Journal of the Korea Industrial Information Systems Research Vol. 24 No.3, Jun. 2019 : 31-38
http://dx.doi.org./10.9723/jksiis.2019.24.3.031 ISSN:1229-3741

그린 공급망 네트워크 모델: 유전알고리즘 접근법

(Green Supply Chain Network Model: Genetic Algorithm Approach)

윤 영 수[1)*], 추룬수크 아누다리[2)]
(Yun Young Su and Chuluunsukh Anudari)

요 약 본 연구에서는 그린공급망(green supply chain: gSC) 네트워크 모델이 제안된다. 제안된 gSC 네트워크 모델은 환경적 요인 및 경제적 요인을 고려한다. 환경적 요인으로는 부품 및 제품 수송과정에서 발생하는 CO2 발생량의 총비용 최소화를 고려하며, 경제적 요인으로는 부품 및 제품 생산처리에 필요한 처리비용, 수송과정에서 발생하는 수송비용, 각 단계에서 고려되는 설비들의 개설을 위한 개설비용의 최소화를 고려한다. 수리모형에서는 환경적 요인 및 경제적 요인을 위해 고려되는 다양한 비용들의 총합의 최소화를 목적함수로 사용하며, 각 단계 간 수송량의 제약 등 다양한 제약조건을 함께 고려한다. 제안된 수리모형의 이행을 위해 유전알고리즘(Genetic algorithm: GA) 접근법을 사용한다. 수치실험에서는 네 가지 규모의 gSC 네트워크 모델을 제시하고, 이를 다양한 수행도 척도들을 사용하여 GA 접근법을 통해 해결하였다. 실험결과는 제안된 gSC 네트워크 모델과 GA 접근법의 우수성을 입증하였다.

핵심주제어: 그린 공급망 네트워크 모델, 환경적 및 경제적 요인, 유전알고리즘

Abstract In this paper, we design a green supply chain (gSC) network model. For constructing the gSC network model, environmental and economic factors are taken into consideration in it. Environmental factor is to minimize the CO_2 emission amount emitted when transporting products or materials between each stage. For economic factor, the total cost which is composed of total transportation cost, total handling cost and total fixed cost is minimized. To minimize the environmental and economic factors simultaneously, a mathematical formulation is proposed and it is implemented in a genetic algorithm (GA) approach. In numerical experiment, some scales of the gSC network model is presented and its performance is analyzed using the GA approach. Finally, the efficiencies of the gSC network model and the GA approach are proved.

Key Words: green supply chain network model, environmental and economic factors, CO_2 emission amount, genetic algorithm

1. Introduction

Supply chain (SC) network model has focused on the efficiency for its operation. For

* Coressponding Author: ysyun@chosun.ac.kr
Manuscript received June 03, 2019 / revised June 07, 2019 / accepted June 08, 2019
1) 조선대학교 경상대학 경영학부
2) 조선대학교 대학원 경영학과

the efficiency, economic factors (e.g., total profit maximization, total cost minimization) have usually been taken into consideration in the SC network design [1, 3, 8, 11]. However, recent years have shown an increased concerns on environmental factors (e.g., total CO_2 emission cost or amount minimization) in the SC network design. Therefore, many companies have been incorporating the environmental factors into their SC network design along with economic factors [5-6, 9-10].

Considering both economic and environmental factors is called as green supply chain (gSC). A few conventional studies have performed on the gSC network model [3-4, 6]. Paksoy [6] proposed a simple SC network model which consists of suppliers, manufacturers and customers. He considered CO_2 emission amount caused by transportation and manufacture in the proposed SC network model. Similar to Paksoy [6], Versei et al. [10] proposed a SC network model for wine production. They considered CO_2 emission amount when transports wine between each stage of the SC network model. Özceylan et al. [5] proposed a SC network model for automotive industry in Turkey and designed a mathematical formulation which maximizes total profit (= total revenue - total cost) under satisfying the constraint of total CO_2 emission amount. Talaei et al. [9] proposed a simple SC network model to minimize the total amount of CO_2 emission when products are produced and transported at each stage.

Another consideration for implementing the gSC network model efficiently is to use various transportation types. In general, transportation between a stage and the next adjoining stage is called as normal delivery (NRD). For example, if a gSC network model with supplier, manufacturer, distribution center (DC), retailer, customer at each stage is considered, the NRD can be used either between suppler and manufacturer or between manufacturer and DC. In additionally, direct delivery (DRD) and direct shipment (DRS) can be also used for the gSC network model. If the DC directly sends some products to customer except for retailer, it can be called as the DRD, also if manufacturer directly send some products to customer except for the DC and retailer, it can be called as the DRS. Therefore, considering various transportation types (i.e., the NRD, DRD, and DRS) in the gSC network model is more reasonable and worthwhile to implement the gSC network model efficiently. Unfortunately, however, most of conventional studies have not considered various transportation types in the gSC network model.

In this paper, we design a new type of the gSC network model. Economic and environmental factors are simultaneously considered and various transportation types (i.e., NRD, DRD, and DRS) are used for the gSC network model. For economic factor, the total cost which is composed of total transportation cost, total handling cost and total fixed cost is considered. For environmental factor, the total cost of the CO_2 amount emitted when transporting products or materials between each stage is taken into consideration. In Section 2, the gSC network model is proposed. A mathematical model is formulated for effectively represent the gSC network model in Section 3. A genetic algorithm (GA) approach is proposed for implementing the gSC network model in Section 4. A numerical experiment using some scales of the gSC network model is done and the performance of the proposed GA approach is analyzed in Section 5. Finally, some conclusions and remarks are mentioned in Section 6.

2. Proposed gSC Network Model

The proposed gSC network model consists of a serial stage of suppler, manufacturer, DC, retailer and customer. At first stage, supplier sends parts (or components) to manufacturer by the NRD. Manufacturer makes products using the parts. Some products are then sent to DC by the NRD and the others are sent to customer by the DRS. A similar situation is also happed at the DC, that is, the DC sends some products to retailer by the NRD and the others are sent to customer by the DRD. Retailer sends products to customer by the NRD. CO_2 is emitted during transportation processes of the NRD, DRD, and DRS between each stage. The conceptual material flow structure for the gSC network model is shown in Fig. 1.

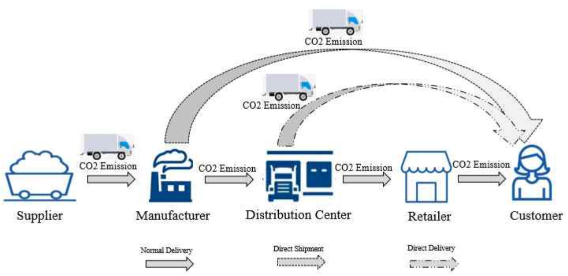

Fig. 1 Conceptual material flow structure for the gSC network model

3. Mathematical Model

For effectively representing the gSC network model proposed in Section 2, a mathematical model is formulated here. Indexes, parameters, and decision variables are as follows.

- Index

s: index of supplier
m index of manufacturer
d: index of DC
r: index of retailer
c: index of customer

- Parameter

Fix_s: fixed cost at suppler s
Fix_m: fixed cost at manufacturer m
Fix_d: fixed cost at DC d
Fix_r: fixed cost at retailer r
Han_s: unit handling cost at suppler s
Han_m: unit handling cost at manufacturer m
Han_d: unit handling cost at DC d
Han_r: unit handling cost at retailer r
Tra_{sm}: unit transportation cost from suppler s to manufacturer m
Tra_{md}: unit transportation cost from manufacturer m to DC d
Tra_{mc}: unit transportation cost from manufacturer m to customer c by the DRS
Tra_{dr}: unit transportation cost from DC d to retailer r
Tra_{dc}: unit transportation cost from DC d to customer c by the DRD
Tra_{rc}: unit transportation cost from retailer r to customer c
$CO2_{MT}$: allowable maximum amount of CO_2 emission in all transportation processes
$CO2_{TA}$: amount of CO_2 emission per material or product when transporting them
$CO2_{TC}$: cost of CO_2 emission per material or product when transporting them
Cap_s: capacity of supplier s
Cap_m: capacity of manufacturer m
Cap_d: capacity of DC d
Cap_r: capacity of retailer r
Cap_c: capacity of customer c

- Decision Variable

a_{sm}: amount of materials transported from suppler s to manufacturer m
a_{md}: amount of products transported from manufacturer m to DC d
a_{mc}: amount of products transported from

manufacturer m to customer c by the DRS

a_{dr}: amount of products transported from DC d to retailer r

a_{dc}: amount of products transported from DC d to customer c by the DRD

a_{rc}: amount of products transported from retailer r to customer c

s_s: takes the value of 1 if supplier s is opened and 0 otherwise

s_m: takes the value of 1 if manufacturer m is opened and 0 otherwise

s_d: takes the value of 1 if DC d is opened and 0 otherwise

The objective for implementing the gSC network model is to minimize the total cost which consists of total fixed cost (TFC), total handling cost (THC), total transportation cost (TTC) and total CO_2 emission cost (TEC). Some constraints such as limited transportation amount, capacity of the facilities considered at each stage should be used for achieving the objective.

$$Minimize\ TC = TFC + THC + TTC + TMC \quad (1)$$

$$TFC = \sum_s Fix_s \cdot s_s + \sum_m Fix_m \cdot s_m + \sum_d Fix_d \cdot s_d + \sum_r Fix_r \cdot s_r \quad (2)$$

$$THC = \sum_s Han_s \cdot Cap_s \cdot s_s + \sum_m Han_m \cdot Cap_m \cdot s_m + \sum_d Han_d \cdot Cap_d \cdot s_d + \sum_r Han_r \cdot Cap_r \cdot s_r \quad (3)$$

$$TTC = \sum_s \sum_m Tra_{sm} \cdot a_{sm} \cdot s_s \cdot s_m + \sum_m \sum_m Tra_{md} \cdot a_{md} \cdot s_m \cdot s_d + \sum_m \sum_c Tra_{mc} \cdot a_{mc} \cdot s_m + \sum_d \sum_r Tra_{dr} \cdot a_{dr} \cdot s_d + \sum_d \sum_c Tra_{dc} \cdot a_{dc} \cdot s_d + \sum_r \sum_c Tra_{rc} \cdot a_{rc} \quad (4)$$

$$TEC = CO2_{TC} \cdot CO2_{TA} (\sum_s \sum_m a_{sm} \cdot s_s \cdot s_m + \sum_m \sum_d a_{md} \cdot s_m \cdot s_d + \sum_m \sum_c a_{mc} \cdot s_m + \sum_d \sum_r a_{dr} \cdot s_d + \sum_d \sum_c a_{dc} \cdot s_d + \sum_r \sum_c a_{rc} \cdot s_r) \quad (5)$$

Subject to

$$\sum_s \sum_m a_{sm} \cdot s_s \cdot s_m - \sum_m Cap_m \cdot s_m \leq 0 \quad (6)$$

$$\sum_m \sum_d a_{md} \cdot s_m \cdot s_d - \sum_d Cap_d \cdot s_d \leq 0 \quad (7)$$

$$\sum_d \sum_r a_{dr} \cdot s_d - \sum_r Cap_r \leq 0 \quad (8)$$

$$\sum_m \sum_c a_{mc} \cdot s_m + \sum_d \sum_c a_{dc} \cdot s_d + \sum_r \sum_c a_{rc} - \sum_c Cap_c \leq 0 \quad (9)$$

$$CO2_{MT} - CO2_{TA} (\sum_s \sum_m a_{sm} \cdot s_s \cdot s_m + \sum_m \sum_d a_{md} \cdot s_m \cdot s_d + \sum_m \sum_c a_{mc} \cdot s_m + \sum_d \sum_r a_{dr} \cdot s_d + \sum_d \sum_c a_{dc} + \sum_r \sum_c a_{rc}) \geq 0 \quad (10)$$

$$\sum_s s_s = 1 \quad (11)$$

$$\sum_m s_m = 1 \quad (12)$$

$$\sum_d s_d = 1 \quad (13)$$

$$s_s = \{0,1\}, \ \forall s \in S \quad (14)$$

$$s_m = \{0,1\}, \ \forall m \in M \quad (15)$$

$$s_d = \{0,1\}, \ \forall d \in D \quad (16)$$

$$a_{sm}, a_{md}, a_{mc}, a_{dr}, a_{dc}, a_{rc}, Cap_s, Cap_m, Cap_d, Cap_r, Cap_c \geq 0, \ \forall s \in S, \forall m \in m, \forall d \in D, \forall r \in R, \forall c \in C \quad (17)$$

Equation (1) shows the objective function to minimize total cost. Equation (6) stands for that total amount sent from suppler to manufacturer is equal or less than the capacity of manufacturer. Equations (7), (8), and (9) mean the same constraints with the Equation (6). In equation (10), total amount of CO_2 emission when transporting parts and products between each stage is the same or less than the allowable maximum amount of CO_2 emission in all transportation processes. Equations (11) to (13) show that only one facility should be opened at each stage of suppler, manufacturer, DC, and retailer, which means that the others should be closed at each stage. Equations (14) to (16) indicate that, if a facility at each stage of supplier, manufacturer, DC and retailer is opened, then it takes the value of 1, else takes 0. Equation (17) shows the non-negativity of each decision variable.

4. Proposed GA approach

Since most of the complicated network problems such as the gSC network model have NP-complete nature [2, 7], GA approach, one of the meta-heuristics, has been successfully adapted to locate global optimal solution in many literatures [4, 12-13]. In this paper, we also propose a GA approach to solve the gSC network model. The detailed implementation scheme is as follows:

Step 1: Parameter setting
Population size, crossover rate, mutation rate, selection scheme, total numbers of generations are set.

Step 2: Initialization
Initial population is randomly generated under satisfying all constraints.
Parent population is made using the initial population.

Step 3: Crossover operation
Two-point (2X) crossover operator [2] is applied to parent population

Step 4: Mutation operation
Random mutation operator [2] is applied to parent population.

Step 5: Selection
Offspring population is made using 1) the population obtained after crossover and mutation operations in Steps 3 to 4 and 2) parent population in Step 2 by the elitist selection scheme [2].

Step 6: Termination condition
If A pre-defined termination condition is satisfied, then stop, else go to Step 3.

5. Numerical Experiment

Four scales for the gSC network model implementation are presented in Table 1. For various comparison, the gSC network model is divided into two types. First type is to consider the NRD only in it, but in the second type, the NRD, DRD and DRS are simultaneously taken into consideration in all transportation routes. For simplicity, the first and second types are called as gSC_1 and gSC_2, respectively. The ratios of transportation amount from manufacturer to DC and customer are 80% and 20% in the gSC_2, respectively. The same ratios are also adapted from DC to retailer and customer. Total 2,000 parts are sent from supplier to manufacturer and 2,000 product sent from manufacturer to the adjoining next stage.

The proposed GA approach in Section 4 is implemented using each scale of Table 1. Parameters used in the proposed GA approach are as follows: Population size is 20, Crossover rate 0.6, mutation rate 0.5, and total number of generations 1,000. Total 30 iterations are performed to eliminate the randomness of the search of the proposed GA approach. To compare the performance of the proposed GA approach between the gSC_1 and gSC_2, some measures of performance are shown in Table 2.

The BS, AS, and AT are the values obtained after 30 iterations and the P/D is the ratio divided by the BS of the gSC_1. The

Table 1 Four scales for the gSC network model implementation

Scale	Supplier	Manufacturer	DC	Retailer	Customer
1	4	3	4	2	5
2	8	6	8	4	10
3	12	10	12	8	15
4	20	15	20	12	20

Table 3 Computation results using the proposed GA approach

	Scale 1		Scale 2		Scale 3		Scale 4	
	gSc_1	gSc_2	gSc_1	gSc_2	gSc_1	gSc_2	gSc_1	gSc_2
BS	406,388	404,737	414,065	411,481	519,684	509,248	530,172	526,637
AS	406,877	405,051	414,788	412,169	522,018	511,006	530,685	527,256
AT	2.25	2.19	2.37	2.24	2.57	2.30	2.64	2.51
P/D	-	0.41%	-	0.62%	-	0.20%	-	0.67%

Table 2 Measure of performance

Measure	Brief description
BS	Best solution
AS	Average solution
AT	Average CPU time
P/D	Percent difference (P/D)

computation results using the proposed GA approach in each scale are shown in Table 3.

In scale 1 of the Table 3, the gSC_1 and gSc_2 has 406,388 and 404,737 in terms of the BS, respectively. The difference between them is 0.41% in terms of the P/D, which stands for that the latter is more efficient than the former. In terms of the AS, the gSC_2 is more efficient than the gSC_1. However, the search speed is almost the same in the gSC_1 and gSC_2.

Similar situation is also shown in the Scale 2, 3, and 4, that is, the gSC_2 is more efficient than the gSC_1 in all measures of performance, except for the AT.

Fig. 2 and 3 show the flows of transportation amount in the gSC_1 and gSC_2. In Fig. 2 and 3, we can see that supplier send 2,000 part from suppler to manufacturer and then 2,000 products are sent from manufacturer to the DC by the NRD in the gSc_1, but the amounts are separated into 1,600 (=2,000×80%) and 400 (=2,000×20%) in the gSC_2. 1,600 products of them are sent from manufacturer to the DC by the NRD and 400 products sent from manufacturer to customer by the DRS. At the DC, 2,000 product are sent to retailer by the NRD in the gSC_1, but 1,280(=1,600×80%) products sent to retailer by the NRD and 320(=1,600 ×20%) products sent to customer by the DRD

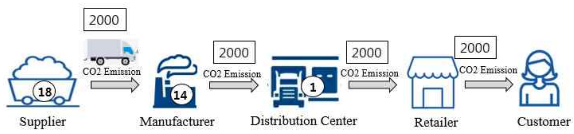

Fig. 2 Flow of transportation amount in the gSC_1

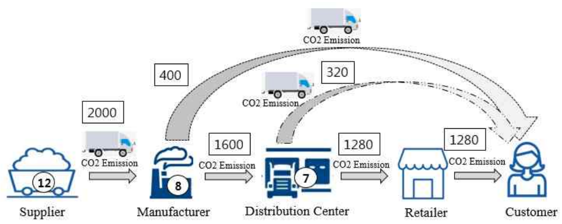

Fig. 3 Flow of transportation amount in the gSC_2

Based on the computation results as shown in Table 3, Fig. 2 and 3, we can reach the following conclusion.

- Various scales of the gSC network has been solved by using the proposed GA approach, which indicates that the proposed GA approach has a robustness in solving complicated multistage network problems such as the gSC network model.
- The performances of the gSC_2 with the NRD, DRD and DRS altogether are more efficient than those of the gSC_1 with the NRD alone, which means that having various transportation types is more suitable to design gSC network model than having only one transportation type.

6. Conclusion

In this paper, we have designed a gSC network model with multistage. Supplier, manufacturer, the DC, retailer and customer have been used for designing the gSC network model. Three types of transportation (NRD, DRD, and DRS) have been adapted for transporting parts and products between each stage. A mathematical model to minimize total cost (= total fixed cost + total handling cost + total transportation cost + total cost of CO_2 emission amount) under satisfying various constraints has been formulated. A GA approach has been proposed to implement the mathematical model.

In numerical experiment, four scales of the gSC network model has been used for proving the performance of the GA approach. The gSC network model is divided into the gSC_1 with the NRD alone and the gSC_2 with the NRD, DRD, and DRS altogether. The gSC_1 and gSC_2 have been compared with each other using several measures of performance. Experimental results have shown that i) the proposed GA approach has a robustness in solving complicated multistage network problems and ii) the gSc_2 with NRD, DRD, and DRS altogether is more efficient that the gSC_1 with the NRD alone.

However, the scales used in numerical experiment are relatively small sizes, thus larger-scales will be used to proving the performance of the proposed GA approach and more various comparisons using GAs, hybrid GAs and other meta-heuristics will be employed in future study.

Acknowledgment

This work is a revised and extended version of the paper (Gen, M., Yun, Y. S. and Chuluunsukh, A., Green supply chain network design, *International Symposium on Innovation in Information Technology and Applications (ISIITA2019)*, Okinawa, Japan, pp. 86-88, 2019)

References

[1] Chen, Y. T., Chan, F. T. S. and Chung, S. H., "An integrated closed-loop supply chain model with location and allocation problem and product recycling decisions," International Journal of Production Research, Vol. 53, pp. 3120-3140, 2015.

[2] Gen, M. and Cheng, R., "Genetic algorithms and engineering optimization," John-Wiley & Sons, New York, 2000.

[3] Min, H., Ko, C. S. and Ko, H. J., "The spatial and temporal consolidation of returned products in a closed-loop supply chain network," Computers and Industrial Engineering, Vol. 51 pp. 309-320. 2006a.

[4] Min, H., Ko, H. J. and Ko, C. S., "A genetic algorithm approach to developing the multi-echelon reverse logistics network for product returns," Omega, Vol. 34, pp. 56-69, 2006b.

[5] Özceylan, E., Demirel, N., Cetinkaya, C. Demirel, E., "A closed-loop supply chain network design for automotive industry in Turkey," Computers and Industrial Engineering, Vol. 113, pp. 727-745, 2017.

[6] Paksoy T., "Optimizing a supply chain network with emission trading factor," Scientific Research and Essays, Vol. 5, No. 17, pp. 2535-2546, 2010.

[7] Savaskan, R. C., Bhattacharya, S. and Van Wassenhove, L. V., "Closed-loop supply chain models with product remanufacturing," Management Science, Vol. 50, No. 2, pp. 239-252, 2004.
[8] Son, D., Kim, S., Park, H. and Jeong, B., "Closed-loop supply chain planning model of rare metals," Sustainability, Vol. 10, No. 4, pp. 1061, https://doi.org/10.3390/su10041061, 2018.
[9] Talaei, M., Moghaddam, B. F., Pishvaee, M. S., Bozorgi-Amiri, A. and Gholamnejad, S. A., "A robust fuzzy optimization model for carbon-efficient closed-loop supply chain network design problem: a numerical illustration in electronics industry," Journal of Cleaner Production, Vol. 113, pp. 662-673, 2016.
[10] Versei M, Polyakovskiy S., "Sustainable supply chain network design: A case of the wine industry in Australia," Omega, Vol. 66, pp. 236-247, 2017.
[11] Wang, H. F. and Hsu, H. W., "A closed-loop logistic model with a spanning tree based genetic algorithm," Computers and Operations Research, Vol. 37, pp. 376-389, 2010.
[12] Yun, Y. S., Chuluunsukh, A. and Chen X., "Hybrid genetic algorithm for optimizing closed-loop supply chain model with direct shipment and delivery," New Physics: Sae Mulli, Vol. 68, No. 6, pp. 683-692, 2018.
[13] Yun, Y. S. and Chuluunsukh, A., "Environmentally-friendly supply chain network with various transportation types," Journal of Global Tourism Research, Vol. 3, No.1 pp. 17-24, 2018.

윤영수 (Yun Young Su)

• 종신회원
• 대구대학교 산업공학과 학사
• 건국대학교 산업공학과 석사,박사
• Waseda University 정보생산시스템연구과 박사
• 현재: 조선대학교 경영학부 교수
• 관심분야: 물류/SCM, 유전알고리즘, 생산최적화

추룬수크 아누다리 (Chuluunsukh Anudari)

• 정회원
• 전남대학교 경영학과 학사
• 현재: 조선대학교 경영학과 박사 과정
• 관심분야: SCM, 생산최적화