Applying Harmony Search to the Bulky Waste Recycling Network Design Problem

Mei-Shiang Chang, and Wei-Chih Yang

Abstract—**Bulky waste includes disused furniture, old bicycles, lopping, and waste upholstery etc. Disintegrating, crumbling and repairing are the main disposition of bulky waste. It depends on the kinds of bulky waste to dispose them. This study extends the research about the stochastic network design of bulky waste recovery by [1]. Because this problem is NP-hard, this study develops a meta-heuristic algorithm based on harmony search to solve it. Several numerical examples are utilized to demonstrate the validness of the developed algorithm. The parameter analysis of this harmony search-based algorithm is done to increase the quality and the speed of searching processes. Furthermore, sensitivity analysis is performed to understand the influence of different parameters on the stochastic network design problem.**

Index Terms—**Bulky waste recovery, harmony search, stochastic network design problem.**

I. Introduction

Recovery of used products is receiving much attention recently due to growing environmental concern. In the past, because of a lack of proper recycling and reuse system of bulky wastes, and bulky wastes were often disposed of by incineration or landfill. Such disposal would increase environmental burdens. In fact, some bulk wastes may still be reused after minor repairs. Even if they are beyond repairs, useful resources such as plastics, metals or wood may still be recovered after they are broken up for recycling.

Bulky waste includes disused furniture, bicycles, mattresses, household electric appliances, waste upholstery, and lopping etc. Of the bulk waste collected, the majority is waste furniture and garden trimming, and the rest contains some useable plastics and metals. Repair, breakup and disassembly are the main disposition of bulky waste. Disused furniture, abandoned bicycles, disused household electric appliances, and antiquated mattresses need exclusive disposition procedures. Waste upholstery, garden trimming, and furniture beyond repairs share partial disposition procedures. Disposition procedures for different kinds of bulky wastes are shown in Fig. 1. The recovery productions of bulky wastes are various, including reused products, reused parts, recycled materials, and valueless materials. In general, reused products have higher market value than others.

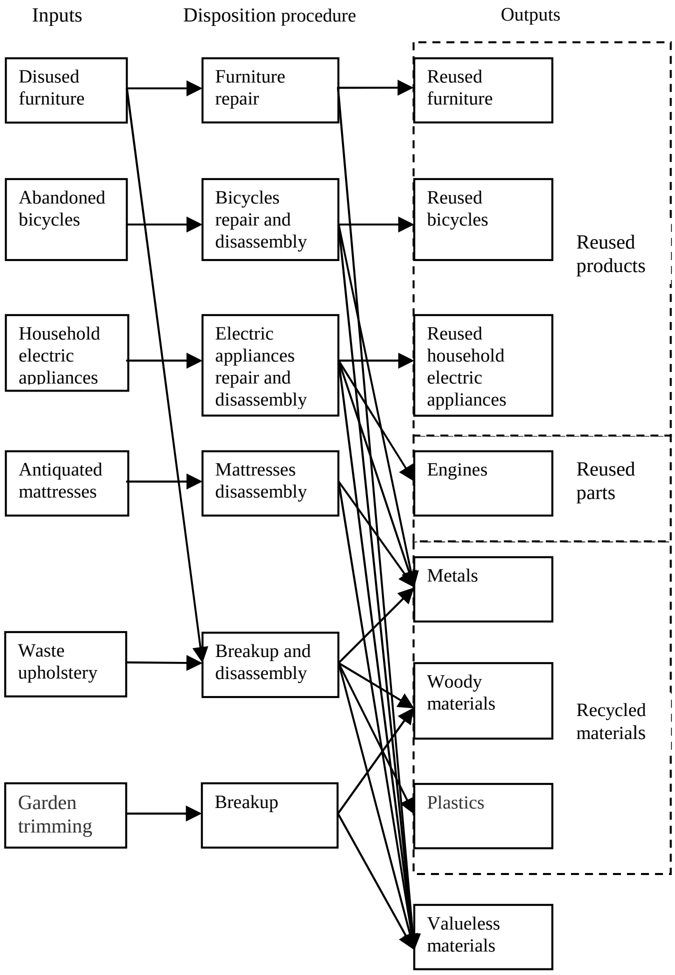

Fig. 1 Disposition Procedures for Bulky Wastes Recovery

A bulky waste recovery network is composed of three subprocedures, as shown in Fig. 2. At first, the bulky waste is delivered from a waste source to a resource recovery center. Through waste disposition, refurbished product, parts, or reusable materials are valuable outputs to a resource recovery center. They are delivered to the corresponding reuse or refurbishment market to earn revenue. Valueless final wastes are delivered to a final disposal site. Thus, the decisions implied in recovery network design of bulky wastes are:

1) To determine the number of repair, breakup, and disassembly centers,
2) To determine the location of repair, breakup, and disassembly centers,
3) To determine the disposition capacities of repair,

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breakup, and disassembly centers,

4) To allocate bulky wastes to repair, breakup, and disassembly centers, and
5) To determine the flow of bulky wastes between all facilities.

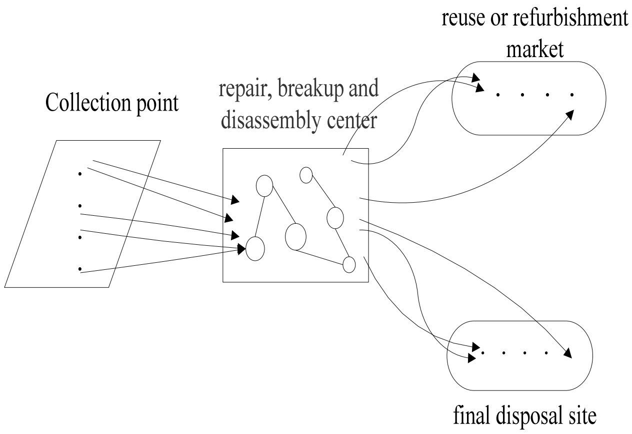

Fig. 2 Bulky Waste Recovery Network

II. LITERATURE REVIEW

The application of stochastic programming to network design problems is however a challenging research subject. Research addressing comprehensive design of forward supply chain networks under uncertainty is significantly smaller in number. We refer the interested reader to the surveys in [2]. To our knowledge, applying stochastic programming theory, related research about bulky wastes recovery is rare. Reference [3], [4] extend the research of [5] and apply the robust programming approach to recovery network design problem of carpet recycling. Reference [6] present a stochastic programming based approach to explore the network design problem of sand recycling which is proposed by [7]. By means of real case study in Netherlands, considering uncertain factors is helpful to designing a better product recovery network.

Stochastic integer models are well-known for their computational intractability. Without any doubts, the network design problem of bulky wastes recovery discussed in this paper is NP-hard since the stochastic facility location problem is NP-hard. In this study, a metaheuristic algorithm integrating harmony search (HS) with scenario generation method is developed. The HS algorithm proposed by [8] is a metaheuristic optimization algorithm and is based on the musical process of searching for a perfect state of harmony, such as jazz improvisations.

The HS algorithm is a recently developed meta-heuristic algorithm, and has been very successful in a wide variety of discrete optimization problems, including the traveling salesperson problem [8], tour routing [9], Sudoku puzzle solving [10], water network design [11], [12], dam operation [13], vehicle routing [14], structural design [15], [16], Ecological conservation [17], and power economic dispatch [18]. Furthermore, the HS algorithm is simple in concept, few in parameters, easy in implementation, imposes fewer mathematical requirements, and does not require initial value settings of the decision variables.

III. A MATHEMATICAL MODEL

A. Notations

The meanings of parameters in this model are given as follows:

c_{is}^{1} : unit transportation cost between occurrence point i and candidate site s of repair, breakup and disassembly centers

c_{sgm}^{2} : unit transportation cost of reused commodity g between candidate site s of repair, breakup and disassembly centers and the market m for reused commodity g

c_{sr}^{3} : unit transportation cost between candidate site s of repair, breakup and disassembly centers and the final disposal site r

c_{sn} : unit operation cost of bulky waste treated by disposition procedure n at candidate site s of repair, breakup and disassembly centers

$d_{is}^{1}(k)$: under generation scenario k of bulky wastes, the transportation distance between occurrence point i and candidate site s of repair, breakup and disassembly centers

d_{sgm}^{2} : transportation distance of reused commodity g between candidate site s of repair, breakup and disassembly centers and market m for reused commodity g

d_{sr}^{3} : transportation distance between candidate site s of repair, breakup and disassembly centers and final disposal site r

f_{sn}^{1} : land cost of setting up disposition procedure n at the candidate site s of repair, breakup and disassembly centers

f_{sn}^{2} : facility and equipment costs of setting up disposition procedure n at the candidate site s of repair, breakup and disassembly centers

$P_{in}(k)$: under generation scenario k of bulky wastes, the quantity of bulky waste generated at occurrence point i and needed the treatment of disposition procedure n

U_{sn} : maximal treatment capacity of disposition procedure n of the candidate site s of repair, breakup and disassembly centers

L_{sn} : minimal treatment capacity of disposition procedure n of the candidate site s of repair, breakup and disassembly centers

V : load capacity of a collection truck

δ_{ng} : a transformation rate which is the ratio of the weight of bulky waste to the weight of reused commodity g through the disposition procedure n; $0 \le \delta_{ng} \le 1$

δ'_{n} : a transformation rate which is the ratio of the weight of bulky waste to the weight of final waste through the disposition procedure n; $0 \le \delta'_{n} \le 1$

B: a big number

The meanings of decision variables in this model are defined as follows:

$X_{isn}(k)$: under generation scenario k of bulky wastes, the quantity of bulky waste which is generated at occurrence point i is treated by the disposition procedure n at the candidate site s of repair, breakup and disassembly centers

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$X_{sgm}(k)$: under generation scenario k of bulky wastes, the quantity of reused commodity g which is treated at the candidate site s of repair, breakup and disassembly centers is sent to the market m of reused commodity g

$X'_{sr}(k)$: under generation scenario k of bulky wastes, the quantity of final wastes which is treated at the candidate site s of repair, breakup and disassembly centers is sent to the final disposal site r

$Y_{isn}(k)$: 0-1 integer variable, its value is 1 if the bulky waste generated at occurrence point i is treated by disposition procedure n which is set up at the candidate site s of repair, breakup and disassembly centers under generation scenario k of bulky wastes; otherwise, its value is 0.

Z_{sn} : 0-1 integer variable, its value is 1 if the disposition procedure n is set up at the resource recovery center s; otherwise, its value is 0.

B. Model Formulation

Except that demand constraints are eliminated, a two-stage stochastic network design model for bulky waste recovery proposed by [1] is introduced.

$$\min \quad OBJ = \sum_{s\in S}\sum_{n\in N_s}\left(f_{sn}^1 \times Z_{sn}\right) + \sum_{s\in S}\sum_{n\in N_s}\left(f_{sn}^2 \times Z_{sn}\right) +$$
$$\frac{1}{|K|}\left\{\sum_{k\in K}\sum_{s\in S}\sum_{n\in N_s} c_{sn}\sum_{i\in I(k)} X_{isn}(k)\right\} +$$
$$\frac{1}{|K|}\left\{\sum_{k\in K}\sum_{i\in I(k)}\sum_{s\in S} c_{is}^1 d_{is}^1(k)\left\lceil \sum_{n\in N_s} X_{isn}(k)/V\right\rceil\right\} +$$
$$\frac{1}{|K|}\left\{\sum_{k\in K}\sum_{s\in S}\sum_{g\in G}\sum_{m\in M_g} c_{sgm}^2 d_{sgm}^2 \left\lceil X_{sgm}(k)/V\right\rceil\right\} +$$
$$\frac{1}{|K|}\left\{\sum_{k\in K}\sum_{s\in S}\sum_{r\in R} c_{sr}^3 d_{sr}^3 \left\lceil X'_{sr}(k)/V\right\rceil\right\} \quad (1)$$

Subject to:

Flow conservation constraints

$$\sum_{n\in N}\delta_{ng}\sum_{i\in I(k)} X_{isn}(k) = \sum_{m\in M_g} X_{sgm}(k),\ \forall s\in S,\ g\in G, k\in K \quad (2)$$

$$\sum_{n\in N}\delta'_{n}\sum_{i\in I(k)} X_{isn}(k) = \sum_{r\in R} X'_{sr}(k),\ \forall s\in S, k\in K \quad (3)$$

$$\sum_{s\in S} X_{isn}(k) = P_{in}(k), \forall i\in I(k), n\in N, \forall k\in K \quad (4)$$

Facility capacity constraints

$$\sum_{i\in I(k)} X_{isn}(k) \le U_{sn}\cdot Z_{sn}, \forall\, s\in S, n\in N_s, k\in K \quad (5)$$

$$\sum_{i\in I(k)} X_{isn}(k) \ge L_{sn}\cdot Z_{sn}, \forall\, s\in S, n\in N_s, k\in K \quad (6)$$

Logicality constraints

$$\sum_{i\in I(k)} Y_{isn}(k) \le \mathrm{B}\cdot Z_{sn},\ \forall s\in S,\ n\in N_s, k\in K \quad (7)$$

$$Z_{sn} \le \sum_{i\in I(k)} Y_{isn}(k),\ \forall s\in S,\ n\in N_s, k\in K \quad (8)$$

$$X_{isn}(k) - B\left[Y_{isn}(k)-1\right] \ge P_{in}(k),\ \forall i\in I(k), s\in S, n\in N, k\in K \quad (9)$$

$$X_{isn}(k) + B\left[Y_{isn}(k)-1\right] \le P_{in}(k),$$
$$\forall i\in I(k), s\in S, n\in N, k\in K \quad (10)$$

$$\sum_{s\in S} Y_{isn}(k) \le P_{in}(k), \forall i\in I(k), n\in N, k\in K \quad (11)$$

$$B\sum_{s\in S} Y_{isn}(k) \ge P_{in}(k), \forall i\in I(k), n\in N, k\in K \quad (12)$$

Domain constraints

$$Y_{isn}(k)\in\{0,1\},\ \forall i\in I(k), s\in S, n\in N, k\in K \quad (13)$$

$$Z_{sn}\in\{0,1\},\ \forall s\in S, n\in N \quad (14)$$

$$X_{isn}(k)\ge 0,\ \forall i\in I(k), s\in S, n\in N, k\in K \quad (15)$$

$$X_{sgm}(k)\ge 0,\ \forall s\in S, g\in G, m\in M, k\in K \quad (16)$$

$$X'_{sr}(k)\ge 0,\ \forall s\in S, r\in R, k\in K \quad (17)$$

The objective of this model is to minimize the first-stage total fixed costs and the expected value of the second-stage variable costs. In other words, the possibility of operation costs and transportation costs for bulky waste recovery is considered while making the first-stage decisions about the network configuration. Detailed explanation for this model is omitted.

IV. Solution Algorithm

For being applied to the stochastic network design problem of bulky wastes recovery, the structure of the original HS algorithm is modified. First, because the decision variable Z_{sn} has only two candidate values $\{0,1\}$, pitch adjustment operation is omitted [17]. Second, because of the high uncertainty in generation of bulky wastes, a large sampling size is helpful to achieve a good approximation but harmful to computation speed.

A. Step-by-step Procedures

The detailed solving procedures are as follows.

Step 1: Parameter Setting

Step 1.1: Specify the parameters of sampling-based approximation algorithm: the number of generation scenario of bulky wastes.

The coordinates $\{n_i^x(k), n_i^y(k)\}$ and the quantity of bulky waste $\{P_{in}(k)\}$ generated at occurrence point i and needed the treatment of disposition procedure n under the distribution scenario k are simulated.

Step 1.2: Specify the HS algorithm parameters: harmony memory size (HMS), harmony memory considering rate (HMCR), the number of improvisations (NI), and generation gaps rate (GGR).

Step 2. Initialize the harmony memory

Step 2.1: Randomly generate solution vectors about recovery network configuration $\{Z_{sn}\}$ and calculate the total fixed costs for building this recovery network.

Step 2.2: Evaluate the second-stage total expected costs by utilizing the proposed sampling-based approximation algorithm in the next section.

Step 2.3: Calculate the objective function values.

Step 2.4: Repeat Steps 2.1 to 2.3 *HMS* times.

Step 2.5: Store the *HMS* sets of decision variables and corresponding objective function values in the harmony memory (HM).

Step 3. Selection

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Select $(1-GGR)\times HMS$ harmony vectors with least objective function values as elitists and let them go to the next generation directly. The rest harmony vectors are put into the HM range and considered improvisation material of the next operation.

Step 4. Improvise a new harmony

Based on two rules: (1) memory consideration, and (2) random selection, each decision variable of a new harmony vector Z'_{sn} is generated in turn till a new harmony vector is formed.

Step 4.1: Randomly generate a number r_1, where $0 \le r_1 \le 1$.

Step 4.2: Memory consideration

If $r_1 \le HMCR$, the value of the decision variable Z'_{sn} is chosen from any value in the HM range.

$$Z'_{sn} \leftarrow Z'_{sn} \in \left\{Z'^{1}_{sn}, Z'^{2}_{sn}, ..., Z'^{GGR\times HMS}_{sn}\right\} \quad \text{if } r_1 \le HMCR$$

Step 4.3: Random selection

Randomly assign the value of 0 or 1 to the decision variable Z'_{sn}.

$$Z'_{sn} \leftarrow Z'_{sn} \in \{0,1\} \quad \text{if } r_1 > HMCR$$

Step 4.4: evaluate the total fixed costs for this new recovery network configuration $\{Z'_{sn}\}$ and the second-stage expected total costs by utilizing the proposed sampling-based approximation algorithm in the next section.

Step 5. Update the harmony memory

The new harmony vector $\{Z'_{sn}\}$ replaces the worst harmony vector in the HM, only if its objective function value is better than that of the worst harmony vector.

Step 6. Check the stopping criterion.

Step 3 to Step 5 are repeated until the termination criterion (NI) is satisfied.

B. *Sampling-based Approximation Algorithm*

The detailed procedures are as follows.

Step 2.2.1: Randomly simulate one generation scenario of bulky wastes $\left\{n_i^x(k), n_i^y(k), P_{in}(k)\right\}$.

The quantities of bulky wastes that needed the treatment of disposition procedure *n* follow given probability distributions. Occurrence points of bulky waste lie randomly within an X-Y coordinate plane. The coordinates $\left\{n_i^x(k), n_i^y(k)\right\}$ and the quantity of bulky waste $\{P_{in}(k)\}$ generated at occurrence point *i* and needed the treatment of disposition procedure *n* under the distribution scenario *k* are simulated.

Step 2.2.2: Calculate the distance costs $\left\{c^2_{sgm} d^2_{sgm}\right\}$ between all candidate sites of repair, breakup, and disassembly centers and markets for reused commodities.

Step 2.2.3: Calculate the distance costs $\left\{c^3_{sr} d^3_{sr}\right\}$ between all candidate sites of repair, breakup, and disassembly centers and final disposal sites.

Step 2.2.4: Flow assignment

According to minimum cost flow assignment rule, assign the bulky wastes of generation scenario *k* to this recovery network. The flow solutions $\{X_{isn}(k)\}$, $\{X_{sgm}(k)\}$ and, $\{X'_{sr}(k)\}$ can be determined.

Step 2.2.5: Verify that flow solutions satisfy the minimum or maximum requirements, that is, Equations (5) to (7). If these flow solutions are infeasible, penalty cost is added to the objective function values.

Step 2.2.6: Calculate the second-stage total cost for treating these bulky wastes, including any penalty cost.

Step 2.2.7: repeat Steps 2.2.1 to 2.2.6 *K* times.

V. Numerical Experiment

A. *Data and Implementation*

We adopt the numerical example of stochastic network design of bulky waste recovery which is addressed by [1]. There are 50 potential occurrence points of bulky waste lie within an X-Y coordinate plane. Their coordinates are generated randomly within [0,100]×[0,100]. The quantity of various kind of bulky waste at each occurrence point is a discrete random variable. There are three generation scenarios, "no occurrence", "low occurrence", and "high occurrence", at each potential occurrence point of bulky waste. The corresponding probabilities are 0.5, 0.25, and 0.25. The detailed data are given in Table 1.

Table 1 Generation Scenarios of Bulky Wastes

amount of bulky waste (tons)	scenarios			expected value
	no occurrence	low occurrence	high occurrence	
disposition procedure 1	0	700	1400	525
disposition procedure 2	0	40	80	30
disposition procedure 3	0	160	320	120
disposition procedure 4	0	200	400	150
disposition procedure 5	0	900	1800	675

Five disposition procedures of bulky wastes are set up. The recovery products of various disposition procedures and the transformation rates are shown in Table 2.

Table 2 Recovery Products of Different Disposition Procedures

disposition procedure	recovery product	transformation rate (%)
disposition procedure 1: to repair disused furniture (70% of the total disused furniture)	reused furniture	90
	valueless materials	10
disposition procedure 2: to repair or disintegrate abandoned bicycles	reused bikes	72
	metals	18
	valueless materials	10
disposition procedure 3: to disintegrate antiquated mattress	metals	75
	valueless materials	25
disposition procedure 4: to repair or disintegrate electric appliances	reused household electric appliances	45
	engines	27
	metals	18
	valueless materials	10
disposition procedure 5: to breakup disused furniture	metals	9
	reused wooden	27

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(30% of the total disused furniture), waste upholstery and garden trimming	parts	
	woody materials	54
	valueless materials	10

Four candidate sites of repair, breakup and disassembly centers are considered. The coordinates and land costs of four candidate locations are listed in Table 3 and Table 4 respectively. The installation costs and capacities of various disposition procedures are listed in Table 5. The variational costs of different disposition procedures are given in Table 6.

Table 3 Coordinates of Four Candidate Sites

coordinates	candidate site			
	1	2	3	4
(X, Y)	(41,42)	(28,25)	(49,90)	(81,23)

unit: km

Table 4 Land Costs of Four Candidate Locations

no. of procedures	1	2	3	4	5
land cost	3000	4000	5000	6000	7000

unit: 10^3 NT dollars

Table 5 Installation Costs and Capacities of Different Disposition Procedures

disposition procedure	installation cost (10^3)	minimal treatment capacity (tons)	maximal treatment capacity (tons)
1	1000	2000	20000
2	500	200	2000
3	1000	1000	10000
4	1000	1600	10000
5	20000	4000	80000

Table 6 Variational Costs of Bulky Waste Disposition

disposition procedure	candidate of resource recovery center			
	1	2	3	4
1	565	552	565	558
2	323	354	360	345
3	139	123	133	104
4	300	303	307	318
5	130	145	126	169

unit: NT dollars/ton

In addition, there are five types of reuse or refurbishment markets. The markets for reused products are assumed at repair, breakup and disassembly centers. The coordinates of other reuse or refurbishment markets and three final disposal sites are listed in Table 7.

Table 7 Coordinates of Reuse or Refurbishment Markets and Final Disposal Sites

facility	(X, Y)		
markets of reused engines	(30,40)	(30,20)	(50,80)
markets of recycled metal materials	(30,41)	(80,80)	(95,60)
markets of reused wooden parts	(42,73)	(60,60)	(67,80)
markets of recycled wooden materials	(43,43)	(48,20)	(98,96)
final disposal sites	(43,43)	(30,46)	(57,80)

unit: km

The load capacity of a truck is one ton. The unit transportation cost is 15 dollars/ton/km. The penalty for breaking the constraints of the maximal or minimal treatment capacity is 1000,000 NT dollars.

B. Solution Parameters

In order to apply the HS algorithm to the stochastic network design problem, algorithm parameters are specified: HMCR = 0.3, 0.6, 0.9; HMS = 25, 50, 100, 150, 200, 300; and stopping criterion NI = 100, 1000.

First, we set HMS, and NI equal to 50 and 100, and the number of generation scenarios of bulky wastes $|K|$ equal to 10. The same testing example is solved for five times. Only when HMCR equals to 0.9, the same network configuration solution can be obtained by the five tries. The convergence processes are shown in Fig. 3.

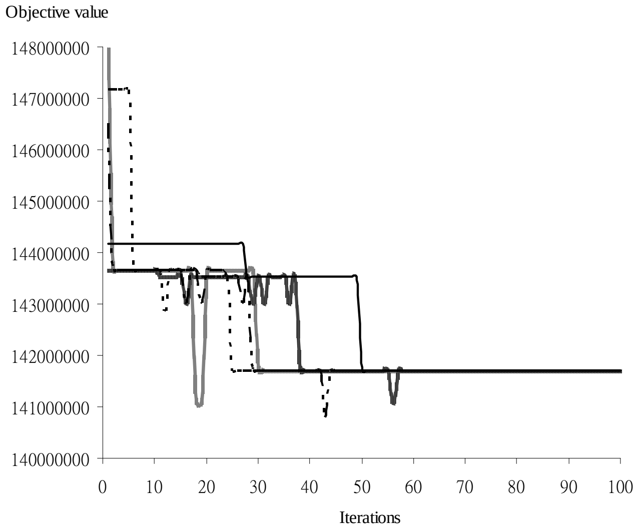

Fig. 3 Fives Convergence Processes (HMCR = 0.9, NI = 100)

Second, we set HMCR, and NI equal to 0.9 and 1000, and the number of generation scenarios of bulky wastes $|K|$ equal to 100. Varying the value of HMS, testing results are listed in Table 8. The frequency of local optimum is the number of iterations that find the local optimum solution during the 1000 iterations. As the value of HMS increase, the stochastic objective value can have a better estimate and a higher frequency of local optimum. Relatively, the CPU time increases.

Table 8 Testing Results with Various HMS

HMS	average of objective value	frequency of local optimum	CPU time (second)
25	143,167,339.90	325	532
50	142,454,634.40	662	1043
100	142,394,302.10	922	2081
150	142,230,308.50	963	3631
200	142,205,041.80	951	4195
300	142,190,994.40	964	5859

C. Sensitivity Analysis

According to the above parameters analysis, we set HMCR, HMS, and NI equal to 0.9, 100, and 1000. Let the number of generation scenarios of bulky wastes $|K|$ equal to 100. In this section, the tradeoff of land cost and transportation cost is explored.

First, six types of land cost structure, as shown in Fig. 4, are used to test the influence of land cost structure on bulky waste recycling network design problem. Testing results are listed in Table 9. As the land cost increases, the number of chosen alternative sites of repair, breakup and disassembly centers decreases. When the basic land cost is more than 10 million NT dollars, only one repair, breakup and disassembly center works. When the basic land cost is less than 500 thousand NT dollars, four repair, breakup and disassembly centers should open together.

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Next, let unit transportation cost be 5, 10, 15, 30, and 35 respectively. Testing results are listed in Table 10. On the contrary, unit transportation cost is higher; the number of chosen alternative sites of repair, breakup, and disassembly centers is more. When the unit transportation cost is more than 30 NT dollars per kilometer, four repair, breakup, and disassembly center should open together. When the unit transportation cost is less than 5 NT dollars per kilometer, only one repair, breakup and disassembly center works.

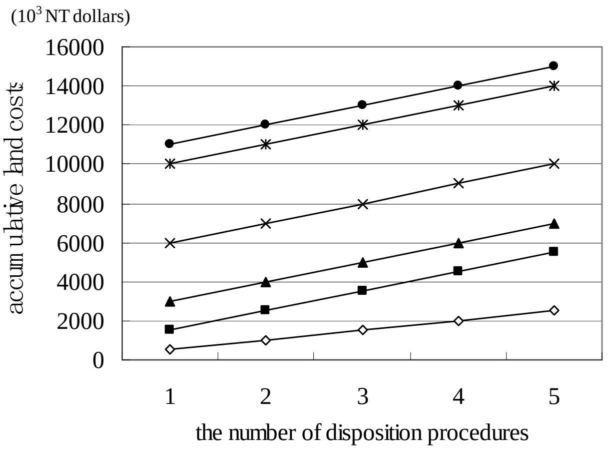

Fig. 4 Six Types of Land Cost Strucure

Table 10 Testing Results with Various Land Costs

type	frequency of local optimum	average of objective value	network configuration solution			
			site 1	site 2	site 3	site 4
1	871	132,065,000	11111*	10000	10000	10000
2	637	137,765,000	11111	00000	10000	10000
3	922	142,239,000	11111	00000	10000	10000
4	921	149,140,000	11111	00000	10000	00000
5	600	156,727,000	11111	00000	00000	00000
6	966	158,057,000	11111	00000	00000	00000

*: the five digital codes represent whether the five disposition procedures are set up or not. 1 means the disposition procedure is set up; 0 means the disposition procedure is not set up.

Table 11 Testing Results with Various Unit Transportation Cost

unit trans. cost ($/km)	frequency of local optimum	average of objective value	network configuration solution			
			site 1	site 2	site 3	site 4
5	932	86,280,000	11111*	00000	00000	00000
10	921	114,892,000	11111	00000	10000	00000
15	922	142,239,000	11111	00000	10000	10000
30	734	222,014,000	11111	00000	10000	10000
35	689	248,235,000	11111	10000	10000	10000

*: the five digital codes represent whether the five disposition procedures are set up or not. 1 means the disposition procedure is set up; 0 means the disposition procedure is not set up.

VI. Conclusion

The HS algorithm was applied to a bulky waste recycling network design problem where the expected value of the total costs is to be minimized while limiting the treatment capacity of disposition procedures of bulky waste recycling.

The HS model in this study was modified from its original structure, including:

1) This HS algorithm does not have pitch adjustment operation because the decision variables about network configuration, whether the disposition procedure n is set
2) This HS algorithm uses sampling-based approximation approach to evaluate the second-stage total expected costs because the quantities of bulky wastes that needed to be treated by different disposition procedures and their locations are hardly to be predicated in advance.

Testing results indicate that the proposed HS based algorithm is an effective way for solving the bulky waste recycling network design problem discussed in this study. Combining sampling-based approximation approach with metaheuristics offers a bright application future to solve stochastic network optimization problem.

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