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재회수를 고려한 공유택배함의 폐쇄 루프 공급망 네트워크

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Replication of Reuse Sharing Express Boxes in Closed Loop Supply Chain Network

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요 약 전자상거래 경제의 발전은 급행산업에 막대한 이익을 가져다주었지만, 압도적인 급행포장은 환경에 돌이킬 수 없는 피해를 가져왔다. 중국의 특급사업량은 세계 1위를 차지한 지 오래지만 특급포장의 재사용 및 재활용률은 20%에도 미치지 못한다. 이러한 문제점을 개선하기 위해 재사용 공유 익스프레스 박스 영역이 많은 관심을 끌고 있다. 따라서 본 연구에서는 공유 익스프레스 박스 산업에서 재사용(CSN)을 동시에 고려한 폐쇄 루프 공급망(CLSC) 네트워크를 제안한다. CSN 모델의 성능을 검증하기 위해 CSN 모델을 수학적 공식으로 표현하고 유전 알고리즘(GA)으로 구현한다. 수치 실험에서 CSN 모델에는 다양한 척도가 적용된다. 계산 결과는 비용 측면에서 CSN 모델의 효율성을 보여주며 GA가 제안된 CSN 모델을 최적화하고 향후 연구 방향을 요약한다는 것을 확인한다.

키워드 : 친환경 폐쇄 루프 공급망 네트워크; 재활용; GA; 환경; 최적화

Abstract The development of e-commerce economy has brought huge profits to the express industry, but the overwhelming express packaging has brought irreparable damage to the environment. China's express business volume has long ranked first in the world, but the reused and recycling rate of express packaging is less than 20%. To improve this problem, reuse sharing express boxes area have attracted much attention. Therefore, this study proposes a closed-loop supply chain (CLSC) network considering reuse (CSN) simultaneously in sharing express boxes industry. To verify the performance of the CSN model, the CSN model is represented as a mathematical formulation and implemented by genetic algorithm (GA). In the numerical experiment, the various scales are applied in the CSN model. Computation results show that the efficiency of CSN model in terms of costs and it confirms that the GA optimizes the proposed CSN model and summarizes the future research direction.

Key Words : Closed loop supply chain network, Reuse, GA, Environment, Sharing express boxes

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1. Introduction

The current use of a large number of packaging materials puts tremendous pressure on the ecological environment and is not conducive to the strategic goal of sustainable development. According to the data released by the State Post Office, as of 2020, China's total express delivery business has reached 2104.32 billion, and the postal delivery service business has reached 25.56 billion in 2020[1]. By using the sharing express box (SHB), the waste in the process of logistics packaging can be reduced, the resources can be reused and recycled, the consumption of natural resources can be reduced, the reuse rate of packaging can be improved, and the environmental ecological health development can be facilitated [2,3].

By 2019, the annual consumption of plastic bags has exceeded 4 million tons, and the annual consumption of express plastic packaging is about 1.8 million tons. Paper express packaging can be recycled, but the recovery rate of plastic material packaging is less than 1%. Behind such a huge amount of data, we are faced with the environmental protection problem of less than 20% recovery rate of express packaging. As early as 2017, Suning has launched the SHB, but it has not been widely promoted [4]. In South Korea, coupang has massively popularized the SHB. And the SHB is a new type of express packaging that generally uses environmentally-friendly degradable plastic, through structure and shape design, and uses intelligent identification and tracking technology[5].

Therefore, an efficient supply chain network considering reuse and is an aren of concern. Thus, this study proposes a closed-loop supply chain (CLSC) network considering reuse (CSN) model simultaneously in SHB industry. Thus, this study attempts to use the single algorithm to verify the performance of the CSN model, the CSN model is implemented using the GA approach, and put forward future research directions.

2. CSN Model

The CSN model comprises the manufacturer (MF), handling center (HC), consumer (CS), collection center (CL) and disassembling center (SC). The conceptual flow of the proposed CSN model is illustrated in Fig. 1. In the CSN model, packaging boxes contain SHB and repair packaging fillers (REF).

In the CSN model, the manufacturer produces a REX, the items ordered by the consumer are packaged at the handling center. They are packed at the handling center based on the method selected by the consumer and finally reach the consumer. After the consumer receives the express, the REF should be sent to a designated location and collected at the collection center in a centralized manner. The collection center will collect the REF that can be used for secondary purposes and deliver it from the collection center to the handling center, while also delivering the rest of the REF to the disassembing center. After being processed by the disassembing center, the REF is delivered to handling center.

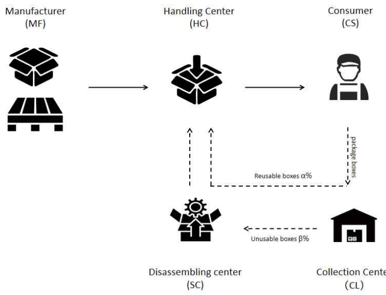

Fig. 1. Conceptual flow of the CSN model

3. Mathematical Formulation

The following assumptions are used in representing the proposed CSN model.

- Consider only linear distance.
- The numbers of MFs, HCs, CLs and SCs are fixed and known beforehand.
- The unit fixed costs considered by each facility are constant, different from each other, and known

beforehand.

- The unit handling costs considered by each facility are constant, different from each other, and known beforehand.

- The unit transportation costs considered for each facility are constant, different from each other, and known beforehand.

- The proposed CSN model is considered to remain in a steady-state condition.

- Index Set

f: index of manufacturer center.

h: index of handling center.

i: index of consumer.

j: index of collection center.

k: index of disassembling center.

- Parameters

FFF_f: fixed cost at manufacturer center f.

FFH_h: fixed cost at handling center h.

FFJ_j: fixed cost at collection center j.

FFK_k: fixed cost at disassembling center k.

HHF_f: unit handling cost of packaged boxes at manufacturer center f.

HHH_h: unit handling cost of packaged boxes at handling center h.

HHJ_j: unit handling cost of packaged boxes at collection center j.

HHK_k: unit handling cost of packaged boxes at disassembling center k.

TFH_{fh}: unit transportation cost from manufacturer center f to handling center h.

THI_{hi}: unit transportation cost from handling center h to consumer i.

TIJ_{ij}: unit transportation cost from consumer i to collection center j.

TJH_{jh}: unit transportation cost from collection center j to handling center h.

TJK_{jk}: unit transportation cost from collection center j to disassembling center k.

TKH_{kh}: unit transportation cost from disassembling center k to handling center h.

QFH_{fh}: quantity of packaging boxes transported from manufacturer center f to handling center h.

QHI_{hi}: quantity of packaging boxes transported from handling center h to consumer i.

QIJ_{ij}: quantity of packaging boxes transported from consumer i to collection center j.

α : the percentage of reused packaging boxes from collection center j to handling center h.

β : the percentage of repair packaging boxes from collection center j to disassembling center k.

- Decision Variables

yf_f : takes the value of 1 if manufacturer center f is opened and 0 otherwise.

yh_h : takes the value of 1 if handling center h is opened and 0 otherwise.

yj_j : takes the value of 1 if collection center j is opened and 0 otherwise.

yk_k : takes the value of 1 if disassembling center k is opened and 0 otherwise.

The objective function serves to minimize the total cost (TTC), as shown in Equation(1). In Equation(1), TTC is the aggregate of the total handling cost (HC), total transportation cost (TC) and total fixed cost (FC).

$$TTC = HC + TC + FC \qquad (1)$$

$$\begin{aligned} HC = & \sum_f \sum_h HHF_f * QFH_{fh} * yf_f * yh_h + \\ & \sum_h \sum_i HHH_h * QHI_{hi} * yh_h + \\ & \sum_i \sum_j HHJ_j * QIJ_{ij} * yj_j + \\ & \sum_i \sum_j \sum_k HHK_k * QIJ_{ij} * \beta * yj_j * yk_k \end{aligned} \qquad (2)$$

$$TC = \sum_f \sum_h TFH_{fh} * QFH_{fh} * yf_f * yh_h + \sum_h \sum_i THI_{hi} * QHI_{hi} * yh_h + \sum_i \sum_j TIJ_{ij} * QIJ_{ij} * yj_j + \sum_i \sum_j \sum_h TJH_{jh} * QIJ_{ij} * \alpha * yj_j * yh_h + \sum_i \sum_j \sum_k TJK_{jk} * QIJ_{ij} * \beta * yj_j * yk_k + \sum_h \sum_i \sum_j \sum_k TKH_{kh} * QIJ_{ij} * \beta * yh_h * yj_j * yk_k \quad (3)$$

$$FC = \sum_f FFF_f * yf_f + \sum_h FFH_h * yh_h + \sum_j FFJ_j * yj_j + \sum_k FFK_k * yk_k \quad (4)$$

Equation(2) represents the sum of the handling costs. Equation(3) represents the sum of the transportation costs. In Equation(4), the first term represents the sum of the fixed cost of MF and the fixed cost of HC, whereas the third term is the fixed cost of CL. The fourth term is the SC fixed cost.

The objective function, shown in Equation(1), should be optimized concerning the following constraints:

$$\sum_f yf_f = 1 \quad (5)$$

$$\sum_h yh_h = 1 \quad (6)$$

$$\sum_j yj_j = 1 \quad (7)$$

$$\sum_k yk_k = 1 \quad (8)$$

$$yf_f \in 0,1, \forall F \quad (9)$$

$$yh_h \in 0,1, \forall H \quad (10)$$

$$yi_i \in 0,1, \forall I \quad (11)$$

$$yj_j \in 0,1, \forall J \quad (12)$$

$$yk_k \in 0,1, \forall K \quad (13)$$

$$QFH_{fh} \leq QHI_{hi} \quad (14)$$

$$QHI_{hi} \leq QIJ_{ij} \quad (15)$$

$$f \in F, h \in H, i \in I, j \in J, k \in K \quad (16)$$

Equations(5) – (8) indicate that only one facility should be opened at each stage. Equations(9) – (13) indicate that the quantity of each stage is the same or greater than that of the previous stage. Moreover Equations(14) – (15) suggest that each decision variable should adopt a value of 0 or 1. Furthermore, Equation(16) refers to the non-negativity.

4. GA Approach

As we known, most of complicated network models including the proposed CSN model have been known as NP-complete[6,7]. Most of conventional literatures have shown that metaheuristic approaches such genetic algorithm (GA), have been applied to efficiently solve the complicated network models[8,9].

The term of genetic algorithm (GA) was firstly proposed by John Holland (1975). Simultaneously, the GA was extended to the area of functional optimization by De Jong (1975), and then improved upon by Goldberg (1985). Finally, an influential book 'Genetic Algorithm in Search, Optimization, and Machine Learning' (Goldberg, 1989) was published. Thus, the GA theory was established along with the sustained development and application.

The GA is a robust, stochastic, and powerful heuristic search method based on the mechanism of natural selection and evolution[10]. The specific implementation process of GA approaches are shown as follows:

```
Procedure: Genetic Algorithm
input: GA parameters
output: best solution
begin
a←0;
initialize H(a) by encoding routine;
evaluate H(a) by decoding routine;
while (not termination condition) do
begin
```

```
crossover H(a) to yield G(a);
mutation H(a) to yield G(a);
evaluate G(a) by decoding routine;
select H(a+1) from H(a) and G(a);
a ← a+1;
end
output best solution;
end
```

5. Numerical Experiments

For the numerical experiments, three scales and various scenarios for the CSN model were considered, as shown in Table 1.

Table 1. Three scales of CSN model

Scale	MF	HC	CS	CL	SC
1	15	15	1	15	15
2	30	30	1	30	30
3	45	45	1	45	45

The conventional GA approach was programmed and run under a same computational environment (MATLAB R2021, DESKTOP-UTMF66M PC 2.50 GHz processor , CPU 4GB RAM, and Windows 10 Chinese Family Edition). The parameter settings for all approaches are as follows: population size is 20, crossover rate 0.5, and mutation rate 0.3 for the search process of GA in the GA. For various comparison using the performances of all approaches, four measures of performance are used as shown in Table 2.

Table 2. Performance Measures

Measure	Description
BS	Best solution(BS) in all trails
AS	Average solution(AS) through all trails
CPU	Averaged CPU time(CPU) through all trails (unit: set.)

From Table 3. It can be seen that the BS value of scale 1 is 179,500, the AS value is 181,283, the BS value of the scale 2 is 178,600, the AS value is 181,106, the BS value of scale 3 is 178,000, and the AS value is 180,880. Among the three scale, no AS or BS is not much different, and the CPU time is not much different. scale 3's BS and AS values are the best, that is, GA can find relatively good results in large scale.

Table 3. Computation Results for Scale 1 to 3

Scale	1	2	3
BS	179500	178600	178000
AS	181283	181106	180880
CPU	2.3s	2.2s	2.4s

Finally, the computational results of the best solution of the CSN model is 178,000, the location and allocation decision of the CSN model is shown in Table 4. The opened number of facility at each stage is shown in Table 4.

Table 4. Location and allocation decision in Scale 3 along with best solution

Stage	MF	HC	CS	CL	SC
No.	32	15	1	8	3

6. Conclusion

In this study, the CSN model proposed by referring to the closed-loop supply chain network used in the existing research has the following characteristics.

Firstly, this study proposes a closed-loop supply chain (CLSC) network considering reuse (CSN) simultaneously in sharing express boxes industry. And through verification, the use of sharing express boxes can not only protect the environment, but also enable the reuse of resources.

Finally, through the results of the value experiment, we can see that the larger the GA's optimization effect in the scale, the more obvious it is, and it plays an optimized role in the CSN model. Explain that GA can solve such problems.

At present, most scholars are concentrated on the theoretical basis such as sharing express box design and have not been applied to the closed-loop supply chain. Therefore, we propose the CSN model considering reuse. This study only considers a single method (GA) to optimize the supply chain network, develop hybrid algorithms in the future, and consider using real data to verify the rationality of the model proposed in the future.

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