20
4	91.72	3.33	100	10	25.69	51.08	200	20
5	68.76	173.12	100	10	118.27	107.00	200	20
6	154.10	44.67	100	10	137.47	99.24	200	20
7	96.91	137.61	100	10	152.93	32.58	200	20
8	199.04	135.93	100	10	6.88	185.71	200	20
9	166.96	57.56	100	10	173.68	137.95	200	20
10	186.57	128.87	100	10	150.23	5.47	200	20

Table 2. Facility Data in the Base-Line Model

	Warehouse			Collection Center			Plant of Client		
Index	x	y	**Capacity**	x	Y	**Capacity**	x	y	**Capacity**
1	74.30	114.15	6000	74.30	114.15	600	20.12	80.02	unlimited
2	91.18	166.71	6000	91.18	166.71	600	197.60	16.06	unlimited
3	98.90	120.47	6000	98.90	120.47	600			
4	90.85	4.13	6000	90.85	4.13	600			
5	58.90	167.85	6000	58.90	167.85	600			

Table 3. Parameter Settings in the Base-Line Model

	Index	Value
Fixed cost of opening warehouse j	w_j	\$10,000
Fixed cost of opening collection center l	r_l	\$5,000
Weight factor of product p based on characteristics of the product type	α_p	1
Maximum capacity of warehouse j	M_j	3000 units
Unit transportation cost of client's plant-warehouse	c_{ij}^f	\$0.05
Unit transportation cost of warehouse-customer	c_{jk}^f	\$0.1
Unit variable cost of serving demand of product p at customer k from plant i and warehouse j, including transportation and handling cost	c_{pijk}^f	$c_{ij}^f k_{ij} + c_{jk}^f k_{jk}$
Unit variable cost for warehouse j	v_j	\$100
Unit variable cost for collection center l	u_l	\$50
Cost savings from opening hybrid warehouse-collection center s	h_s	\$4,000
Maximum capacity of collection center l	M_l	300 units
Unit transportation cost of collection center-client's plant	c_{li}^r	\$0.05
Unit transportation cost of customer-collection center	c_{kl}^r	\$0.5
Unit variable cost of taking back returned product p from customer k via collection center l to plant i, including transportation and handling cost	c_{pkli}^r	$c_{kl}^r k_{kl} + c_{li}^r k_{li}$

k_{xy} indicates the Euclidian distance between locations x and y.

Based on the above data, we solved the base-line model using the Lagrangian method on a Pentium IV personal computer equipped with 512MB of memory. The solution showed that opening a warehouse (W3) and two collection centers (R1, R3) was recommended, in which one hybrid facility was set up so that possible effect of cost savings was gained. Table 4 and 5 show a summary of the base-line model.

Table 4. The Summary of the Solutions in the Base-Line Model

Index	1	2	3	4	5
Warehouse	0	0	1	0	0
Collection center	1	0	1	0	0
Hybrid	0	0	1	0	0

1 (=opening); 0 (=closing)

Table 5. The Cost Summary of the Base-Line Model

Cost components	
Cost of operating warehouses	\$310,000.0
Cost of forward transportation	\$25,000.0
Cost of operating collection centers	\$41,341.1
Cost of reverse transportation	\$12,426.6
Savings	-\$4,000.0
Total cost	**\$384,767.7**

Then, to check the robustness of the base-line solution, additional computational experiments were conducted to assess the computational effectiveness of the Lagrangean heuristic. This involved solving five test problems of varying the number of products, distribution centers, collection centers, and customer zones including the above example problem. The potential locations of the centers and customers were generated from a uniform distribution with minimum and maximum distance of 0 and 200, respectively on the x and y coordinates. Customer demands were also generated as uniformly distributed random numbers from 100 to 300. Cost data and other parameters were appropriately set according to the problem size. In subgradient method, the convergence criteria = 0.001; maximum iteration = 50; Lagrangean relaxation method in this paper was carried out using GAMS software. Table 6 shows the results of the test problems. The performance of the Largaingian method provided tight bound since the gaps in all cases were less than 2%.

Table 6. The Results of the Test Problems

No.	P	W	R	C	Lagrangean (Lower bound; Upper bound)	Gap (UB-LB)/LB
1	1	5	5	20	(131,667.5; 132,585.3)	0.007
2	2	5	5	40	(377,320.6; 384,767.8)	0.020
3	3	10	10	60	(738,069.9; 744,275.9)	0.010
4	3	15	15	120	(1,455,805.3; 1,467,490.1)	0.008
5	3	20	20	180	(2,173,621.3; 2,180,926.0)	0.003

P: the total number of clients' products; W: the total number of warehouses; R: the total number of collection centers; C: the total number of customer zones.

6. CONCLUSIONS

A growing number of companies begin to realize the importance of implementing integrated supply chain management since they are under pressure for filling customers' orders on time as well as for efficiently taking returned products back from customers after selling products. In terms of product flows, there are two flows in an integrated supply chain, which are forward logistics and reverse logistics. 3PLs are playing an increasing role in supporting such integrated supply chain management using sophisticated information systems and dedicated equipments. Up to date, most studies however have involved in either forward or reverse flows so that the objective of this paper aims to aid 3PLs in making strategic decisions with their network design, considering possible effects by integrating forward and reverse flows. This paper aims to help 3PLs to make strategic decisions for designing their logistics networks with both forward and reverse flows. This paper thus proposed a mixed integer programming model and an efficient heuristic based on Lagrangean relaxation since the mathematical model belongs to a class of NP hard problem. Then, the validity of proposed heuristic was evaluated using some test problems. As a result, it provided tight bound having less than 2% of gaps in all cases.

As further research areas, we suggest to apply this kind of approach in the real world situation with the cooperation of 3PLs. And we also need to develop another heuristics such as genetic algorithm and tabu search, and conduct more efficient solution method by comparing their solution performances with the lower and upper bound in this paper.

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