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Optimization of green closed loop supply chain network considering recycling express box

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재활용 익스프레스 박스를 고려한 친환경 폐쇄 루프 공급망 네트워크 최적화

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Abstract This paper proposes a green closed-loop supply chain network (GCSN) for optimizing closed-loop supply chains. The GCSN focuses on the application of the recycling express box in logistics circulation, accelerates the standardization of logistics operations and the use of express packaging in e-commerce companies, and promotes the reduction and greening of recycling express box in the e-commerce industry. The GCSN is represented as a mathematical formulation and implemented using LINGO. Greening, environmental protection, and wisdom are the general trends for promoting the growth of the e-commerce industry. Meanwhile, the price of raw materials has increased owing to a shortage of resources, which emphasizes the need for e-commerce enterprises to develop green packaging. Therefore, this study considers the shared circular packaging launched by e-commerce enterprises as the research object, and integrates the problem of facility positioning and path planning in the logistics system. The conclusion summarizes the significance of this study.

Key Words : Green closed loop supply chain network; recycling; LINGO; environment; optimization

요 약 본 연구는 폐쇄루프 공급망을 최적화하기 위한 녹색 폐쇄루프 공급망 네트워크(GCSN)를 제안한다. GCSN은 물류 유통과정에 투입되는 익스프레스 박스의 재활용에 중점을 두고 연구하였다. 이를 통해 물류공급망 작업의 표준화와 전자상거래 업체의 증가에 따른 익스프레스 박스의 사용의 가속화와 전자상거래 업계의 익스프레스 상자의 재활용을 통한 자원 낭비를 최소화하는 녹색공급망을 추진한다. GCSN은 유통흐름과 자원의 투입요소는 수학식으로 표현하며 LINGO를 사용하여 구현된다. 녹생 즉, 환경 보호의 관점에서 전자상거래 산업의 지속가능한 발전을 견인하는 유통의 과정이다. 또한 자원 부족에 따른 원자재 가격 상승에 대응하고 전자상거래 업체들의 친환경적으로 익스프레스 상자를 투입하는 전략의 필요성을 부각시켰다. 이와 같은 이유로 본 연구는 전자상거래 업체에서 사용하는 재활용이 가능한 익스프레스상자를 연구대상으로 하며, 공급망 네트워크에서 시설 위치와 할당문제도 통합적으로 고찰한다. 마지막으로 본 연구의 결론과 시사점을 도출하였다.

주제어 : 친환경 폐쇄 루프 공급망 네트워크; 재활용; LINGO; 최적화

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1. Introduction

The growth in express business has raised certain environmental concerns owing to the use of express packaging. Express packaging boxes are generally disposable and include items such us plastic bags and tapes, which exhibit non-degradable features. Consequently, the garbage pollution caused by express packaging is currently one of the most important environmental concerns to be addressed[1].

As a part of the drive toward sustainable development, the state has introduced a series of measures to promote the development of green packaging, with the aim of addressing environmental pollution. There also exists a growing emphasis on the development of the recycling express box (REX). Therefore, to realize the sustainable development of logistics enterprises, the preparation and production processes of express boxes should incorporate green environmental protection, strengthen the reuse of express boxes, achieve the goal of ecological protection, and build a good circular economy system[2].

The Chinese scholar Lei[3] was the first to systematically propose the concept of shared recycling packaging (SCP). REX refers to express packaging that can be reused; the turnover cost for a single use is lower than that for standard disposable express packaging boxes. Compared with traditional boxes, REX features sufficient hardness, effectively reduces internal filling, and adopts folding methods during the recycling stage to improve the actual loading rate of transportation [4]. Furthermore, the most significant change in the case of "REX" is the reduction of the box and packaging waste generated by express parcels, thus resulting in a reduction in the overall packaging waste [5].

Lulu et al. (2018) established a location optimization model based on LINGO packaging waste recycling logistics nodes[6]. Zhangxinwei et al. [7] used LINGO to determine the initial candidate location of the air hub. Wei et al. (2021) utilized LINGO to solve the vehicle routing problem (VRP)[8]. With regard to such existing literature , this study employs LINGO to solve the model. Specifically, this study aims to develop a REX, establish and optimize a green closed loop supply chain network (GCSN), considering the location problem. This study draws on the existing distribution methods of Coupang in South Korea to conduct research, which lays a practical foundation for the large-scale implementation of REX in the future.

The remainder of this study is organized as follows. In Section 2, we comprehensively describe the GCSN to be studied . Section 3 presents the mathematical model for the GCSN. In Section 4, the LINGO approach is presented by implementing the mathematical model and considering the relative weights. Section 5 presents the computational results and analyses of the numerical experiments using various relative weights. Lastly, the conclusions of this study are presented in Section 6.

2. GCSN

The GCSN comprises the handling center (HC), distribution center (DC), consumer (CS), disposal center (DP), collection center (CL), and recycling center (RC). The conceptual flow of the proposed GCSN is illustrated in <Figure. 1>. In the GCSN, packaging boxes contain REX and non-reusable packaging fillers (n-RPF). The n-RPF includes non-reusable packaging fillers such as plastic, paper bags, etc.

Under the GCSN, the items ordered by the consumer are packaged at the HC. They are packed at the HC based on the method selected by the CS, distributed centrally from the DC, and finally reach the CS. After the CS receives the express, the REX should be sent to a designated

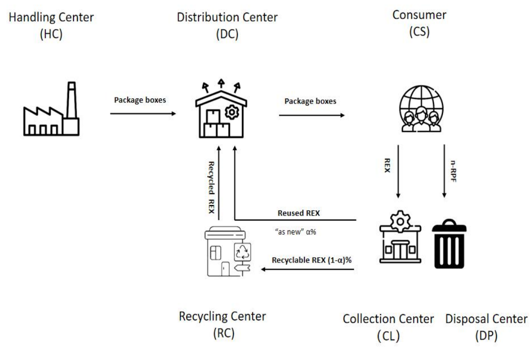

Fig. 1. Conceptual flow of the GCSN

location and collected at the CL in a centralized manner. Meanwhile, n−RPF is directly sent to the DP by the CS. The CL will collect the REX that can be used for secondary purposes and deliver it from the CL to the DC, while also delivering the rest of the REX to the RC. After being processed by the RC, the REX is delivered to DC.

3. Mathematical Formulation

The following assumptions are used in representing the proposed GCSN.

- Consider only linear distance.
- No priority in the distribution, recycling and reuse of the packaging box.
- The un−REX that cannot be used again is directly transferred from the CS to the DP.
- Only one CS and one DP are available in each group.
- The numbers of HCs, DCs, CLs and RCs are fixed and known beforehand.
- Consider only two packaged boxes.
- Each facility is open during distribution and collection.
- Delivery, collection, and recycling are performed irrespective of packaged box damage.
- The unit fixed costs considered by each facility are constant, different from each other, and known beforehand.
- The unit handing 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 GCSN model is considered to remain in a steady−state condition.

− Index Set

h: index of handling centers (h∈H)
i: index of distribution centers (i∈I)
j: index of collection centers (j∈J)
k: index of recycling centers (k∈K)
l: index of customer l (l∈L)
m: index of disposal center m (m∈M)

− Parameters

FH_h : fixed cost at handing center h.
FI_i : fixed cost at distribution center i.
FJ_j : fixed cost at collection center j.
FK_k : fixed cost at recycling center k.
FM_m : fixed cost at disposal center m.
HH_h : unit handling cost of packaged boxes at handing center h.
HI_i : unit handling cost of packaged boxes at distribution center i.
HJI_{ji} : unit handling cost of packaging box from collection center j to distribution center i.
HJK_{jk} : unit handling cost of packaging box from collection center j to recycling center k.
HK_k : unit handling cost of packaged boxes at recycling center k.
HM_m : unit handling cost of packaged boxes at disposal center m.
THI_{hi} : unit transportation cost from handing center h to distribution center i.

TIL_{il} : unit transportation cost from distribution center i to consumer l.

TLJ_{lj} : unit transportation cost from consumer l to collection center j.

TLM_{lm} : unit transportation cost from consumer l to disposal center m.

TJI_{ji} : unit transportation cost from collection center j to distribution center i.

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

TKI_{ki} : unit transportation cost from recycling center k to distribution center i.

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

QIL_{il} : quantity of packaging boxes transported from distribution center i to consumer l.

QLJ_{lj} : quantity of packaging boxes transported from consumer l to collection center j.

QLM_{lm} : quantity of packaging boxes transported from consumer l to disposal center m.

QKI_{ki} : quantity of packaging boxes transported from recycling center k to distribution center I.

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

p : the percentage of unusable packaging boxes in disposal center m.

PF : unit penalty fee in disposal center m.

\- Decision Variables

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

yi_i : takes the value of 1 if distribution center i 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 recycling center k is opened and 0 otherwise.

yl_l : takes the value of 1 if consumer l is opened and 0 otherwise.

ym_m : takes the value of 1 if disposal center m is opened and 0 otherwise.

The objective function serves to minimize the total cost (TC), as shown in Equation (1). In Equation (1), TC is the aggregate of the total handling cost (THC), total transportation cost (TTC), total fixed cost (TFC), and penalty fee in the disposal center (TNC).

$$TC = THC + TTC + TFC + TNC \tag{1}$$

$$\begin{aligned} THC = & \sum_h \sum_i HH_h * QHI_{hi} * yh_h + \\ & \sum_i \sum_l HI_i * QIL_{il} * yi_i + \\ & \sum_j \sum_i \sum_l HJI_{ji} * QLJ_{lj} * \alpha * yj_j + \\ & \sum_j \sum_k \sum_l HJK_{jk} * QLJ_{lj} * (1-\alpha) * yj_j + \\ & \sum_l \sum_m HM_m * QLM_{lm} * ym_m + \\ & \sum_k \sum_i HK_k * QKI_{ki} * yk_k \end{aligned} \tag{2}$$

$$\begin{aligned} TTC = & \sum_h \sum_i THI_{hi} * QHI_{hi} * yh_h + \\ & \sum_i \sum_l TIL_{il} * QIL_{il} * yi_i + \\ & \sum_l \sum_j TLJ_{lj} * QLJ_{lj} * yj_j + \\ & \sum_l \sum_m TLM_{lm} * QLM_{lm} * ym_m + \\ & \sum_l \sum_j \sum_i TJI_{ji} * QLJ_{lj} * \alpha * yj_j + \\ & \sum_l \sum_j \sum_k TJK_{jk} * QLJ_{lj} * (1-\alpha) * yj_j + \\ & \sum_k \sum_i TKI_{ki} * QKI_{ki} * yk_k \end{aligned} \tag{3}$$

$$\begin{aligned} TFC = & \sum_h FH_h * yh_h + \sum_i FI_i * yi_i + \\ & \sum_j FJ_j * yj_j + \sum_k FK_k * yk_k + \\ & \sum_m FM_m * ym_m \end{aligned} \tag{4}$$

$$TNC = (1+P) * QLM_{lm} * PF \tag{5}$$

Equation (2) represents the sum of the handling costs. In Equation (2), the first term is the HC handling cost, the second term is the DC handling cost, the third and fourth terms are the sum of the handling costs in the CL, the fifth term is the DP handling cost, and the sixth term is the RC handling cost.

Equation (3) represents the sum of the transportation costs. In Equation (3), the first term is the sum of the transportation costs from the HC to the DC. The second term is the sum of the transportation costs from the DC to the CS. The third term is the sum of the transportation costs from the CS to the CL. Further, the fourth term is the sum of the transportation costs from the CS to the DP. The fifth item is the sum of the transportation costs from the CL to the DC. The sixth term is the sum of the transportation costs from the CL to the RC. Lastly, the seventh item is the sum of transportation costs from the RC to the DC.

In Equation (4), the first term represents the sum of the fixed cost of HC and the fixed cost of DC, whereas the third term is the fixed cost of CL. The fourth term is the RC fixed cost. The fifth term is the DP fixed cost.

Equation (5) represents the sum of the penalty fee in the DP. This formula implies that excessive n-RPF will increase the penalty fee.

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

$$\sum_h yh_h = 1 \tag{6}$$
$$\sum_i yi_i = 1 \tag{7}$$
$$\sum_l yl_l = 1 \tag{8}$$
$$\sum_j yj_j = 1 \tag{9}$$
$$\sum_m ym_m = 1 \tag{10}$$
$$\sum_k yk_k = 1 \tag{11}$$
$$yh_h \in 0,1, \forall h \tag{12}$$
$$yi_i \in 0,1, \forall i \tag{13}$$
$$yl_l \in 0,1, \forall l \tag{14}$$
$$yj_j \in 0,1, \forall j \tag{15}$$
$$ym_m \in 0,1, \forall m \tag{16}$$
$$yk_k \in 0,1, \forall k \tag{17}$$
$$QHI_{hi} \leq QIL_{il} \tag{18}$$
$$QIL_{il} \leq QLJ_{lj} + QLM_{lm} \tag{19}$$
$$QHI_{hi} \geq QLJ_{lj} * \alpha + QKI_{ki} \tag{20}$$
$$QKI_{ki} \leq QLJ_{lj} * (1-\alpha) \tag{21}$$
$$h \in H, i \in I, l \in L, j \in J, m \in M, k \in K \tag{22}$$

Equations (6) – (11) indicate that only one facility should be opened at each stage. Equations (12) – (17) indicate that the quantity of each stage is the same or greater than that of the previous stage. Moreover Equations (18) – (21) suggest that each decision variable should adopt a value of 0 or 1. Furthermore, Equation (22) refers to the non-negativity.

4. LINGO Approach

LINGO is a set of software packages developed by LINGO Systems, United States, for solving optimization problems. It incorporates all the functions of Lindo for solving linear programming and quadratic programming problems and can also be used to address nonlinear programming problems, among others [9]. This study mainly focuses on the new version of the neutron model function in LINGO. The following is a brief introduction of the software neutron model: In LINGO 9.0 and the earlier versions, only one optimization model is allowed for each LINGO model window, which can be termed as the MAIN MODEL. In LINGO 10.0, in addition to this main model, users can also define a sub−model (SUBMODEL) in each LINGO model window. This sub model can be called in the calculation section of the main model, which further enhances the programming ability of LINGO[10]. Herein, considering the number of sites under Scale 1 as an example, each step under Scale 1 is explained in detail. The detailed implementation procedure for the LINGO approach is presented in <Figure 2>.

Fig. 2. LINGO approach

5. Numerical Experiments

For the numerical experiments, three scales and various scenarios for the GCSN were considered, as shown in <Table 1>.The first scenario includes the performance of the Best solution (BS); in this case, the CPU time and best stage are verified based on the results of each scale respectively .

The unit transportation cost data used in GCSN is randomly generated by EXCEL. The fixed cost is 100, the unit handling cost is 100, and the number of REX is 100. The ratios from CS to DP and CL are 0.1 and 0.9; and 0.5 and 0.5 from CL to RC and DC. The number of express boxes from CS to DP is 10, the number of REX from CS to CL is 90, and the number of REX from CL to DC and RC is 45 and 45.

To validate the viability of the proposed LINGO−based GCSN, numerical experiments are conducted in this section. The implementation environment is presented as follows:

- Operating system: Windows 10 Chinese Family Edition.
- CPU:DESKTOP−UTMF66M PC 2.50 GHz processor (Intel Core i5−7200U CPU)
- RAM: 4.0GB
- Programming language:LINGO 18.0 x64

We use LINGO to analyze the data of three different scales and calculate the minimum cost.

5.1 Case Study

The mathematical formulation suggested in Section 3 was implemented at three different scales of the GCSN model, as shown in <Table 1>.

In <Table 2>, the random data generated in the EXCEL table are considered. Adopting Scale 1 as an example, the number of HCs that can be considered is 3, which implies that only one of the three HCs should be opened, while the others remain closed. The numbers of the CL and the RC are also interpreted under the same concept

Table 1. Three scales of GCSN

Scale	HC	DC	CS	DP	CL	RC
1	3	5	1	1	3	3
2	9	15	1	1	9	9
3	27	45	1	1	27	27

as that for HC. The number of DCs that can be considered is 5, which indicates that only one of the five DCs should be opened, while the others remain closed. However, the numbers of the CS and the DP are fixed and always considered as 1.

Considering the numbers of each stage in Scale 1, the total possible routes are 135(=3*5*3*3), and they can be easily solved using conventional approaches such as listing math formulas. However, when considering the numbers of each stage in Scale 3, the total possible routes are 885,735(=27*45*27*27); these cannot be easily solved using conventional approaches. Therefore, we adopt the LINGO method to determine the optimal solution.

For Scale 1,it is concluded that the best solution is 26,520, and the running time of the CPU is 0.19s. For Scale 2, it is concluded that the best solution is 26,440, and the running time of the CPU is 0.16 s. With regard to Scale 3,it is concluded that the best solution is 26,495, and the running time of the CPU is 0.18 s. Thus, it is clear that the performance of the LINGO solution continues to remain stable.

Table 2. Decision for GCSN

	Scale 1	Scale 2	Scale 3
BS	26520	26440	26495
CPU Time	0.19	0.16	0.18

Table 3. Decision for GCSN in Scale 3 along with best solution

Scale 3				
Stage	HC	DC	CL	RC
No.	14	20	22	22

<Table 3> shows the best sites selected under Scale 3. In terms of site selection, among the 27 HC sites, the 14th site was selected, while the rest were excluded; the 20th site was selected among the 45 DCs, while the rest were excluded; the 22nd site was selected among the 27 CLs site, while the rest were neglected; and the 22nd site was selected among the 27 RCs, while the rest were neglected.

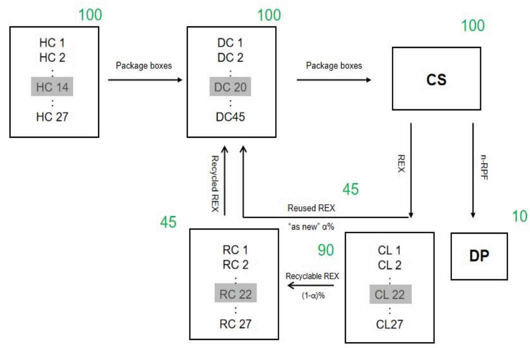

Fig. 3. Transport volume of REX in GCSN

As shown in <Figure. 3>, a more intuitive display of the best sites for Scale 3, and a detailed introduction to the number of REX in the delivery process.

As demonstrated in <Table 4>, the ratios of CL to DC and RC in Scale 3 are maintained at 0.5 and 0.5, respectively. In Scale 1, the number of n-RPF from CS to DP is 10%, and the total cost is 26,520; the number of n-RPF is 30%, and the total cost is 28,980; and the number of n-RPF is 50%, and the total cost is 32,940. In Scale 2, the proportion of n-RPF from CS to DP is 10%, and the total cost is 26,440; the proportion of n-RPF is 30%, and the total cost is 28,950; and the proportion of n-RPF is 50%, and the total cost is 28,950. The fee is 33,140. In Scale 3, the proportion of n-RPF from CS to DP is 10%, and the total cost is 26,495; the proportion of n-RPF is 30%, and the total cost is 29,005; and the proportion of n-RPF is 50%, and the total cost is 29,005. Furthermore, the total cost is 33,290.

Table 4. Total Cost Under Different Penalty Fees

P	10%	30%	50%
Scale 1	26520	28980	32940
Scale 2	26440	28950	33140
Scale 3	26495	29005	33290

From <Figure 4>, we can clearly see that, for the same proportion value, the final cost in different scenarios is not significantly different; however, as the proportion value increases, the penalty cost continues to increase, resulting in a steady growth in the overall cost. Specifically, reducing the number of n-RPF can considerably reduce the total cost and help achieve our ultimate goal. As the proportion of n-RPF under the penalty cost increases from 10% to 50%, the total cost also increases continuously. The growth trends of these three scales are roughly the same and relatively consistent. Therefore, the increase in the penalty cost has a greater impact on the total cost under the same scale and a limited impact on the total cost for different scales under the same ratio.

Fig. 4. Trend graph of total cost under different fines

5.2 Sensitivity Analysis

In order to verify whether GCSN has been in steady state, as shown in <Table 5>, we first verify by increasing the number of n-RPF to keep the CL to DC and RC ratios unchanged. Meanwhile, we increase the number of REX that can be used directly to retain the CS to CL and DP ratios unchanged as shown in <Table 6>.

As shown in <Table 5>, taking the data of Scale 3 as an example, the scales of the one stage is changed respectively. We can see that maintain the transport ratio of CL to DC and RC respectively from 1 to 9 cases. In the case of 0.1 and 0.9 unchanged, changing the transport ratio of CL to DC and RC .

Table 5. Total cost value under CL to DC and RC change

Case	BS	CL→DC	CL→RC
C1	24288	0.9	0.1
C2	24846	0.8	0.2
C3	25404	0.7	0.3
C4	25962	0.6	0.4
C5	26495	0.5	0.5
C6	27290	0.4	0.6
C7	27636	0.3	0.7
C8	28194	0.2	0.8
C9	28752	0.1	0.9

It can be clearly seen from <Figure 5> that under the same scale, the growth trend of CL to DC and RC is basically the same when the ratio is different, which is 2.3%. It means that GCSN has been in a stable state.We clearly found that the higher the number from CL to DC, the higher the total cost.Therefore, we should increase the number of REX that can be used directly, reduce the number of reprocessing REX, and greatly reduce the total cost.

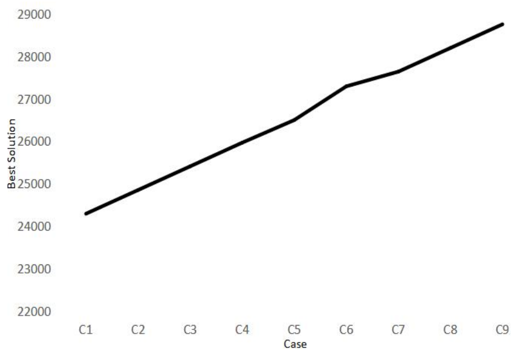

Fig. 5. Trends in Total Fees Changed from CL to DC and RC

As demonstrated in <Table 6>, taking the data of Scale 3 as an example, the scales of the one stage is changed respectively. In the case of 0.1 and 0.9 unchanged, changing the transport ratio of CS to CL and DP.

Table 6. Total cost value under CS to CL and DP change

Case	BS	CS→CL	CS→DP
C1	26495	0.9	0.1
C2	27750	0.8	0.2
C3	29005	0.7	0.3
C4	31147	0.6	0.4
C5	33290	0.5	0.5
C6	35433	0.4	0.6
C7	38576	0.3	0.7
C8	41719	0.2	0.8
C9	44674	0.1	0.9

It is evident from <Figure 6> that, under the same scale, the growth trend from the CS to the CL and DP is essentially the same when the ratio is different, which is 7.3%.The growth trend in the early stages is relatively stable, whereas it is slightly large in the later stages. This implies that the GCSN remains in a stable state. Thus, We clearly determined that the lower the number from the CS to the DP, the lower the total cost. Therefore, it is imperative to reduce the discarding of n-RPF.

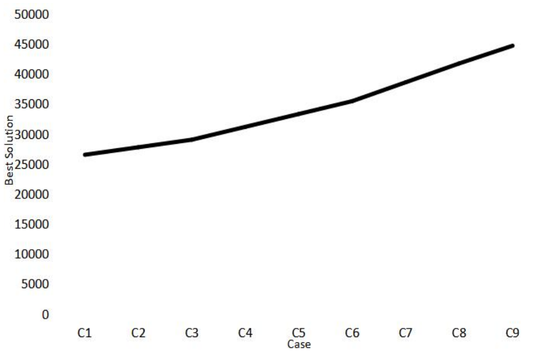

Fig. 6. Trends in Total Fees Changed from CS to CL and DP

6. Conclusion

This study advances the operation mode of simultaneous distribution and recycling using REX, employing LINGO to solve this problem. Finally, through the analyses of examples, the optimal decision for vehicle routing under the distribution and recycling mode is obtained, and the influence of relevant parameters on the optimal decision of the system is analyzed. With regard to solving the aforementioned problems, the main conclusions of this study can be summarized as follows :

From the perspective of penalty costs, n-RPF waste can be reduced and REX use can be increased, such that the total cost is the lowest and the penalty fee is low. We should reduce the use of n-RPF or look for alternative eco-friendly packaging fillers.

The recycling of express boxes for reprocessing can also be reduced. During the transportation process, it is important to ensure the service life of REX. The REX distributed from a CL to the DC can be used directly, thereby reducing the cost of reprocessing and the overall cost.

This study only considers one type of REX, and most of the packaging fillers are not reusable. In the future, more environmentally friendly packaging fillers that can replace n-RPF can be developed.

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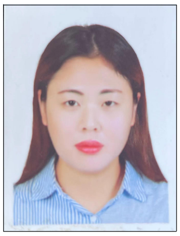

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