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A modified genetic algorithm for maximizing handling reliability and recyclability of distribution centers

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ABSTRACT

Nowadays, many 3PL providers usually equip their distribution centers with different facilities, enabling them to be specialized in handling certain products types, and enhancing their ability of reuse and recycle the waste produced from packaging and repackaging. In practice, this problem type has been attracted much attention by researchers and environmental protectionisms. More importantly, because of the difference in product handling specialty, this induces different processing efficiency, handling reliability, and costs. In this connection, the objective of this paper is to propose a modified genetic algorithm to deal with the problem. The new chromosome encoding enhances the searching ability of the genetic algorithm in finding location, allocation, and routing solutions with high handling reliability and recycling ability for the distribution centers. To test the optimization reliability of the modified genetic algorithm, a number of numerical experiments have been carried out. The results demonstrated that the modified algorithm is able to obtain the Pareto solutions under multi-criterion decision making. Meanwhile, the handling reliability and recycling of the distributed centers are increased and the overall performance of the distribution network is improved.

1. Introduction

Distribution centers (DCs) in a third-party logistics (3PL) company have a role of temporary storing and distributing goods to customers. It is defined as a place similar to a transportation organizational centre, where goods from various origins are grouped or split, and is located at nodal point in the logistics system (Nam & Song, 2011). According to a survey conducted by Ansari and Modarress (2010), DC management is one of the most frequent services being used in 3PL, with close to 70% shippers subscribed to the service. Recent research related to DC management includes application of Radio Frequency Identification (RFID) in DC goods and process management (Bahr & Lim, 2010), rescheduling of goods arrivals at DC to off-peak hours (Verlinde et al., 2011), determination of optimal location, allocation and routing of supply chain network with mixed integer programming to minimize cost (Lee, Moon, & Park, 2010), selection of appropriate locations for DC with fuzzy set theory to solve distribution network design problem (Ustundag and Cevikcan, 2012), and network design of OEM manufacturing (Adrian, Chandra, & Christian, 2011) etc.

In logistics business, delivery performance is generally characterized into at least two factors – speed and reliability. Speed is defined as the responsiveness to perform an activity or to fulfill an order, while reliability is defined as the capability to fulfill the delivery as promised (Milgate, 2001). It is known that they are closely related to the cost factor and can be improved by establishing more facilities, and keeping more safety stock. Improvement of a particular factor may be based on the sacrificing the others (Cai, Liu, Xiao, & Liu, 2009). The tradeoff increases the complexity of distribution network consequently influencing the performance of the distribution network. In practical situations, there are many other factors have to be considered, such as economic delivery quantity and economic delivery cost, mode of transportation, delivery time, delivery time window, etc (Sana, 2011).

Warehousing services and DCs are essential elements in distribution network. Their efficiency and effectiveness is the key to the successes to the whole supply chain (Angerhofer & Angelides, 2006). In many practical situations, warehouses and DCs usually have different configurations, designing to service and handle different product types (Baker & Canessa, 2009). As a result, handling different products usually require different handling cost, handling lead time, and efficiency (Gaiardelli, Saccani, & Songini, 2007). In addition, the customer service level will also be different. Customer service level can be measured by customer response time, ability to respond to market changes, consistent order cycle time, accuracy

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of order fulfillment rate, short delivery time, flexibility in order quantity, flexibility in product specification, accuracy of information system, etc.

In fact, there are many factors should be considered in a production and distribution network (Ko, Ko, & Kim, 2006). Especially in recent years, environmental issue is one of the major concerns. More customers are expecting to reduce the environmental burden in their product. The image of "green" has already been another critical issue for many companies to be considered and treated as social responsibility and used as criteria in selecting suppliers (Stock, 1998; Rogers & Tibben-Lembke, 1999). The objective of this paper is to study the impact of these factors to the network and to propose an optimization methodology, which determines the flow and route of the product flowing in a distribution network based on the performance of the DCs, including cost, distance, handling reliability, and recycling ability. The paper will be divided into the following sections. Section 2 gives a literature review. Section 3 describes the problem background and explanation of problem formulation. Section 4 presents the proposed optimization methodology. Section 5 carries out some numerical examples and discusses the results obtained. Lastly, the paper will be concluded with a conclusion in Section 6.

2. Literature review

Because of green legislation, social responsibility, or corporate imaging, environmental concern has attracted much attention of many researchers and practitioners. The conflict between economic optimization and environmental protection has been widely discussed and studied in recent years. Petek and Glavic (1996) stated that there are three main requirements for sustainable development, which are resources conversation, environmental protection, and social economic development. Reverse logistics concept of a supply chain provides the best strategy to reduce and reutilize waste (Jahre, 1995; Beullens, 2004).

Indeed, encouraging the re-use of products and materials and waste reduction is one of most popular topics in environmental issues and concern in industrialized countries. Fleischmanna, Krikkea, Dekkerb, and Flapperc (2000) stated that efficiency implementation of required appropriate logistics structures for the arising products flow from users back to producers for such reverse logistics operations. They gave a detail review of the logistics network design for the product recovery in different industries, and defined a classification scheme for different types of recovery networks. Maximizing the ability to reuse and recycle and to retrieve back the used products through a reverse logistics network for reuse, remanufacture, recycle or disposal has also been adopted by various original equipment manufacturers (OEMs) (Mutha & Pokharel, 2009). They design the network points and assign capacities to OEMs depend on the volume of returned products and the demand for remanufactured products and the parts of used products.

Distribution network deals with the flow of products from different source points (suppliers) to different demand points (customers), through various DCs commonly known as DCs. These facilities may be located geographically differently connecting the suppliers and customers together. Many research studies indicated that a good network design can increase value added, reduce costs, and increase customer service level (Cheung, Leung, & Tam, 2005). However, in recent years, due to globalization the problem in distribution networks has become more complex than decades. Warehousing services becomes one of the most important parts, playing a vital role in the success or failure of business in modern supply chains today (Frazelle, 2002). Customers are expecting warehousing services can helping them to improve in various areas such as reducing order lead times, increasing fill rates, implementing reverse logistics, etc (Liu, Kumar, & Aalst, 2007).

In literatures regarding the optimization of production and distribution networks, both mathematical programming approach and heuristics approach have been proposed and adopted by many researchers. With a set of demands (known or estimated from historical data), the interrelationship, the demand allocation, inventory management, location of facilities, determination of transportation policy have been studied. Some adopted linear programming, mixed integer programming, fractional programming, and multi-objective linear fractional programming (Abdinnour-Helm, 1999; Chakraborty & Gupta, 2002; Marmol, Puerto, & Fernandez, 2002; Wilson, 1995).

Related to environmental problems, Patia, Vratb, and Kumarc (2008) proposed a mixed integer goal programming to assist the management of a paper recycling logistics system. They considered various factors including the reduction of reverse logistics cost, improving the product quality, and environmental benefits through increased wastepaper recovery to determine the facility location, route and flow of different varieties of recyclable wastepaper in India. Schultmann, Zumkeller, and Rentz (2006) proposed a linear programming and meta-heuristics methods to minimize the travel routes between dismantling centers and reprocessing facilities for a recycling network for the German automotive industry. Many other examples such as Carlson (1985) and Chang (1993) used weighted non-linear goal programming to determine the economic impacts of material recycling on energy recovery facilities. Perlack and Willis (1985) proposed an analysis of multi-objective decision making in waste disposal planning.

Mathematical programming approaches can obtain optimal solutions. However, the computational time is usually long and the model construction is complicated (Abdinnour-Helm, 1999). In addition, practical applications may involve nonlinear modeling, such as the delivery cost changes along with the delivery quantity/batch size. The modeling and computation becomes even more complex. Near-optimal solutions determined by heuristic approach (sometime optimal) are more preferable and acceptable because the computational time required is relatively less.

Among heuristics approaches in solving distribution network problems, Genetic algorithms (GAs) are widely adopted (Berry, Murtagh, McMahon, Sugden, & Welling, 1998). Abdinnour-Helm (1999) testified the reliability and robustness of GA by deploying five different distribution networks with the geographical layouts of Continental USA, Regional USA, Canada, and Western Europe. The optimization results obtained by GAs were compared with the one obtained by mixed integer programming for the objective of minimization of the overall transportation cost. The results proved that the technique of GA is reliable and robust. Vignaux and Michalewica (1991) adopted GAs to minimize the cost factor for a linear transportation problem. Abdinnour-Helm (1998, 1999) proposed a hybrid GA, which combined with Tabu search, to enhance the optimization results (Glover, 1986, 1989). Some researchers combined GAs with fuzzy to overcome uncertainties present in supply chain, such as demand fluctuation (Gonzalez & Fernandez, 2000; Miznuma & Watada, 1995).

3. Problem description and formulation

The following notations are used to describe the problem studied throughout the paper:

Data parameters:

t	Index for DC (1,...,T)
i	Index for DC $(0, \ldots, T) \in A$, set of DCs plus the initial source point
j	Index for DC $(1, \ldots, T+1) \in B$, set of DCs plus the final demand point
n	Index for product types, $n = 1,\ldots,N$
D	Set of demand points, representing the customers
S	Set of source points, representing the suppliers
c^H_{nt}	Handling cost of product type n required in the DC t
c^T_{nij}	Transportation cost required for product type n to move from point i to point j in the distribution network
p^H_{nt}	Handling processing time of product type n required in the DC t
p^T_{nij}	Transportation time required for product type n to move from point i to point j in the distribution network
h_{nt}	Handling reliability of product type n required in the DC t
r_{nt}	Recycling ability of product type n required in the DC t
ϕ_t	Physical capacity of DC t
C'	Optimal value of cost
P'	Optimal value of processing time
H'	Optimal value of handling reliability
R'	Optimal value of recycling ability
Decision Variable:	
μ_{nij}	=1, if the product type n is passing through from the DC i to DC j =0, otherwise

We studied a distribution network modeled from one of the largest 3PL service providers operating in Mainland China. The distribution network consists of a set of product types N in a set of demand points D passing through a set of transition points (DCs) T to a set of source points S, as shown in Fig. 1. Different product type ($n \in N$) passing through different DCs ($t \in T$) will induce different handling cost (c^H_{nt}), handling processing time (p^H_{nt}), handling reliability (h_{nt}), and recycling ability (r_{nt}). In addition, each DC will have its capacity limitation (ϕ_t). Between each point, there will be transportation cost (c^T_{nij}), and the travelling time (p^T_{nij}). In the model, product can pass through one or more DC, but the repackaging must be done in the last DC because that will be the temporary storage location.

3.1. Performance measurement considered

3.1.1. Handling cost (c^H_{nt})

Depending on the efficiency of the DCs, they may usually have different basic operating cost. In addition, some of them may be specialized in handling certain product types. Therefore, the handling cost, and the storage cost required for different product type will be different.

3.1.2. Handling processing time (p^H_{nt})

It refers to the handling time of releasing an order to DCs, the product move In and Out of the DC, and it will include the time required for the repackaging of the product if that is the last distribution center for a particular product.

3.1.3. Handling reliability (h_{nt})

Based on the knowledge and experience of the DCs in handling of the similar kind product type, the handling reliability can be different in respect to different product types, for example, product damage, on time delivery, order quantity accuracy, etc. This paper represents the handling reliability in the percentage of order fulfillment of the product type in the particular DC, which can be obtained by the historical data in practice.

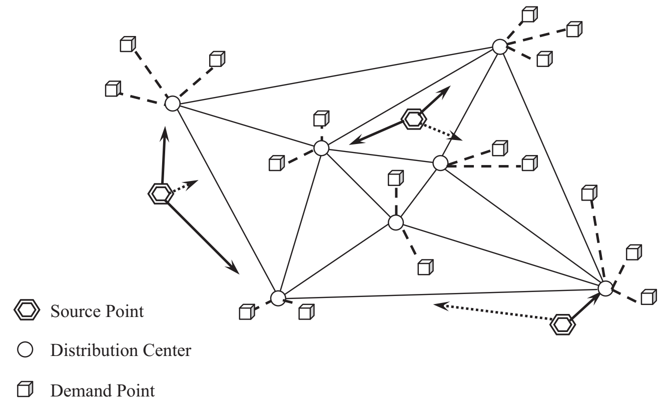

Fig. 1. Layout of the studied distribution network.

3.1.4. Recycling ability (r_{nt})

This refers to the environmental concern issues. It considers the plan or strategy that the DCs introduced and implemented to reuse, recycle, and reduce the waste during various operations in repackaging of the product, for examples, green procurement, reuse the package through reverse logistics, and/or minimization of the unnecessary packaging during shipment. Similar as the handling reliability, different DCs will have different recycling ability for different product types. The recycling ability will be represented in terms of percentage.

3.2. Objective function and constraints

The distribution network problem is (i) to determine how to transport the product from different source points to different demand points by passing through which DCs, and (ii) to determine the final DC for repackaging. The decision variables are μ_{nij}. The objective function is shown as in Eq. (1).

$$Objective\ Z : MIN[\alpha(C) + \beta(P) + \chi(1 - H) + \delta(1 - R)] \tag{1}$$

Eq. (1) aims to minimize the total cost of distribution network (C), total processing time (P), maximize the total handling reliability (H), and total recycling ability (R).

$$C = \left(\sum_{n \in N} \sum_{i \in A} \sum_{j \in B} \left(\mu_{ijn} c^H_{nt} \right) + \sum_{n \in N} \sum_{i \in A} \sum_{j \in B} \left(\mu_{ijn} c^T_{nij} \right) \right) \Big/ C' \tag{2}$$

Eq. (2) defines the total cost of the distribution network (C), which consists of the handling cost induced by the DCs, and the transportation cost induced by travelling between the DCs.

$$P = \left(\sum_{n \in N} \sum_{i \in A} \sum_{j \in B} (\mu_{nij} p^H_{nt}) + \sum_{n \in N} \sum_{i \in A} \sum_{j \in B} (\mu_{nij} p^T_{nij}) \right) \Big/ P' \tag{3}$$

Eq. (3) defines the total processing time (P) required by all the product in the distribution network, which consists of the handling time induced by the DCs for the product, and the travelling time consumed between the DCs.

$$H = \left(\sum_{n \in N} \sum_{i \in A} \sum_{j \in B} \mu^{TT}_{nij} h_{nt} \right) \Big/ H' \tag{4}$$

Eq. (4) defines the handling reliability (H) of the distribution network in handling all products, counting all the DCs involved for each product.

$$R = \sum_{n \in N} \sum_{i \in A} (\mu_{niT+1} r_{nt}) \Big/ R' \quad (5)$$

Eq. (5) defines the recycling ability (R) of the distribution network in recycling the packaging of all products. It is assumed that each product type will be repackaged at the last DC that it visited. r_{nt} demonstrates the ability that the DC can reduce and reuse the wasted package the product n. The ability will be defined into 0, 0.5, and 1, representing unable, partial, and fully capable.

3.2.1. Problem Constraints

The problem is subject to the following constraints:

Capacity constraints

$$\phi_t \geqslant \sum_{n \in N} \sum_{i \in A} \sum_{j \in B} \mu_{nij} d_n \quad \forall t \quad (6)$$

Constraints (6) ensure that the capacity of each DC will not be violated.

Transportation constraints

$$\sum_{n \in N} \sum_{j \in B} \mu_{n0j} = 1 \quad \forall n \quad (7)$$

$$\sum_{n \in N} \sum_{i \in A} \mu_{niT+1} = 1 \quad \forall n \quad (8)$$

$$\sum_{i \in A} \mu_{nij} \leqslant 1 \quad \forall j, n \quad (9)$$

$$\sum_{j \in B} \mu_{nij} \leqslant 1 \quad \forall i, n \quad (10)$$

$$\sum_{n \in N} \sum_{i \in A} \mu_{nij} - \sum_{n \in N} \sum_{k \in B} \mu_{njk} = 0 \quad \forall j, n \quad (11)$$

Constraints (7) and (8) ensure that each product type will start to pass through the DC and end once. Constraints (9) and (10) ensure each product will only passing in and out by one DC only. Constraints (11) ensure that the product type passing into the DC will pass out again.

4. Optimization methodology: a modified genetic algorithm (GA)

4.1. Encoding of chromosome

The encoding of chromosome consists of $|\boldsymbol{T}| * |\boldsymbol{N}|$ number of genes. Each gene is modeled by two parameters (TF). T represents the transition point (DC), while F represents whether the product type n will flow through the DC or not. F is modeled in binary value, with the value 1 representing that the product type n will pass through the DC t, otherwise 0, as shown in Fig. 2. The visiting sequence is from the left to the right.

In the example, there are five product types transporting to the demand points through the distribution network. A total of 3 DCs can be utilized. The product type 1 will pass through DCs 2, while product type 5 will pass through DCs 3 and then 1.

Encoding of Chromosome

1			2			3			4			5		
TF	TF	TF	TF	TF	TF	TF	TF	TF	TF	TF	TF	TF	TF	TF
3,0	2,1	1,0	2,0	1,1	3,0	1,1	2,1	3,0	2,1	1,1	3,0	3,1	1,1	2,0

Decoding of Chromosome

Product Type (n)	Distribution centers Sequence	
1	2	
2	1	
3	1	2
4	2	1
5	3	1

Fig. 2. Encoding and decoding of chromosome.

4.2. Formation of initial pool and mating pool

The chromosomes in the initial pool are randomly generated. The size of the mating pool is the same as the initial pool. The chromosomes are randomly selected by the roulette wheel selection approach. To prevent the loss of the best chromosome(s), the elitist strategy is applied. In the mating pool, the weakest chromosome, which means the one with the lowest fitness value, will be replaced by the stored best chromosome found during the evolution. To prevent the genetic search around a local optimal and the prematurity of the solution pool, 20% of chromosomes will be randomly regenerated.

4.3. Crossover operation

In each pair of chromosomes, a predefined number of genes will be randomly selected according to the crossover rate. For example, if the crossover point is the one as shown in Fig. 3, the gene (1,1) from Parent A will crossover with the gene (3,0) in Parent B. After crossover, the redundant DCs will be replaced by the missing one, which is originally in the parent.

4.4. Mutation operation

Two types of mutation will be applied. Mutation 1 aims to increase the diversity of the product type passing through the DCs. A predefined number of genes will be randomly selected and mutated in the value of F according to the mutation rate. As shown in an example in Fig. 4, the third gene (1,0) is randomly selected and mutated to (1,1).

Mutation 2 aims to swap the genes in the chromosome in order to increase the diversity of the visiting sequence. In such case, a pair of gene will be randomly selected and swapped as shown in Fig. 5. However, the pair of gene is constrained to be under the same product type n.

4.5. Fitness value

The fitness values of the GA are calculated by the following equations. Eqs. (10)–(refspseqn12), (11)–(13) are used when individually optimize the value of C', D', H', and R'. These values will be adopted in Eq. (14) for the optimization when considering multi-criterion decision making. The value of are α, β, χ, and δ the weightings for the criteria of total cost of the distribution network, total processing time, handling reliability, and recycling ability.

Total cost of distribution network

$$F_i^C = 1 - (c_i^H + c_i^T) \Big/ \left(\sum_i (c_i^H + c_i^T) \right) \quad (10)$$

Total processing time

$$F_i^P = 1 - (p_i^H + p_i^T) \Big/ \left(\sum_i (p_i^H + p_i^T) \right) \quad (11)$$

Total handling reliability

$$F_i^H = h_i \Big/ \left(\sum_i h_i \right) \quad (12)$$

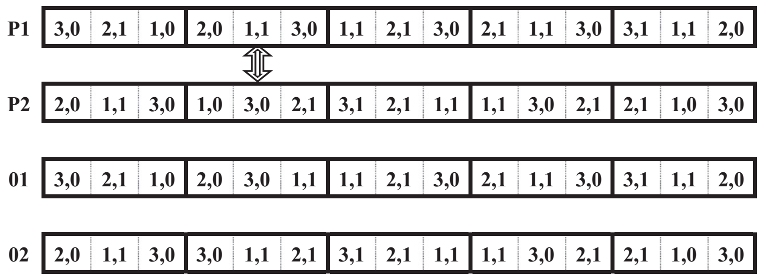

Fig. 3. Sample of crossover.

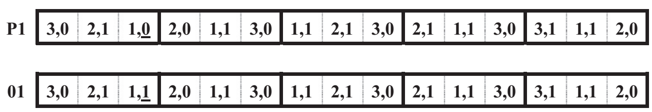

Fig. 4. Sample of Mutation 1.

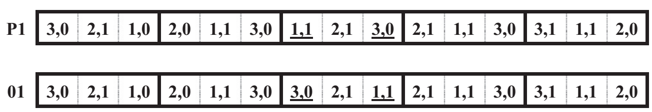

Fig. 5. Sample of Mutation 2.

Table 1
The problem parameters of situation A.

Product type	20
Distribution centers	3
	Range
Quantity (d)	1000–2000
Handling	0.7–1.0
Recycling	0||0.5||1
Travel distance	
Sources point to distribution centers	50–300
Between distribution centers	10–50
Distribution centers to demand points	50–300
Cost	
Sources point to distribution centers	2000–3000
Between distribution centers	500–1500
Distribution centers to demand points	2000–3000

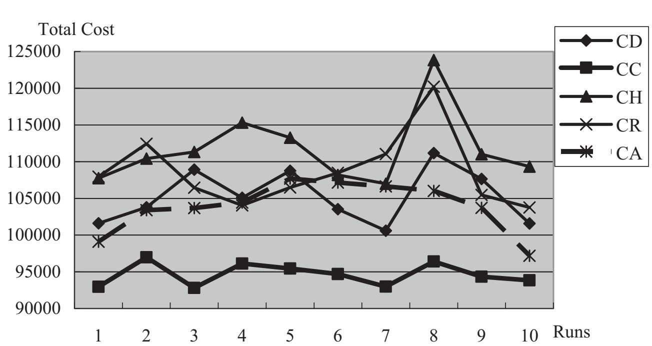

Fig. 6. Results of numerical example 1 for cost factor.

Total recycling ability

$$F_i^R = r_i \Big/ \left(\sum_i r_i \right) \tag{13}$$

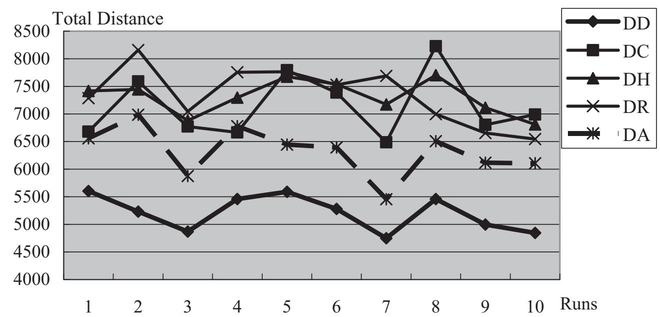

Fig. 7. Results of numerical example 1 for distance factor.

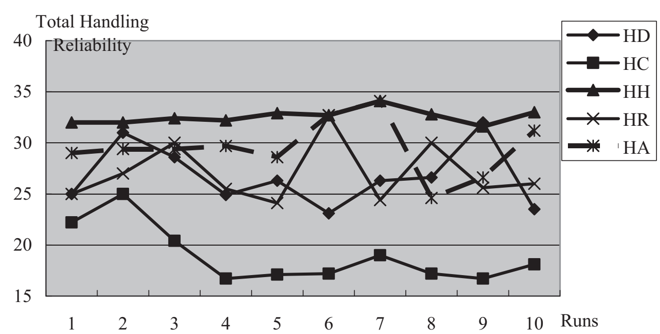

Fig. 8. Results of numerical example 1 for total handling reliability factor.

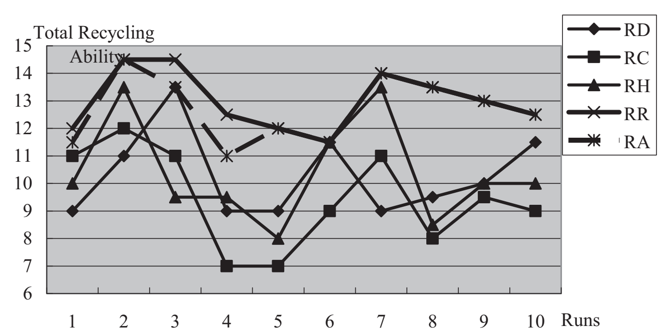

Fig. 9. Results of numerical example 1 for total recycling ability factor.

Overall

$$F_i^A = \frac{[\alpha(c_i/C') + \beta(p_i/P') + \chi(1 - h_i/H') + \delta(1 - r_i/R')]}{\left[\sum_i c_i/C' + p_i/P' + (1 - h_i/H') + (1 - r_i/R') \right]} \tag{14}$$

Table 2
Summary of the optimization results obtained for numerical example 1.

Runs	Optimal				Optimal				Optimal				Optimal				All			
	D^D	C^D	H^D	R^D	D^C	C^C	H^C	R^C	D^H	C^H	H^H	R^H	D^R	C^R	H^R	R^R	D^A	C^A	H^A	R^A
1	5605	10,1607	25	9	6681	92,956	22.2	11	7417	107,742	32	10	7287	107,948	25	12	6558	99,095	29	11.5
2	5230	103,771	31	11	7589	96,974	25	12	7445	110,406	32	13.5	8159	112,431	27	14.5	6986	103,406	29.4	14.5
3	4869	108,906	28.6	13.5	6774	92,798	20.4	11	6880	111,323	32.4	9.5	7046	106,462	30	14.5	5875	103,674	29.4	13.5
4	5457	105,088	24.9	9	6664	96,114	16.7	7	7295	115,316	32.2	9.5	7754	104,047	25.5	12.5	6781	104,419	29.7	11
5	5589	108,769	26.3	9	7793	95,439	17.1	7	7676	113,254	32.9	8	7765	106,471	24.1	12	6444	107,701	28.6	12
6	5281	103,515	23.1	11.5	7387	94,690	17.2	9	7540	108,178	32.7	11.5	7527	108,480	32.7	11.5	6394	107,142	32.7	11.5
7	4749	100,600	26.3	9	6487	92,971	19	11	7172	106,991	34.1	13.5	7688	111,039	24.4	14	5455	106,643	34.1	14
8	5457	111,174	26.6	9.5	8227	96,394	17.2	8	7703	123,845	32.8	8.5	6997	120,200	30	13.5	6508	106,009	24.6	13.5
9	4998	107,651	31.7	10	6802	94,320	16.7	9.5	7115	111,002	31.6	10	6656	105,458	25.6	13	6118	103,712	26.6	13
10	4844	101,584	23.5	11.5	6989	93,835	18.1	9	6811	109,315	33	10	6546	103,758	26	12.5	6107	97,181	31.2	12.5

Table 3
The problem parameters of situation B.

	Range
Travel distance	
Sources point to distribution centers	50–300
Between distribution centers	50–300
Distribution centers to demand points	50–300
Cost	
Sources point to distribution centers	2000–3000
Between distribution centers	2000–3000
Distribution centers to demand points	2000–3000

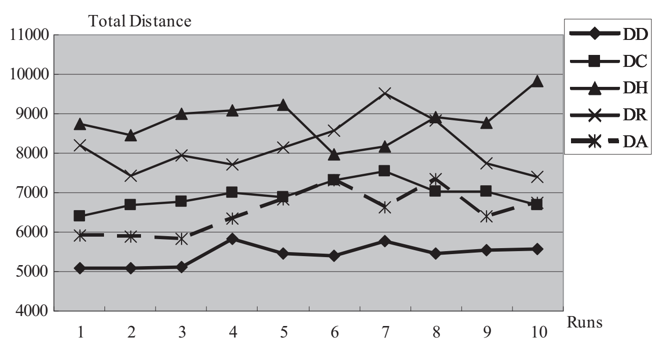

Fig. 10. Results of numerical example 2 for total distance factor.

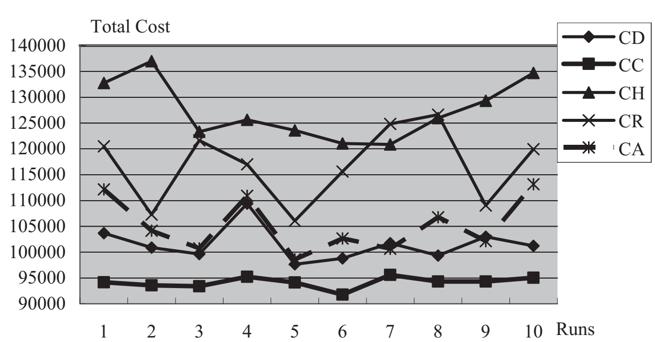

Fig. 11. Results of numerical example 2 for total cost factor.

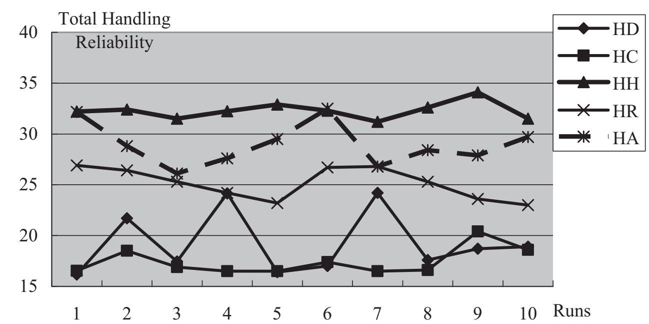

Fig. 12. Results of numerical example 2 for total handling reliability factor.

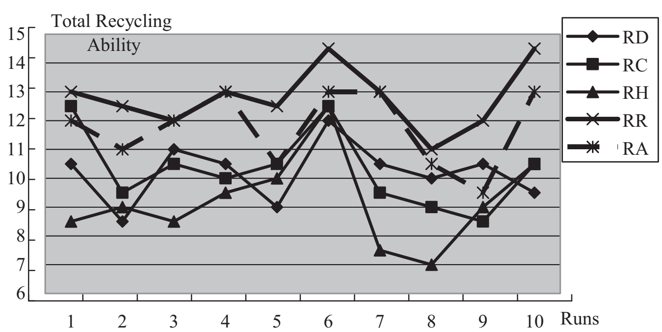

Fig. 13. Results of numerical example 2 for total recycling ability factor.

5. Numerical examples

The objective of these numerical examples is to serve two purposes, (i) to demonstrate the performance of the proposed algorithm in handling multi-criterion decision making, and (ii) to demonstrate the tradeoff of the factors in the distribution networks.

5.1. Situation A

In this situation, we simulate a distribution network that with the DCs are located close together, while the distance between the both the source points and the demand points and the DCs are relatively longer. The problem parameters are shown as in Table 1. The distribution network consists of 3 DCs with 20 sources points supplying product to 20 demand points. A total of 10 different sets of data are randomly generated according to the parameter ranges. The quantity is in the range of 1000–2000 units. The handling reliability of each product type in each DC is in the range of 0.7–1.0, meaning 70–100% accuracy. The recycling ability in each DC for different product type is classified into 0, 0.5, and 1, meaning unable, partial, and fully capable. In the Travel Distance table, the first row represents the distance randomly generated in the range between the source point to the DCs, the second row represents the distance between the DCs, while the last row represents the distance between the DCs to each demand point (Same as in the Cost table).

Table 4
Summary of the optimization results obtained for numerical example 2.

Runs	Optimal				Optimal				Optimal				Optimal				All			
	D^D	C^D	H^D	R^D	D^C	C^C	H^C	R^C	D^H	C^H	H^H	R^H	D^R	C^R	H^R	R^R	D^A	C^A	H^A	R^A
1	5075	103,682	16.16	10.5	6410	94,134	16.53	12.5	8741	132,767	32.2	8.5	8186	120,479	26.9	13	5905	112,152	32.16	12
2	5099	100,872	21.7	8.5	6674	93,580	18.51	9.5	8448	136,990	32.4	9	7418	107,271	26.42	12.5	5897	104,129	28.8	11
3	5121	99,627	17.45	11	6780	93,381	16.9	10.5	8986	123,309	31.5	8.5	7934	121,630	25.3	12	5827	100,713	26.1	12
4	5824	109,381	24.15	10.5	6994	95,215	16.5	10	9084	125,650	32.23	9.5	7716	116,998	24.2	13	6353	110,907	27.6	13
5	5454	97,626	16.4	9	6887	94,115	16.5	10.5	9237	123,564	32.9	10	8134	106,059	23.2	12.5	6827	98,603	29.5	10.5
6	5387	98,794	17	12	7303	91,763	17.4	12.5	7985	121,036	32.3	12.5	8565	115,620	26.7	14.5	7320	102,653	32.5	13
7	5783	101,714	24.2	10.5	7547	95,577	16.5	9.5	8162	120,856	31.2	7.5	9507	124,831	26.8	13	6642	100,669	26.8	13
8	5452	99,319	17.6	10	7023	94,294	16.6	9	8916	25,980	32.6	7	8824	126,627	25.3	11	7340	106,760	28.4	10.5
9	5538	102,977	18.7	10.5	7020	94,282	20.4	8.5	8778	129,325	34.1	9	7735	109,041	23.6	12	6401	102,141	27.9	9.5
10	5580	101,187	18.9	9.5	6681	95,031	18.6	10.5	9817	134,715	31.5	10.5	7413	119,944	23	14.5	6741	113,133	29.7	13

Each of the set will be individually solved by the proposed genetic algorithm to individually determine the optimal value of cost (C'), distance (D'), handling reliability (H'), and recycling ability (R') without the consideration of the other factors. Lastly, each set will be simultaneously considering all the 4 factors by using the weighting of $\alpha = 0.25, \beta = 0.25, \chi = 0.25,$ and $\delta = 0.25$. For the optimization, each individual set for each factor will be run by the proposed genetic algorithm for 10 runs, with the genetic parameter: Pool Size 20, Evolution 1000, Crossover Rate 0.1, and Mutation Rate 0.1. The best result among each 10 runs is recorded and plotted as in Figs. 6–9, and summarized in Table 2.

In Figs. 6 and 7, the bottom line shows the optimal values obtained for (C') and (D') by the proposed algorithm, while the top line in Figs. 8 and 9 shows the ones obtained for (H') and (R'). As expectation, the results demonstrate that optimizing in one factor will sacrifice the others. For example, minimizing only the total cost factor may induce low handling reliability and recycling ability in some runs. However, with the weighting taken equally importance for all the factors, the results indicated that the performance for each factor getting closer to the optimal values as shown in Figs. 6–9 as plotted in the dotted lines, and in some runs they can be the same as the optimal obtained. This demonstrates the optimization reliability of the proposed genetic algorithm in dealing with multi-criterion decision making.

5.2. Situation B

We further studying whether the geographical distribution of the DCs in the distribution network will have influence to the result or not. Accordingly, in this situation, we simulate a distribution network that the distance between the source points, the demand points, and the DCs are equally separated. The problem parameters are similar to the previous example with the only difference in the distance and the cost parameters as shown in Table 3. A total of 10 different sets of data are randomly generated, and solved independently for the (C'), (D'), (H'), and (R'). Similarly, the weighting of $\alpha = 0.25, \beta = 0.25, \chi = 0.25,$ and $\delta = 0.25$ will be used again. The number of runs and the genetic parameters adopted are the same. The results are shown as in Figs. 10–13, and summarized in Table 4. Similar results are found as in Situation A.

As expectation, the results demonstrated that optimizing only a single factor may have poor performance on the other factors. The geographical distribution of the DCs has no effect in these sets. Taking in the considerations of different factors can still lead to a better tradeoff between them.

6. Conclusions

Environmental concern is one of the hottest topics and abiding challenges to many researchers and practitioners. The conflict between economic optimization, such as minimizing cost, and environmental protection, such as recycling, exist. The problem of determining the product flow and route among a distribution network has to simultaneously consider many factors. This paper proposed a genetic algorithm to simultaneously consider the total cost, total distance, total handling reliability and the total recycling ability of different DCs to deal with the problem. The numerical examples demonstrate that optimizing one single factor will sacrifice the others. However, by considering all the factors simultaneously, the overall performance of the distribution network in all the aspect is being controlled getting closer to the optimal one, such as the system reliability and the recycling ability of the network are increased with slightly increment in the total cost and distance.

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