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혼합형 메타휴리스틱 접근법을 이용한 지속가능한 폐쇄루프 공급망 네트워크 모델: 국내 모바일폰 산업을 중심으로+

(Sustainable Closed-loop Supply Chain Model using Hybrid Meta-heuristic Approach: Focusing on Domestic Mobile Phone Industry)

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요 약 본 연구는 국내 모바일폰 산업을 위한 지속가능한 폐쇄루프 공급망 (Sustainable closed-loop supply chain: SCLSC) 네트워크 모델을 제안한다. 제안된 SCLSC 네트워크 모델의 지속가능성을 위해 경제적, 환경적, 사회적 요인들이 각각 고려된다. 이들 세 가지 요인들은 SCLSC 네트워크 모델의 각 단계에서 고려되는 설비의 구축 및 운영으로부터 발생하는 총비용 최소화, CO_2 방출 총량 최소화, 사회적 영향력 최대화를 목표로 한다. 이러한 목표들은 SCLSC 네트워크의 모델링 단계에서 각각 개별적인 목적함수로 고려되어야 하기 때문에 SCLSC 네트워크 모델은 다목적 최적화 문제로 간주할 수 있다. SCLSC 네트워크 모델은 수리모델을 사용하여 표현되며, 혼합형 메타휴리스틱 접근법을 수리모델에 적용하여 그 해를 구한다. 수치실험에서는 제안된 혼합형 메타휴리스틱 접근법의 수행도가 기존의 메타휴리스틱 접근법들의 수행도와 비교된다. 실험결과는 본 연구에서 제안된 혼합형 메타휴리스틱 접근법이 기존의 메타휴리스틱 접근법들과 비교하여 더 뛰어난 수행도를 보여주는 것을 알 수 있다.

핵심주제어: 지속가능한 폐쇄루프 공급망 네트워크 모델, 국내 모바일 산업, 다목적 최적화, 혼합형 메타휴리스틱 접근법

Abstract In this paper, a sustainable closed-loop supply chain (SCLSC) network model is proposed for domestic mobile phone industry. Economic, environmental and social factors are respectively considered for reinforcing the sustainability of the SCLSC network model. These three factors aim at minimizing total cost, minimizing total amount of CO_2 emission, and maximizing total social influence resulting from the establishment and operation of facilities at each stage of the SCLSC network model. Since they are used as each objective function in modeling, the SCLSC network model can be a multi-objective optimization problem. A mathematical formulation is used for representing the SCLSC network model and a hybrid meta-heuristic approach is proposed for efficiently solving it. In numerical experiment, the performance of the proposed hybrid meta-heuristic approach is compared with those of conventional meta-heuristic approaches using some scales of the SCLSC network model. Experimental results shows that the proposed hybrid meta-heuristic approach outperforms conventional meta-heuristic approaches.

Keywords: Sustainable closed-loop supply chain network model, Domestic mobile phone industry, Multi-objective optimization, Hybrid meta-heuristic approach.

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1. Introduction

In general, closed-loop supply chain (CLSC) network model is considered as an integrated network model with forward logistics (FL) and reverse logistics (RL). In the FL, parts and products are produced and distributed from part suppler to customer via manufacturer, distribution center (DC) and retailer, whereas, in the RL, the end-of-life (EOL) products are collected, recovered or disposed at collection center, recovery center and disposal center, respectively.

Among the major trends in the CLSC network model, reinforcing sustainability in it has become popular in many literatures (Savaskan et al., 2004; Min et al., 2006; Paksoy et al., 2011; Eskandarpour et al., 2015; Talaei et al., 2016; Özceylan et al., 2017; Yun et al., 2017; Son et al., 2018). With this trend, economic, environmental and social factors are usually considered to construct sustainable CLSC (SCLSC) network model effectively.

For economic factor, the maximization of total profit or the minimization of total cost resulting from establishment and operation of the SCLSC network model are usually considered in literatures (Savaskan et al., 2004; Min et al., 2006; Son et al., 2018). For environmental factor, the minimization of total amount or cost of CO_2 emitted during the production and transportation of part and products is considered in literatures (Paksoy et al., 2011; Talaei wt al., 2016; Özceylan et al., 2017). For social factor, various social influences such as the number of newly created job opportunity by introducing new technology, and the number of lost days by work damage are considered in literatures (Eskandarpour et al., 2015; Özceylan et al., 2017).

One of the important issues in the SCLSC network model is to effectively handle EOL products at the RL under the consideration of economic, environmental and social factors. The handling at the RL is generally classified as reuse, recycling and waste disposal of the EOL products. Of them, the increasing the rates of reuse and recycling can reinforce the economic and environmental factors. For instance, in mobile phone industry, a huge amount of the EOL mobile phones is collected and handled in the RL, since its product life cycle becomes shorter and most of customers requires higher quality and specification.

Therefore, how to handle the EOL mobile phones in the RL becomes vitally important in the construction and operation of the SCLSC network model. If the EOL mobile phones are effectively handled in the RL by using reuse and recycling instead of waste disposal, economic factor such as the increase of resale profit by using recovered mobile phone and environmental factor such as the decrease of CO_2 emission amount by increasing the reuse and recycling of the EOL mobile phones can be reinforced in the SCLSC network model.

In the case of Korea, 85% higher customers of total population use mobile phone and 30% higher customers of them change their mobile phones as new ones within one year (Chuluunsukh, 2020). The higher usage rate and shorter life cycle of mobile phone have caused a huge amount of EOL mobile phones, and polluted environment by disposing them without any environmentally-friendly treatment. Therefore, increasing the rates of reuse and recycling instead of waste disposal can reinforce economic and environmental factors in mobile phone industry. Few papers suggested the construction and operation of the SCLSC network model for mobile phone industry (Kim and Jung, 2007; Jang and kim, 2010; John et al., 2018; Ahmadi and Amin, 2019).

Kim and Jung (2007) suggested a SCLSC network model which consists of part suppler (PS), product manufacturer (PM), distribution center (DC), tele-communication company (TC) and customer in the FL and RL stages. The EOL mobile phones are collected at TC and then recovered their qualities. The recovered mobile phones are resold at customer and the unrecovered ones are disposed. However, there is a limitation in the handling of collection and recovery processes at the TC, since the main function of the TC is to sell new mobile phone, not the recovered one. They also do not consider a disposal center to treat unrecovered mobile phone.

John et al. (2018) suggested a SCLSC network model for India's mobile phone industry. In the SCLSC network model, the collected EOL mobile phones from customer are sent to disassembly center. The recovered mobile phones after disassembly and recovery processes are resold at second market, the recovered parts (or materials) are sent to recycling center to be recycled, and unrecovered mobile phones are sent to disposal center to be disposed. However, the SCLSC network model considers the RL stage alone, which means that they do not take into account the FL stage.

Compared with Kim and Jung (2007) and John et al. (2018), the SCLSC network model by Ahmadi and Amin (2019) has an advantage that the production of new mobile phone and the handling of EOL one are effectively considered at various facilities of the FL and RL. However, the economic, environmental and social factors do not be sufficiently considered in their SCLSC network model.

In this paper, we propose an effective SCLSC network model for domestic mobile phone industry by improving the limitations of the conventional studies (Kim and Jung, 2007; John et al., 2018; Ahmadi and Amin, 2019). First, various facilities at each stage of the FL and RL are considered to effectively handle the production and distribution of new mobile phone and the recovery and disposal of EOL mobile phone. Second, customers are classified into first and second customers, respectively. First customer (FC) is for the purchase of new mobile phone and second customer (SC) for the purchase of recovered mobile phone. For effective distribution of new mobile phone and recovered one to the FC and SC, retailer is also classified into first and second retailers, respectively. First retailer is for the FC and second one for the SC. Third, the three factors (economic, environmental and social factors) are simultaneously taken into consideration for reinforcing the sustainability of the proposed SCLSC network model. Table 1 clearly explain the difference and originality of this paper compared with previous studies.

In Section 2, a conceptual flow of the proposed SCLSC network model is suggested for effectively presenting domestic mobile phone industry. Section 3 shows a mathematical formulation for representing the proposed SCLSC network model. The mathematical formulation is implemented using a hybrid meta-heuristic approach in Section 4. The numerical experiments using three-scaled SCLSC network models are conducted for comparing the performance of the hybrid meta-heuristic approach with those of some conventional meta-heuristic approaches in Section 5. Finally, some conclusions are summarized and future research directions are suggested in Section 6.

2. SCLSC Network Model

Before explain and present the SCLSC network model for domestic mobile phone industry, we analyze the SCLSC or supply chain (SC) network model for foreign mobile phone industry. We et al. (2023) suggested the recycling and reuse SC network model for used mobile in China, but they do not considered a material flows in FL. The SC network model by Scanlon R. (2009) consists of component suppliers, manufacturers, distributors and retailer/customer in FL, but a material flows in RL do not be handled in mobile phone industry in USA. Similar to Scanlon R. (2009), Catalan and Kotzab (2003) also suggested a SCLSC network model in FL in Danish mobile phone industry. Ahmadi and Amin (2019) suggested a SCLSC network model in FL and RL in Canadian mobile phone industry, but economic, environmental and social factors do not be taken into consideration.

There are some differences between foreign mobile phone industry mentioned in conventional literatures and domestic one proposed in this paper. First, We et al. (2023), Scanlon R. (2009), and Catalan and Kotzab (2003) considered a material flow in either FL or RL. Second, Ahmadi and Amin (2019) does not taken into consideration economic, environmental and social factors in SCLSC network model, although they handled a material flow in FL and RL simultaneously. Differ from these conventional literatures, this paper considers a material flow in FL and RL simultaneously, and also handles various factors (economic, environmental and social factors) in SCLSC network model. A conceptual material flow of the SCLSC network model for domestic mobile phone industry is shown in Fig. 1. For the FL, parts (or components) produced by the PS are

Table 1 Difference and Originality of This Paper Compared with Previous Studies on SCLSC Network Model

Authors	Three Factors Eco.	Env.	Soc.	Math. Model	Obj. Type	Approach	Items
Savaskan et al. (2004)	■	-	-	■	Single Obj.	-	-
Min et al. (2006)	■	-	-	■	Single Obj.	Meta-heuristic	-
Zhalechian et al. (2016)	■	-	■	■	Multi Obj.	Meta-heuristic	-
Paksoy et al. (2011)	■	■	-	■	Single Obj.	Scenario-based	-
Talaei et al. (2016)	■	■	-	■	Multi Obj.	ε-constrained method	-
Özceylan et al. (2017)	■	■	■	■	Single Obj.	Scenario-based	Auto. Industry
Son et al. (2018)	■	-	-	■	Single Obj.	ε-constrained method	Auto Parts Industry
Sahebjamnia et al. (2018)	■	■	■	■	Multi Obj.	Meta-heuristic	Auto Parts Industry
Fahimnia et al. (2013)	■	■	-	■	Multi Obj.	Scenario-based	Auto Parts Industry
Kim & Jung (2007)	■	-	-	■	Single Obj.	ILOG CPLEX	Mobile Phone
John et al. (2018)	■	-	-	■	Single Obj.	Scenario-based	Mobile Phone
Ahmadi & Amin (2019)	■	-	-	■	Multi Obj.	ε-constrained method	Mobile Phone
This Paper	■	■	■	■	Multi Obj.	Meta-heuristic	Mobile Phone

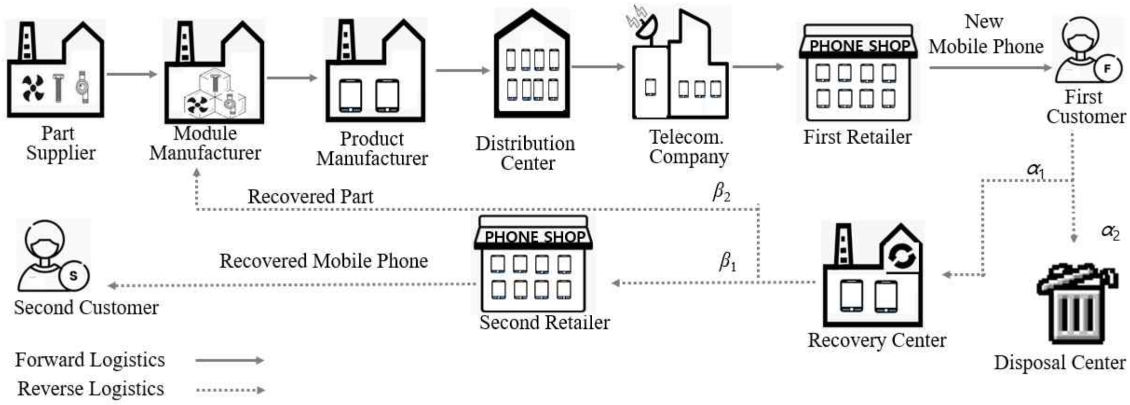

Fig. 1 Conceptual Flow of the Proposed SCLSC Network Model

sent to module manufacturer (MM). At the MM, various modules using parts are assembled and then send to the PM. New mobile phones produced at the PM are sent to the first retailer (FR) via the DC and TC and finally sold at the FC. For the RL, some (α_1) of the total EOL mobile phones corrected from the FC are sent to recovery center (RC) and the others (a_2) sent to the disposal center (DP) to be disposed, where a_1 and a_2 have the value in [0, 1], and $a_1+\alpha_2=0$. At the RC, the quality of the EOL mobile phones are checked and then classified into two types (reusable EOL mobile phones with β_1 and unusable ones with β_2), where β_1 and β_2 have the value in [0, 1] and $\beta_1+\beta_2=0$. The reusable EOL mobile phones are recovered at the RC and then resold at the SC via the second retailer (SR). The unusable mobile phones are disassembled into parts and then their qualities are recovered at the RC. The recovered parts are sent to the MM for assembling module.

3. Mathematical Formulation

For presenting the proposed SCLSC network model in Fig. 1, various assumptions should be considered. These assumptions are generally used in most of the existing SCLSC network models (Wang and Hsu, 2010; Yun et al., 2018, 2020). Indices, parameters, and decision variables are defined as follows:

- Indices and Sets

a : index of PS, $a \in A$
m : index of MM, $m \in M$
p : index of PM, $p \in P$
d : index of DC, $d \in D$
t : index of TC, $t \in T$
r : index of FR, $r \in R$
f : index of FC, $f \in F$
i : index of DP, $i \in I$
c : index of RC, $c \in C$
s : index of SR, $s \in S$
e : index of SC, $e \in E$

- Parameter

I_a : fixed cost at PS a
I_m : fixed cost at MM m
I_p : fixed cost at PM p
I_d : fixed cost at DC d
I_t : fixed cost at TC t
I_r : fixed cost at FR r
I_c : fixed cost at RC c
I_s : fixed cost at SR s

H_a: unit handling cost at PS a
H_m: unit handling cost at MM m
H_p: unit handling cost at PM p
H_d: unit handling cost at DC d
H_t: unit handling cost at TC t
H_r: unit handling cost at FR r
H_c: unit handling cost at RC c
H_s: unit handling cost at SR s
T_{am}: unit transportation cost at from a to m
T_{mp}: unit transportation cost at from m to p
T_{pd}: unit transportation cost at from p to d
T_{dt}: unit transportation cost at from d to t
T_{tr}: unit transportation cost at from t to r
T_{rf}: unit transportation cost at from r to f
T_{fi}: unit transportation cost at from f to i
T_{fc}: unit transportation cost at from f to c
T_{ca}: unit transportation cost at from c to a
T_{cs}: unit transportation cost at from c to s
T_{se}: unit transportation cost at from s to e
D_{am}: distance between a and m
D_{mp}: distance between m and p
D_{pd}: distance between p and d
D_{dt}: distance between d and t
D_{tr}: distance between t and r
D_{rf}: distance between r and f
D_{fi}: distance between f and i
D_{fc}: distance between f and c
D_{cs}: distance between c and s
D_{se}: distance between s and e
D_{sm}: distance between s and m
Q_{am}: quantity transported from a and m
Q_{mp}: quantity transported from m and p
Q_{pd}: quantity transported from p and d
Q_{dt}: quantity transported from d and t
Q_{tr}: quantity transported from t and r
Q_{rf}: quantity transported from r and f
Q_{fi}: quantity transported from f and i
Q_{fc}: quantity transported from f and c
Q_{cs}: quantity transported from c and s
Q_{se}: quantity transported from s and e
Q_{sm}: quantity transported from s and m
C_a: capacity at PS a
C_m: capacity at MM m
C_p: capacity at PM p
C_d: capacity at DC d
C_t: capacity at TC t
C_r: capacity at FR r
C_f: capacity at FC f
C_i: capacity at DP i
C_c: capacity at RC c
C_s: capacity at SR s
C_e: capacity at SC e
CA: capacity shipped in a vehicle
CV: CO_2 amount emitted from vehicle per kilometer
CM_p: unit CO_2 amount emitted from manufacturing process at PM p
CW: weight for the created job opportunity
CJ_p: number of the created job opportunities at PM p when using new technology
UW: weight for unemployment
UN_p: number of the unemployment caused by using new technology at PM p

- Decision variable

x_a: takes the value of 1, if PS a is opened and 0 otherwise
x_m: takes the value of 1, if MM m is opened and 0 otherwise
x_p: takes the value of 1, if PM p is opened and 0 otherwise
x_d: takes the value of 1, if DC d is opened and 0 otherwise
x_t: takes the value of 1, if TC t is opened and 0 otherwise
x_r: takes the value of 1, if FR r is opened and 0 otherwise
x_c: takes the value of 1, if RC c is opened and 0 otherwise

x_s: takes the value of 1, if SR s is opened and 0 otherwise

n_p: takes the value of 1, if new technology is used at PM p and 0 otherwise

Economic, environmental and social factors should be considered as each objective function since they are represented as a form of multi-objective optimization problem. First objective function $F_1(x)$ is to minimize the total cost, second one $F_2(x)$ to minimize the total amount of CO_2 emission, and third one $F_3(x)$ to maximize the social influence for economic, environmental and social factors, respectively.

$$\min \quad F_1(x) = \sum_a I_a x_a + \sum_m I_m x_m + \sum_p I_p x_p + \sum_d I_d x_d + \sum_t I_t x_t + \sum_r I_r x_r + \sum_c I_c x_c + \sum_s I_s x_s + \sum_a H_a C_a x_a + \sum_m H_m C_m x_m + \sum_p H_p C_p x_p + \sum_d H_d C_d x_d + \sum_t H_t C_t x_t + \sum_r H_r C_r x_r + \sum_c H_c C_c x_c + \sum_s H_s C_s x_s + \sum_a \sum_m T_{am} C_a x_a x_m + \sum_m \sum_p T_{mp} C_m x_m x_p + \sum_p \sum_d T_{pd} C_p x_p x_d + \sum_d \sum_t T_{dt} C_d x_d x_t + \sum_t \sum_r T_{tr} C_t x_t x_r + \sum_r \sum_f T_{rf} C_r x_r + \sum_f \sum_i T_{fi} C_f \alpha_2 x_c + \sum_f \sum_c T_{fc} C_f \alpha_1 x_c + \sum_c \sum_s T_{cs} C_c x_c x_s + \sum_s \sum_m T_{sm} C_s \beta_2 x_s + \sum_s \sum_e T_{se} C_s \beta_1 x_s \quad (1)$$

$$\min F_2(x) = \sum_a \sum_m D_{am} x_a x_m \left(\frac{C_a}{CA}\right) CV + \sum_m \sum_p D_{mp} x_m x_p \left(\frac{C_m}{CA}\right) CV + \sum_p \sum_d D_{pd} x_p x_d \left(\frac{C_p}{CA}\right) CV + \sum_d \sum_t D_{dt} x_d x_t \left(\frac{C_d}{CA}\right) CV + \sum_t \sum_t D_{tr} x_t x_r \left(\frac{C_t}{CA}\right) CV + \sum_r \sum_f D_{rf} x_r \left(\frac{C_r}{CA}\right) CV + \sum_f \sum_i D_{fi} \left(\frac{C_f \alpha_2}{CA}\right) CV + \sum_f \sum_c D_{fc} x_c \left(\frac{C_f \alpha_1}{CA}\right) CV + \sum_c \sum_s D_{cs} x_c x_s \left(\frac{C_s}{CA}\right) CV + \sum_s \sum_m D_{sm} x_s x_m \left(\frac{C_s \alpha_2}{CA}\right) CV + \sum_s \sum_e D_{se} x_s \left(\frac{C_s \alpha_1}{CA}\right) CV \quad (2)$$

$$\max F_3(x) = \mathrm{CW}\left(\sum_p CJ_p x_p n_p\right) - \left(UW \sum_p UN_p x_p n_p\right) \quad (3)$$

Equation (1) shows that the total cost (= total fixed cost + total handling cost + total transportation cost) resulting from each stage is minimized. In Equation (2), the total amount of CO_2 emitted during transportation process between each stage is minimize. In Equation (3), the social influence which consists of the number of the created job opportunity and the number of the unemployment caused by using new technology at the PM is maximized. The three objectives of equations (1) - (3) should be optimized under satisfying the following constraints.

$$\sum_a \sum_m Q_{am} x_a x_m - \sum_m C_m x_m \le 0 \quad (4)$$

$$\sum_m \sum_p Q_{mp} x_m x_p - \sum_p C_p x_p \le 0 \quad (5)$$

$$\sum_p \sum_d Q_{pd} x_p x_d - \sum_d C_d x_d \le 0 \quad (6)$$

$$\sum_d \sum_t Q_{dt} x_d x_t - \sum_t C_t x_t \le 0 \quad (7)$$

$$\sum_t \sum_r Q_{tr} x_t x_r - \sum_r C_r x_r \le 0 \quad (8)$$

$$\sum_r \sum_f Q_{rf} x_r - \sum_f C_f \le 0 \quad (9)$$

$$\sum_f \sum_i Q_{fi} - \sum_i C_i \le 0 \quad (10)$$

$$\sum_f \sum_c Q_{fc} x_c - \sum_c C_c x_c \le 0 \quad (11)$$

$$\sum_c \sum_s Q_{cs} x_c x_s - \sum_s C_s x_s \le 0 \quad (12)$$

$$\sum_s \sum_m Q_{sm} x_s x_m - \sum_m C_m x_m \le 0 \quad (13)$$

$$\sum_s \sum_e Q_{se} x_s - \sum_e C_e \le 0 \quad (14)$$

$$\sum_a x_a = 1, \sum_m x_m = 1, \sum_p x_p = 1, \sum_d x_d = 1, \sum_t x_t = 1, \sum_r x_r = 1, \sum_c x_c = 1, \sum_s x_s = 1 \quad (15)$$

$$x_a, x_m, x_p, x_d, x_t, x_r, x_c, x_s \in \{0,1\}, \forall a \in A, m \in M, p \in P, \forall d \in D, t \in T, \forall r \in R, c \in C, s \in S \quad (16)$$

$$C_a, C_m, C_p, C_d, C_t, C_r, C_f, C_i, C_c, C_s, C_e \ge 0, \forall a \in A, m \in M, p \in P, \forall d \in D, t \in T, \forall r \in R, \forall f \in F, \forall i \in I, c \in C, s \in S, \forall e \in E \quad (17)$$

The transportation amounts between each stage are constrained by Equations (4) - (14). Equations (15) imposes that only one facility at each stage should be opened. In Equation

```
procedure: GA-rCS approach
input: problem data, parameters
output: Pareto optimal solution set
begin
  t ← 0    //t : generation number
  randomly generate parent population P(t);
  calculate three objective functions F1(x), F2(x), F3(x) using P(t);
  find Pareto optimal solution set E(P) by non-dominated solution routine;
  calculate fitness assignment function and keep best Pareto optimal solution set;
  while (t < max generation)
     produce offspring population O(t) from P(t) by adapting 2X crossover operator and random mutation
     operator (Gen and Cheng, 2000);
     find current E(O) by non-dominated solution routine;
     calculate fitness assignment function, update best Pareto optimal solution set;
     save a best solution set GAbest using E(P);
    for each solution xi of O(t) do
      generate a new solution xn from xi using Lévy flight (Kanagaraj et al., 2013);
      randomly choose another solution xj in O(t);
      if (F(xn) > F(xj)), then C(t) ← xn  //C(t): CS population
    end for
    abandon worst solutions with fraction rate (ar) in C(t);
    randomly generate new solutions xr as many as ar;
    C(t) ← xr;
    find current E(C) by non-dominated routine;
    save a best solution set CSbest using current E(P);
    if (F(GAbest) > F(CSbest))
       then update current E(P) using GAbest by non-dominated routine;
       else update current E(P) using CSbest by non-dominated routine;
    end if
    reproduce P(t+1) using O(t) and C(t) by elitist selection scheme (Gen and Cheng, 2000);
    t ← t+1;
  end while
  output best Pareto optimal solution set E(P);
end;
```

Fig. 2 Implementation Procedure of the GA-rCS Approach

(16), all decision variables should have 0 or 1. Equation (17) constraints the non-negativity of each parameter.

4. Hybrid Meta-heuristic Approach

In general, complicated multi-stage network problems including the proposed SCLSC network model have known NP-complete problem (Gen and Cheng, 2000; Savaskan et al., 2004; Gen et al., 2018; Anudari and Yun, 2021). Meta-heuristic approaches have adapted for solving them effectively. However, most of conventional single meta-heuristic approaches such as genetic algorithm (GA), teaching and learning-based optimization, Tabu search, Jaya algorithm, Cuckoo search (CS) and particle swarm optimization do not be well adapted particularly. To mitigate this weakness, various hybrid meta-heuristic approaches combining the strengths of conventional single meta-heuristic approaches have been proposed (Eskandarpour et al., 2015; Gen et al., 2018; Chuluunsukh et al., 2018; Yun et al., 2020; Yun, 2022). By using hybrid meta-heuristic approaches, both global search ability and local search one can be reinforced (Chuluunsukh et al., 2018; Yun et al., 2020).

Yun et al. (2020) suggested a hybrid

meta-heuristic approach using GA approach for global search and CS approach for local search in solving complicated network problems. The hybrid meta-heuristic approach suggested by Gen et al. (2018) combines GA approach for global search with iterative hill climbing approach for local search.

In this paper, we also suggest a hybrid meta-heuristic approach for effectively solving the proposed SCLSC network model. The suggested hybrid meta-heuristic approach, called the GA-rCS approach, is to use GA approach for global search and revised CS approach for local search. The revised CS scheme used in the GA-rCS approach is an improved version of conventional CS scheme proposed by Kanagaraj et al. (2013). Main difference between the conventional CS scheme and the revised SC one is as follow. In the conventional CS scheme, Lévy flight (Kanagaraj et al., 2013) is adapted to only one solution randomly chosen among all solutions resulting from GA search loop. However, in the revised CS scheme, Lévy flight is applied to all solutions resulting from GA search loop. By applying all solutions in the revised CS scheme, more possibility to locate global optimal solution can be achieved. The detailed implementation procedure of the GA-rCS approach is shown in Fig. 2.

5. Numerical Experiment

In numerical experimental, three scales as shown in Table 2 are used for the proposed SCLSC network model. Various sized facilities are used at each stage. Data (fixed cost, unit handling cost, unit transportation cost, distance, quantity, etc.) for the establishment and operation of the facilities considered at each stage are randomly generated using Microsoft Excel.

Table 2 Three Scales for the Proposed SCLSC Network Model

Scale	PS	MM	PM	DC	TC	FR
1	20	20	20	20	1	20
2	40	40	40	40	1	40
3	60	60	60	60	1	60

Scale	FC	RC	SR	DP	SC
1	1	20	20	1	1
2	1	40	40	1	1
3	1	60	60	1	1

Using three scales, the performance of the GA-rCS approach is compared with those of two conventional meta-heuristic approaches (GA by Gen and Cheng (2000) and GA-CS by Kanagaraj et al. (2013).

All approaches were programmed by MATLAB version 2014b and ran under a same computation environment (IBM compatible PC 1.3 Ghz processor-Intel core I5-1600 CPU, 4GB RAM, and OS-X EI). The parameter settings are as follow: total number of generations is 1,000, population size 20, crossover rate 0.5, and mutation rate 0.3 for GA search scheme in the GA, GA-CS and GA-rCS approaches, and the number of host nest 10, $\alpha = 1$, and $p_a = 0.25$ for CS search scheme in the GA-CS and GA-rCS approaches. Total 10 independent trials were carried out to eliminate the randomness of the search process of each approach. Various measures of performance as shown in Table 3 are used for comparing the performances of the GA, GA-CS and GA-rCS approaches.

Since three objectives in Section 3 are represented as a form of multi-objective optimization problem, they are divided into the following three groups for providing a convenience of performance comparison of each approach (Gen et al., 2018).

Table 3 Various Measures of Performance

Measure	Description
$\vert S_j\vert$	Number of Pareto optimal solutions which coincide with reference solution set (S^*) (Ishibuchi and Murata, 1998)
$R_{NDS}(S_j)$	Rates of Pareto optimal solutions within the S^*(Ishibuchi and Murata, 1998)
$DI_R(S_j)$	Average distance between Pareto optimal solutions and the S^*(Ishibuchi and Murata, 1998)
CPU	Average CPU time over 10 runs (unit: Sec.)

Problem 1: min $F_1(x)$ and min $F_2(x)$
Problem 2: min $F_1(x)$ and max $F_3(x)$
Problem 3: min $F_2(x)$ and max $F_3(x)$

Tables 4, 5 and 6 show the computation results of each approach. In Problem 1 of Table 4, the GA-rCS approach shows that two Pareto optimal solutions coincide with reference solution set (S^*) in terms of the $|S_j|$. However, only one Pareto optimal solution in the GA approach coincides with the S^*, and none of Pareto optimal solution in the GA-CS approach. These results also have influence on the results of the $R_{NDS}(S_j)$, that is, the rates are respectively 0.33, 0.00 and 0.66 in the GA, GA-CS and GA-rCS, approaches, which means that the performance of the GA-rCS approach is superior to those of the GA-CS and GA approaches. In terms of the $DI_R(S_j)$, the average distances in the GA, GA-CS and GA-rCS approaches are 0, 4,626, and 962, respectively. This indicates that the GA approach outperforms the GA-CS and GA-rCS approaches. In terms of the CPU time, all approaches have no significant difference.

In Problem 2 of Table 4, the performances of the GA-rCS approach are more efficient in terms of the $|S_j|$, $R_{NDS}(S_j)$, and $DI_R(S_j)$ than

Table 4 Computation Results of Each Approach in Scale 1

	Problem 1			Problem 2			Problem 3		
Measure	GA	GA-CS	GA-rCS	GA	GA-CS	GA-rCS	GA	GA-CS	GA-rCS
$\vert S_j\vert$	1	0	2	0	2	3	1	2	2
$R_{NDS}(S_j)$	0.33	0.00	0.66	0.00	0.40	0.60	0.20	0.40	0.40
$DI_R(S_j)$	0	4,626	962	256	99	47	100,437	130,181	66,745
CPU	50.37	50.62	52.06	50.37	50.62	52.06	50.37	50.62	52.06

Table 5 Computation Results of Each Approach in Scale 2

	Problem 1			Problem 2			Problem 3		
Measure	GA	GA-CS	GA-rCS	GA	GA-CS	GA-rCS	GA	GA-CS	GA-rCS
$\vert S_j\vert$	1	1	2	0	1	3	1	2	3
$R_{NDS}(S_j)$	0.25	0.25	0.50	0.00	0.25	0.75	0.17	0.33	0.50
$DI_R(S_j)$	63,593	67,922	0	756	318	1	8,040	0	3,093
CPU	51.27	51.49	52.57	51.27	51.49	52.57	51.27	51.49	52.57

Table 6 Computation Results of Each Approach in Scale 3

	Problem 1			Problem 2			Problem 3		
Measure	GA	GA-CS	GA-rCS	GA	GA-CS	GA-rCS	GA	GA-CS	GA-rCS
$\vert S_j\vert$	2	1	3	1	0	3	1	1	2
$R_{NDS}(S_j)$	0.33	0.17	0.50	0.25	0.00	0.75	0.25	0.25	0.50
$DI_R(S_j)$	78,220	58,126	1,505	386	140	26	129,859	57,697	51,954
CPU	51.99	52.48	52.89	51.99	52.48	52.89	51.99	52.48	52.89

those of the GA and GA-CS approaches.

In Problem 3 of Table 4, the GA-rCS and GA-CS approaches have same results in terms of the $|S_j|$ and $R_{NDS}(S_j)$, but, the former is more efficient than the latter in terms of the $DI_R(S_j)$. In terms of the CPU times of Problems 2 and 3, there is no significant differences among all approaches.

In Problems 1 and 2 of Table 5, the GA-rCS approach outperforms the GA and GA-CS approaches in terms of the $|S_j|$, $R_{NDS}(S_j)$, and $DI_R(S_j)$. However, in Problem 3, the performance of the GA-CS approach is significantly superior to those of the GA-rCS approach in terms of the $DI_R(S_j)$, though the latter shows to be more efficient results in terms of the $|S_j|$ and $R_{NDS}(S_j)$, than the former. Similar to the result analysis of Table 4, the CPU times shows to be little difference among all approaches in Problems 1, 2, and 3.

In Problems 1, 2 and 3 of Table 6, the GA-rCS approach shows to be significantly better performances in terms of the $|S_j|$, $R_{NDS}(S_j)$, and $DI_R(S_j)$ than the GA and GA-CS approaches. In the comparison between the GA and GA-CS approaches, the former is more efficient in terms of the $|S_j|$, and $R_{NDS}(S_j)$ than the latter, which means that the former locates more Pareto optimal solutions within the S^* than the latter.

Figs. 4, 5, and 6 show the convergence behaviours of Pareto optimal solutions in each approach when compared with the S^*. Fig. 3 shows that three Pareto optimal solutions in the GA-rCS approach coincide with the S^*, but, two Pareto optimal solution in the GA approach and one Pareto optimal solution in the GA-CS approach coincide with the S^*. This implies that the GA-rCS approach outperforms the GA and GA-CS approaches. Fig. 4 and 5 also show that more Pareto optimal solutions in the GA-rCS approach than those in the GA and GA-CS approaches coincide with the S^*. The results shown in Figs. 3, 4, and 5 are the same as those in terms of the $|S_j|$ in Table 6.

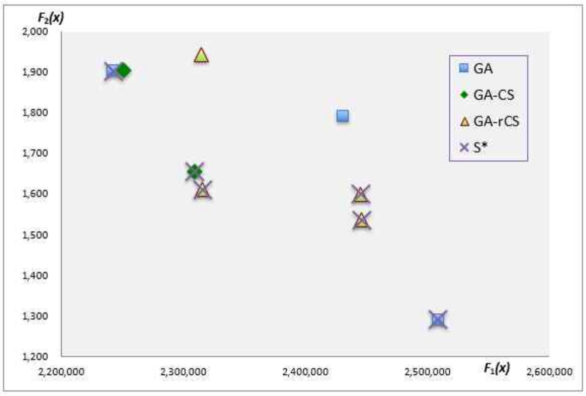

Fig. 3 Pareto Optimal Solutions of Each Approach in Problem 1 of Scale 3

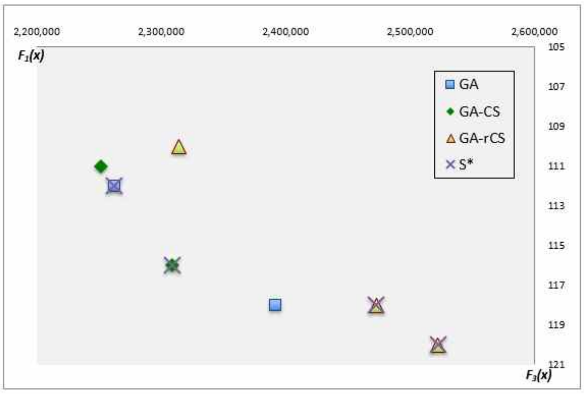

Fig. 4 Pareto Optimal Solutions of Each Approach in Problem 2 of Scale 3

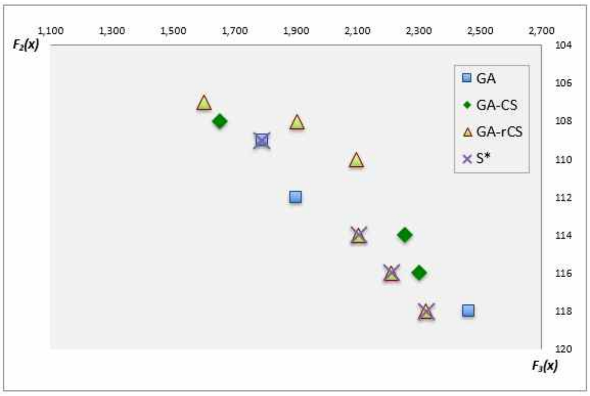

Fig. 5 Pareto Optimal Solutions of Each Approach in Problem 3 of Scale 3

We can reach the following conclusion using the computational results of Table 4, 5, and 6 and the Pareto optimal solutions of Figs. 3, 4 and 5.

- In terms of the $|S_j|$, $R_{NDS}(S_j)$, and $DI_R(S_j)$, the performances of the GA-rCS approach are more efficient than those of the GA and GA-CS approaches, which means that the former can explore larger space than the latter. In terms of the CPU, the GA-CS approach is slightly quicker than the the GA-rCS approach, but there is no significant difference. This slight difference can be overcome because the GA-rCS approach outperforms the the GA-CS approach in terms of $|S_j|$, $R_{NDS}(S_j)$, and $DI_R(S_j)$.
- In the proposed SCLSC network model, three conflicting objectives (minimization of total cost as economic factor, minimization of total amount of CO_2 emission as environmental factor, and maximization of social influence as social factor) are used. Since there is a trade-off among the objectives, it is impossible to reach a single optimal solution that optimize the values of all objectives simultaneously. This trade-off often lead to a set of optimal solutions, called Pareto optimal solutions. In this paper, the comparison of each approach was done by Pareto optimal solutions. As shown in Figs. 3, 4, and 5, Pareto optimal solutions of the GA-rCS approach are more efficient than those of the GA and GA-CS approaches, which implies that the GA-rCS approach can achieve these three objectives more efficiently than the the GA and GA-CS approaches.

6. Conclusion

In this paper, we have proposed a SCLSC network model for domestic mobile phone industry. Various facilities at each stage of the FL and RL have been considered in the proposed SCLSC network model. For reinforcing sustainability in the SCLSC network model, the minimization of total cost, the minimization of total amount of CO_2 emission, and the maximization of total social influence have been taken into consideration for economic, environmental and social factors, respectively. Since the three factors have been used as each objective function in modeling, the SCLSC network model can be a multi-objective optimization problem. Various meta-heuristic approaches for effectively solving the multi-objective optimization problem have been developed in conventional literatures.

In this paper, the GA-rCS approach which combines GA approach with revised CS approach has been proposed as one of hybrid meta-heuristics approaches. In numerical experiment, three scales of the SCLSC network model have presented to compare the performance of the GA-rCS approach with those of two conventional approaches (GA and GA-CS approaches) using various measures of performance. Experimental results have shown that the performance of the GA-rCS approach is more efficient than those of the GA and GA-CS approaches in terms of the $|S_j|$, $R_{NDS}(S_j)$, and $DI_R(S_j)$ except for the CPU time.

Since the SCLSC network model and the GA-rCS approach proposed in this paper have strengths against conventional network models and meta-heuristic approaches, we can apply and extend the proposed SCLSC network model and the GA-rCS approach to real-world business environment. First, considering three factors (economic, environmental and social factors) in the SCLSC network model can reinforce enterprise's reliability and responsibility, which will lead to customer's satisfaction and enterprise's sustainability. Second, using the GA-rCS approach, a hybrid meta-heuristic approach, can inspire the researchers to develop more reliable or robust hybrid meta-heuristic approaches.

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