Journal of the Korea Industrial Information Systems Research Vol. 23 No. 5, Oct. 2018 : 33-41
http://dx.doi.org./10.9723/jksiis.2018.23.5.033 ISSN:1229-3741

# Supply Chain Network Design Considering Environmental Factor and Transportation Types

Yun YoungSu[1)]*

**Abstract** Most important thing when designing and implementing a supply chain network is to consider various problems which may occur in real world situation. In this paper, we propose a supply chain network considering two problems (environmental factor and transportation types) under real world situation. CO2 emission amount as environmental factor is considered since it is usually generated from production and transportation processes. Normal delivery, direct delivery and direct shipment as transportation types are also considered since many customers ask various transportation types for delivery or shipment of their products under on-line or off-line purchase environment. The proposed supply chain network considering environmental factor and transportation types is represented in a mathematical formulation and implemented using hybrid genetic algorithm (HGA) approach. In numerical experiments, several scales of supply chain networks are presented and implemented using HGA approach. The performance of the HGA approach is compared with those of some conventional approaches under various measures of performance. Finally, it is proved that the performance of the HGA approach is superior to those of the others.

**Key Words** : Supply Chain Network, Environmental Factor, $CO_2$ Emission, Transportation Type, Normal Delivery, Direct Delivery and Shipment, Hybrid Genetic Algorithm

## 1. Introduction

Supply chain (SC) network usually considers various facilities such as suppliers, manufacturers, distribution centers (DCs), retailers and customers at each stage for producing and transporting materials or products. Most important thing when designing and implementing the SC network is to consider various problems which may occur in real world situation.

Recently, with the increased concerns on economic and environmental problems, many companies have focused on constructing their SC networks efficiently. Among the environmental problems, the $CO_2$ emission amount resulting from the production and transportation of materials or products between various stages of the SC network has been continuously increasing, which stimulates many researchers to develop more efficient SC network in order to decrease it [1, 9-10, 12].

Özceylan et al. [9] proposed a SC network for automotive industry in Turkey. They considered the $CO_2$ emission amount when transporting products between each stage in their SC network. Similar to Özceylan et al. [9], Varsei and Polyakovskiy [10] also proposed a SC network to minimize the total $CO_2$ emission amount when transporting products

---

* Corresponding Author : ysyun@chosun.ac.kr

+ This paper was supported by research fund from Chosun University, 2018.

Manuscript received October 9, 2018 / accepted October 14, 2018

1) Division of Business Administration, Chosun University, First author

between each stage. Arampantzi and Minis [1] considered the green house gas such as $CO_2$ in their SC network to minimize the total cost resulting from transporting and producing materials and product.

Among economic problems, minimizing transportation cost resulting from each stage has been considered for constructing efficient SC network. The efficiency can be calculated by applying various transportation types to the SC network [2-5, 9, 13-14]. In general, normal delivery (ND), direct delivery (DD) and direct shipment (DS) are considered in the SC network. In the ND, materials or products is transported from a stage to another adjoining. In the DD, some products can be directly delivered from DCs to customers not via retailers. Another products can be also directly shipped from manufacturers to customers not via DCs and retailers and this type is called as the DS.

Chiang et al. [3] proposed a dual-channel SC network. The proposed SC network consider the DS by transporting a product to customer directly and showed that, by using the DS, the profit and efficiency of the SC network can be increased. Chen et al. [2] proposed a SC network with the ND, DD, and DS simultaneously. In numerical experiment, they proved that the SC network with three types of transportation outperforms the SC network with the ND alone. Özceylan et. al. [9] suggested a SC network for automotive industry in Turkey. They considered the ND for transporting automotive and automotive-related components from supplier to user cluster via manufacturer and DC.

By analyzing the previous studies mentioned above, we can reach the following two key issues:

1) For environmental problems, many researchers have considered $CO_2$ emission in their SC networks. However, except for Arampantzi and Minis [1], the others only considered $CO_2$ emission in transporting materials or products between each stage. Since $CO_2$ is usually emitted when producing and transporting materials or products, both cases should be considered in SC network simultaneously.
2) In general, considering various transportation types can increase the efficiency of the SC network and also decrease $CO_2$ emission amount. However, most of conventional studies [2-3, 9] does not considered the ND, DD and DS simultaneously. Therefore, all types of transportation should be considered when designing a SC network so that it's efficiency can be increased.

Therefore, in this paper, we develop an efficient SC (eSC) network. The eSC network i) considers $CO_2$ emission amount when producing and transporting materials and products between each stage and also ii) considers various transportation types such as the ND, DD, and DS. By considering $CO_2$ emission and various transportation types, the eSC network will become more efficient and robust one. In Section 2, a conceptual flow of the eSC network is shown and it is represented using a mathematical formulation in Section 3. In Section 4, a hybrid genetic algorithm (pro-HGA) approach is proposed to implement the mathematical formulation. In numerical experiment of Section 5, several scales of the SC network are presented and used for comparing the performance of the pro-HGA approach with those of some conventional approaches. Finally, some conclusions and remarks are summarized in Section 6.

## 2. Proposed eSC Network

In this section, the structure of the eSC network is described. First, materials are sent from supplier to manufacturer by the ND. Secondly, products are sent from manufacturer to customers via DS and DC by the ND, Thirdly, the DS also send products

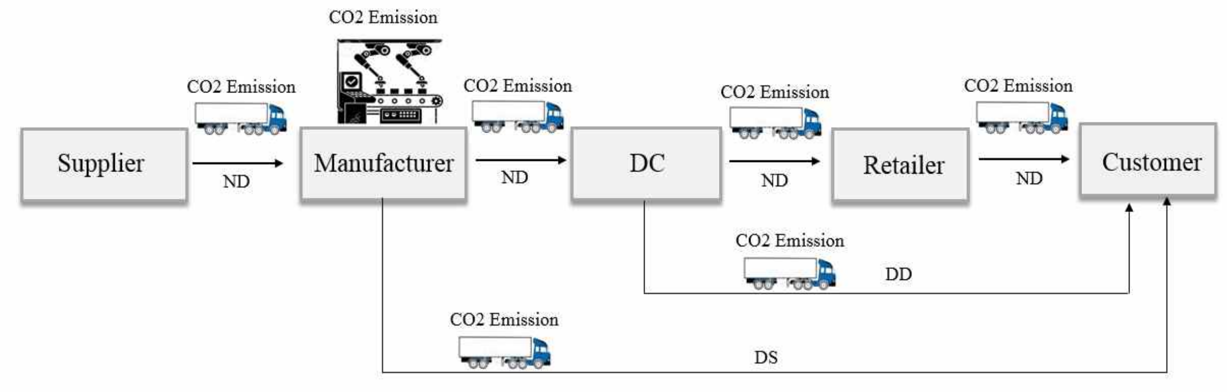

Fig. 1 A Conceptual Flow of the eSC Network

to retailer by the ND and customer by the DD. Finally, the retailer sends product to customer by the ND. $CO_2$ is emitted when transporting materials and products between each stage and it is also emitted when producing products at manufacturer. Fig. 1 shows a conceptual flow of the eSC network under considering various transportation types and $CO_2$ emission situation.

## 3. Mathematical Model

First, some assumptions are considered to present the eSC network described in Fig. 1.

- Only single type of product is considered.
- The numbers of facilities considered at each stage as shown in Fig. 1 are fixed and already known.
- Only one facility at suppler, manufacturer, and DC is opened and the others are closed. However, all facilities at retailer and customer are always opened.
- The fixed costs for opening and operating the facilities considered at each stage of suppler, manufacturer, DC, and retailer are different each other and already known.
- The unit handling costs and unit transportation costs at each stage are different each other and already known.
- Amount and cost of $CO_2$ emission per material or product when transporting and producting them are equal at each stage and already known.

Index set, parameters and decision variables are as follows:

**- Index Set**

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

**- Parameter**

*Fs*: fixed cost at suppler *s*
*Fm*: fixed cost at manufacturer *m*
*Fd*: fixed cost at DC *d*
*Fr*: fixed cost at retailer *r*
*Hs*: unit handling cost at suppler *s*
*Hm*: unit handling cost at manufacturer *m*
*Hd*: unit handling cost at DC *d*
*Hr*: unit handling cost at retailer *r*
*Tsm*: unit transportation cost from suppler *s* to manufacturer *m*
*Tmd*: unit transportation cost from manufacturer *m* to DC *d*
*Tmc*: unit transportation cost from manufacturer *m* to customer *c* by the DS

*Tdr*: unit transportation cost from DC *d* to retailer *r*

*Tdc*: unit transportation cost from DC *d* to customer *c* by the DD

*Trs*: unit transportation cost from retailer *r* to customer *s*

*MXm*: allowable maximum amount of $CO_2$ emission in manufacturer

*MXt*: allowable maximum amount of $CO_2$ emission in all transportation processes.

*$CO_2ma$*: amount of $CO_2$ emission per product when producing it

*$CO_2mc$*: cost of $CO_2$ emission per product when producing it

*$CO_2a$*: amount of $CO_2$ emission per material or product when transporting them

*$CO_2c$*: cost of $CO_2$ emission per material or product when transporting them

*Cs:* capacity of supplier *s*

*Cm:* capacity of manufacturer *m*

*Cd:* capacity of DC *d*

*Cr:* capacity of retailer *r*

*Cc:* capacity of customer *c*

**- Decision Variable**

$t_{sm}$: amount of materials transported from suppler *s* to manufacturer *m*

$t_{md}$: amount of products transported from manufacturer *m* to DC *d*

$t_{mc}$: amount of products transported from manufacturer *m* to customer *c* by the DS

$t_{dr}$: amount of products transported from DC *d* to retailer *r*

$t_{dc}$: amount of products transported from DC *d* to customer *c* by the DD

$t_{rc}$: amount of products transported from retailer *r* to customer *c*

$x_s$: takes the value of 1, if supplier *s* is opened and 0 otherwise

$x_m$: takes the value of 1, if manufacturer *m* is opened and 0 otherwise

$x_d$: takes the value of 1, if DC *d* is opened and 0 otherwise

Using the index, parameters and decision variables mentioned above, a mathematical formulation for effectively representing the eSC network is developed. Objective function is to minimize total cost (*TC*) which is consisted of the sum of total fixed cost (*TFC*), total handling cost (*THC*), total transportation cost (*TTC*), and total $CO_2$ emission cost (*TCC*) at each stage.

$$\text{Minimize } TC = TFC + THC + TTC + TCC \tag{1}$$

$$TFC = \sum_s Fs \cdot x_s + \sum_m Fm \cdot x_m + \sum_d Fd \cdot x_d + \sum_r Fr \tag{2}$$

$$THC = \sum_s Hs \cdot c_s \cdot x_s + \sum_m Hm \cdot c_m \cdot x_m + \sum_d Hd \cdot c_d \cdot x_d + \sum_r Hr \cdot c_r \tag{3}$$

$$TTC = \sum_s \sum_m Tsm.t_{sm} \cdot x_s \cdot x_m + \sum_m \sum_d Tmd.t_{md} \cdot x_m \cdot x_d + \sum_m \sum_c Tmc.t_{mc} \cdot x_m + \sum_d \sum_r Tdr.t_{dr} \cdot x_d + \sum_d \sum_c Tdc.t_{dc} \cdot x_d + \sum_r \sum_c Trc.t_{rc} \tag{4}$$

$$TCC = \sum_m CO_2mc.c_m \cdot x_m + CO_2a(\sum_s \sum_m Tsm.t_{sm} \cdot x_s \cdot x_m + \sum_m \sum_d Tmd.t_{md} \cdot x_m \cdot x_d + \sum_m \sum_c Tmc.t_{mc} \cdot x_m + \sum_d \sum_r Tdr.t_{dr} \cdot x_d + \sum_d \sum_c Tdc.t_{dc} \cdot x_d + \sum_r \sum_c Trc.t_{rc}) \tag{5}$$

*Subject to*

$$\sum_s \sum_m t_{sm} \cdot x_s \cdot x_m - \sum_m c_m \cdot x_m = 0 \tag{6}$$

$$\sum_m \sum_d t_{md} \cdot x_m \cdot x_d - \sum_d c_d \cdot x_d = 0 \tag{7}$$

$$\sum_m \sum_c t_{mc} \cdot x_m - \sum_c c_c = 0 \tag{8}$$

$$\sum_d \sum_r t_{dr} \cdot x_d - \sum_r c_r = 0 \tag{9}$$

$$\sum_{d}\sum_{c} t_{dc} \cdot x_d - \sum_{c} c_c = 0 \tag{10}$$

$$\sum_{r}\sum_{c} t_{rc} - \sum_{c} c_c = 0 \tag{11}$$

$$\sum_{m} CO_2 ma.c_m \cdot x_m \leq MX_m \tag{12}$$

$$CO_2 a\Big(\sum_{s}\sum_{m} t_{sm} \cdot x_s \cdot x_m + \sum_{m}\sum_{d} t_{md} \cdot x_m \cdot x_d + \sum_{m}\sum_{c} t_{mc} \cdot x_m + \sum_{d}\sum_{r} t_{dr} \cdot x_d + \sum_{d}\sum_{c} t_{dc} \cdot x_d + \sum_{r}\sum_{c} t_{rc}\Big) \leq MXt \tag{13}$$

$$\sum_{s} x_s = 1 \tag{14}$$

$$\sum_{m} x_m = 1 \tag{15}$$

$$\sum_{d} x_d = 1 \tag{16}$$

$$x_s = \{0,1\}, \forall s \tag{17}$$

$$x_m = \{0,1\}, \forall m \tag{18}$$

$$x_d = \{0,1\}, \forall d \tag{19}$$

$$c_s, c_m, c_d, c_r, c_c \geq 0, \forall s,m,d,r,c \tag{20}$$

Equation (1) shows the objective function of the *TC*. Equations (2) through (5) show the *TFC*, *THC*, *TTC*, and *TCC* respectively. Equations (6) through (11) show that the transportation amount sent from a stage to the adjoining stage is the same as that at the adjoining stage. Equations (12) and (13) stand for the limitation of $CO_2$ emission amount when producing product at manufacturer and transporting material and product between each stage. Equations (14) through (16) show that only one facility should be opened at each stage. Equations (17) through (19) represent that each decision variable should take a value of 0 or 1. Equation (20) refers to non-negativity.

## 4. Proposed Approach

In this section, we develop the pro-HGA approach to efficiently solve the eSC network. A conventional genetic algorithm (GA) approach and revied Cuckoo search (CS) approach are combined for constructing the pro-HGA approach, which is an improved version of the HGA approach by Kanagaraj et al. [7]. Kanagaraj et al. [7] proposed a HGA approach combining GA with CS approaches. The main search process is as follows: First, GA approach is applied to produce new population using GA operators such as crossover, mutation and selection. Secondly, CS approach is adapted to produce more respective solutions using the new population produced by GA approach. The key point of this approach is to locate global optimal solution more quickly using Lévy flight scheme of CS approach. However, the Lévy flight scheme is applied to only one solution among all the solutions of the new population produced by GA approach and its use is done by only one time in each iteration. Also, if the fitness value of the solution produced by Lévy flight scheme is inferior to that of the solution randomly selected in the new population produced by GA approach, the improvement of the solution produced by Lévy flight scheme can become impossible [12].

To overcome the mentioned-above weakness of the HGA approach by Kanagaraj et al. [7], the production of the respective solutions and the improvement of the solution during HGA search processes should be continuously needed. For this strategy, all the solutions of the offspring produced by GA approach in each generation should be adapted to Lévy flight scheme. The detailed implementation procedure of the pro-HGA approach is shown in Fig. 2.

## 5. Numerical Experiment

In numerical experiment, four scales of the eSC network are taken into consideration. The detailed information of the facilities considered at each stage is shown in Table 1.

For example, in scale 2 of Table 1, six suppliers and DCs, four manufactures and retailers and ten customers are considered. These scales are used for comparing the performance of the pro-HGA approach with those of some conventional approaches. The detailed information of each approach are summarized in Table 2.

```
procedure: pro-HGA approach
begin
  $G_{best}$ = 0;
  t ← 0;                    // t: generation number
  initialize initial population P(t) from n host nest $x_i (i = 1,...,n)$;
  while (not termination condition)
    create O(t) from P(t) by crossover and mutation routines;   // O(t): offspring at t
    evaluate O(t) and store the best solution $L_{best}$;
    for each solution $x_i$ of O(t) do
      generate a new solution $x_{lnew}$ from $x_i$ by applying Lévy flight scheme;
      randomly choose a solution $x_i$ among O(t);
      if ($f(x_{lnew}) > f(x_i)$) then
        C(t) ← $x_{lnew}$   //C(t): population of CS
      end
    end
    a fraction ($p_a$) with worst solutions after sorting C(t) is abandoned;
    randomly regenerate new solutions $N_i$ as many as the $p_a$;
    C(t) ← $N_i$;
    evaluate C(t) and store the best solution $C_{best}$;
    if ($f(L_{best}) \geq f(C_{best})$) then
      $G_{best}$ ← $L_{best}$
    else
      $G_{best}$ ← $C_{best}$
    end
    produce new P(t) using O(t) and C(t) by selection routine;
    t ← t+1;
  end
  output: the best solution $G_{best}$;
end
```

Fig. 2 Implementation Procedure of the Pro-HGA Approach

In Table 2, except for LINGO, one conventional GA approach (GA) and three HGA approaches (HGA1, HGA2 and pro-HGA) are considered for comparison. All the approaches, except for LINGO, are 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 for the GA, HGA1, HGA2 and pro-HGA approaches are as following: total numbers of generations is 2,000, population size 30, crossover rate 0.5, and mutation rate 0.2. Number of host nest (*n*) is 20, $\alpha$ = 1, and $p_a$ = 0.25 for the search of the CS used in the HGA1 and the revised CS approaches in pro-HGA approaches. All parameters were used after fine tuning of each approach.

Table 1 Four Scales Considered in the eSC Network

| Scale | Suppler | Manufacturer | DC | Retailer | Customer |
|---|---|---|---|---|---|
| 1 | 3 | 2 | 3 | 2 | 5 |
| 2 | 6 | 4 | 6 | 4 | 10 |
| 3 | 12 | 8 | 12 | 8 | 15 |
| 4 | 24 | 12 | 24 | 12 | 20 |

Table 2 Each Approach for Comparison

| Approach | Description |
|---|---|
| GA | GA by Gen and Cheng [6] |
| HGA1 | HGA with GA and CS by Kanagaraj et al. [7] |
| HGA2 | HGA with GA and Tabu Search by Xinyu and Liang [11 |
| pro-HGA | HGA with GA and revised CS proposed in this paper |
| LINGO | Optimization solver by Lindo [8] |

Table 3 Some Measures of Performances

| Measure | Description |
|---|---|
| Best Solution (BS) | Best solution in total 30 runs |
| Average Solution (AS) | Value averaged over total 30 runs |
| Average Iteration (AI) | Iteration number averaged over total 30 runs |
| Average Time (AT) | CPU time averaged over total 30 runs |
| Performance Difference (P/D) | Performance difference between a approach and LINGO in terms of the BS |

Table 4 Computation result using Scales 1 and 2

| | Scale 1 | | | | | Scale 2 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | GA | HGA1 | HGA2 | pro-HGA | LINGO | GA | HGA1 | HGA2 | pro-HGA | LINGO |
| BS | 489,338 | 488,860 | 488,860 | 488,860 | 488,860 | 519,565 | 493,798 | 494,200 | 493,646 | 554,276 |
| AS | 489,338 | 488,860 | 489,014 | 488,860 | - | 521,345 | 494,419 | 494,906 | 494,789 | - |
| AI | 6 | 16 | 12 | 1 | - | 21 | 15 | 16 | 5 | - |
| AT | 2.37 | 2.36 | 76.40 | 4.24 | - | 2.42 | 2.38 | 113.8 | 4.44 | - |
| P/D | 0.1% | 0.0% | 0.0% | 0.0% | 0.0% | -6.3% | -10.9% | -10.8% | -10.9% | 0.0% |

Table 5 Computation result using Scales 3 and 4

| | Scale 3 | | | | | Scale 4 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | GA | HGA1 | HGA2 | pro-HGA | LINGO | GA | HGA1 | HGA2 | pro-HGA | LINGO |
| BS | 503,566 | 530,369 | 499,046 | 493,646 | 502,485 | 513,935 | 557,109 | 519,289 | 503,759 | 539,172 |
| AS | 503,898 | 530,842 | 499,493 | 494,787 | - | 514,142 | 557,696 | 519,899 | 503,765 | - |
| AI | 8 | 59 | 25 | 105 | - | 34 | 29 | 12 | 21 | - |
| AT | 2.45 | 2.47 | 147.7 | 4.55 | - | 2.46 | 2.64 | 202.1 | 4.82 | - |
| P/D | 0.2% | 5.5% | -0.7% | -1.8% | 0.0% | -6.5% | 3.3% | -6.5% | -6.6% | 0.0% |

Total 30 runs were independently carried out to eliminate the randomness of the search of each approach. Some measures as shown in Table 3 are used for comparing the performances of all the approaches. Using the four scales of Table 1, the computation results of all approaches are shown in Tables 4 and 5.

In Scale 1, all the approaches including the pro-HGA approach locate the same solution in terms of the BS. Also, all of them find the solution at the initial generations in terms of the AI. However, in terms of the AT, the GA and HGA1 approaches are about two times quicker than the pro-HGA and the HGA2 approach is the slowest. In Scale 2, the performance of the pro-HGA is equal to that of the HGA1 and their performances are superior to those of the GA and HGA2. In terms of the AS, the HGA1 has a slight better result than the pro-HGA and the GA is the worst. However, the pro-HGA outperforms the others in terms of the AI, though the former is slower than the GA and HGA1. In the comparison between the pro-HGA and LINGO, the former shows a better result than the latter in terms of the BS.

In scale 3, the pro-HGA shows better performance in terms of the BS and AS than the others. However, in terms of the AI and AT, the performance of the pro-HGA is worse than those of the GA and HGA1. Similar to the Scale 3, the pro-HGA outperforms LINGO in terms of the BS. In scale 4, the HGA1 has the worst result and the pro-HGA has the best one in terms of the BS and AS. In terms of the AI, the performance of the HGA2 is slightly better than the others. However, in terms of the AT, the HGA2 is the slowest and the GA and HGA1 is the quickest. When compared with LINGO, the GA, HGA2 and pro-HGA show a better result in terms of the BS.

Figures 3 and 4 show the convergence behaviors of each approach when they reach to 500 generations. In Fig. 3, the GA, HGA1 and HGA2 do not show any convergence behaviors in all generations, though they show a little convergence behaviors in initial generations. However, the pro-HGA shows a better behaviors that the others, though it does not show any convergence behaviors after 100 generations. In Fig. 4, the pro-HGA shows a better convergence behaviors than the others, though all approaches shows various behaviors in their intial generations.

Using the analyzed results of Tables 4 and 5, and Figures 3 and 4, the following conclusions can be reached.

- The pro-HGA approach proposed in this paper shows to be better performance in terms of the BS than the GA, HGA1 and HGA2 approaches in Scales 2, 3 and 4. This means that the search schemes of GA and revised CS used in the pro-HGA approach is more efficient than those used in the others, though the former does not shows any merits in terms of the AT rather than the latter.
- When compared with LINGO as a benchmark, the pro-HGA shows slightly better performances, which indicates that the latter is more reliable in searching the optimal solution of eSC network than the former.
- In the comparison of search speed, the pro-HGA is about two times slower than those of the GA and HGA1. This stands for that the pro-HGA requires more computation times to find optimal solution than the others.

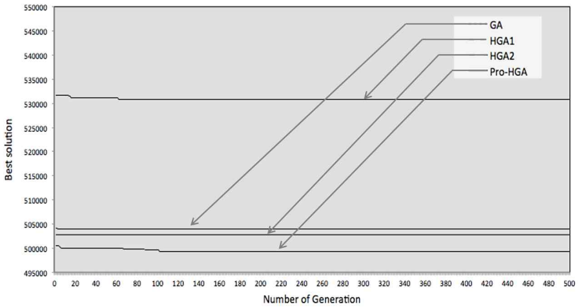

Fig. 3 Convergence Behaviors of Each Approaches in Scale 3

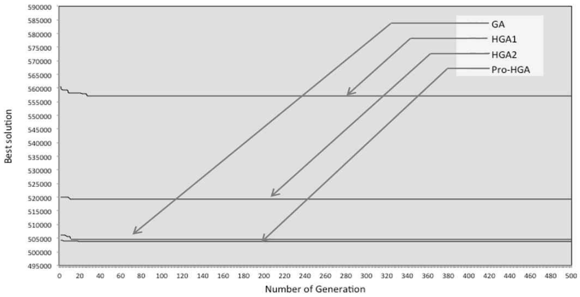

Fig. 4 Convergence Behaviors of Each Approaches in Scale 4

## 6. Conclusion

In this paper, we have designed and implemented an efficient supply chain network, called the eSC network. The proposed eSC network is consisted of suppliers, manufacturers, DCs, retailers and customers at each stage. A mathematical formulation has been suggested for representing the eSC network, and it has been implemented using the pro-HGA approach which combines GA with revised CS approaches.

In numerical experiments, four scales of the eSC network have been presented and they have been used for comparing the performances of the pro-HGA with those of the other competing approaches (GA, HGA1, HGA2 and LINGO) under various measures. Experimental results have shown that the pro-HGA approach outperforms the others.

The main objective of this paper is to consider $CO_2$ emission amount as a environmental factor and various transportation type as a economic factor in the proposed eSC network. For environmental factor, $CO_2$ emission amount when transporting materials and products between each stage and producing products in manufacturer has been considered. For economic factor, three types of transportation such as normal delivery, direct delivery and direct shipment have been taken into consideration. These considerations can reinforce the eSC network more efficiently and effectively. However, larger-scaled eSC networks should be considered and more various HGA approaches such as particle swam optimization (PSO), Tabu search, etc., will be considered for comparing the performance of the pro-HGA approach. This will be left to our future study.

## References

[1] Arampantzi, C. and Minis, I., “A New Model for Designing Sustainable Supply Chain Networks and Its Application to a Global Manufacturer,” Journal of Cleaner Production, Vol. 156, pp. 276-292, 2017.

[2] Chen, X., Chuluunsukh, A. and Yun, Y. S., “Design of Closed-Loop Supply Chain Model with Various Transportation Methods,” Proceedings of the Asia Pacific Industrial Engineering and Management Systems Conference (APIEMS2017), pp. 18-23, 2017.

[3] Chiang, W. Y. K., Chhajed, D. and Hess, J. D., “Direct Marketing, Indirect Profits: a Strategic Analysis of Dual-channel Supply Chain Design,” Management Science, Vol. 49, No. 1, pp. 1-20, 2003.

[4] Chuluunsukh, A, Chen, X. and Yun, Y. S., “Optimization of Integrated Supply Chain Network Problem using Hybrid Genetic Algorithm Approach,” International Journal of Engineering and Technology, Vol. 7, No 1.1, pp. 1-8, 2018.

[5] Hua, G., Wang, S. and Cheng, T. C. E., “Price and Lead Time Decisions in Dual-channel Supply Chains,” European Journal of Operational Research, Vol. 205, No. 1, pp. 113-126, 2010.

[6] Gen, M. and Cheng, R., “Genetic Algorithms and Engineering Optimization,” John-Wiley and Sons, New York, 2000.

[7] Kanagaraj, G., Ponnambalam, S. G. and Jawahar, N., “A Hybrid Cuckoo Search and Genetic Algorithm for Reliability-redundancy Allocation Problems,” Computers and Industrial Engineering, Vol. 66, No. 4, pp.1115-1125, 2013.

[8] Lingo, Lindo Systems (www.lindo.com), 2015.

[9] 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.

[10] Varsei, M. and Polyakovskiy, S., “Sustainable Supply Chain Network Design: A Case of the Wine Industry in Australia,” OMEGA, Vol. 66, pp. 236-247. 2017.

[11] Xinyu Li, Gao, L., “An Effective Hybrid Genetic Algorithm and Tabu Search for Flexible Job Shop Scheduling Problem,” International Journal of Production Economics, Vol. 174, pp. 93–110, 2016.

[12] 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.

[13] Yun, Y. S., Chuluunsukh, A. and Xing, C., “Hybrid Genetic Algorithm Approach using Closed-Loop Supply Chain Model,” Journal of the Korea Industrial Information Systems Research Vol. 21, No. 4, pp. 31-41, 2016.

[14] Yun, Y. S., Chuluunsukh, A. and Xing, C., “Adaptive Hybrid Genetic Algorithm Approach for Optimizing Closed-Loop Supply Chain Model,” Journal of the Korea Industrial Information Systems Research, Vol. 22, No. 2, pp. 79-90, 2017.

**윤 영 수** (Yun YoungSu)

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