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An adapted harmony search based algorithm for facility layout optimization

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Abstract

This paper presents a strategy for using Harmony Search algorithm in facility layout optimization problems. In this paper an adapted harmony search algorithm is developed for solving facility layout optimization problems. This method finds an optimal facility arrangement in an existing layout. Two real-world case studies are employed to demonstrate the efficiency of this model. A comparison is also made to illustrate the efficiency of these strategies in facility layout optimization

Keywords: Facility layout optimization, Architecture, Adapted harmony search algorithm

1. Introduction

Proper arrangement of facility layout is very important to the efficiency and cost saving of a project. Planning of facility layout depends on a number of factors such as the adjacency of facilities, distance between facilities, facilities resources and locations of facilities. Inappropriate facility layout can cause major time and cost overruns. The facility layout design consists of looking for the best allocation of n activities to facilities to n locations, where the terms activity and location should be considered in their most general sense. The applications have been described concerning planning of buildings in campuses, arrangement of departments in hospitals, minimization of total wire length in electronic circuits, etc. [1].

Facility layout problem is an NP-hard combinatorial optimization problem [2], and the exact solution of the problem is complex and highly time consuming for graphs with a large number of nodes. Therefore, many approximate algorithms are developed for finding the location of such facilities [3-11]. Due to the combinatorial complexity, it cannot be solved exhaustively for reasonably sized layout problems. Several heuristic strategies have been developed to find solutions without searching the design space exhaustively.

A meta-heuristic algorithm, mimicking the improvisation process of music players, has been recently developed and named harmony search (HS). Applications of HS algorithm had been very successful in a wide variety of optimization problems [12-19], presenting several advantages with respect to traditional optimization techniques such as the following:

(a) HS algorithm imposes fewer mathematical requirements and does not require initial value settings of the decision variables.

(b) As the HS algorithm uses stochastic random searches, derivative information is also unnecessary [19].

These features increase the flexibility of the HS algorithm and produce better solutions. In the present paper we adapted HS algorithm for facility layout optimization problem. Two real-world case studies are used to illustrate the details of the searching concepts. The computational results of the adapted HS algorithm are compared to various heuristics.

2. Adapted harmony search algorithm

This section describes the proposed adapted harmony search algorithm. HS algorithm was developed in an analogy with music improvisation process where music players improvise the pitches of their instruments to obtain better harmony [16]. The steps in the procedure of HS are as follows [17]:

Step 1. Initialize the problem and algorithm parameters.
Step 2. Initialize the harmony memory.
Step 3. Improvise a new harmony.
Step 4. Update the harmony memory.
Step 5. Check the stopping criterion.

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The adapted HS has the same steps as HS with the difference of using a special strategy in Step 3.

Initialize the problem and the algorithm parameters:

The HS algorithm parameters are specified in this step: HMS (harmony memory size), HMCR (harmony memory considering rate), PAR (pitch adjusting rate), and the number of improvisations or stopping criterion.

Initialize the harmony memory:

The harmony memory (HM= similar to the genetic pool in the GA) is a memory location where all the solution vectors are stored.

The HM matrix is filled with randomly generated solution vectors as shown in the following:

$$[H]=\begin{bmatrix} x_{1,1} & x_{2,1} & \cdots & \cdots & x_{n-1,1} & x_{n,1} \\ x_{1,2} & x_{2,2} & \cdots & \cdots & x_{n-1,2} & x_{n,2} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ x_{1,hms-1} & x_{2,hms-1} & \cdots & \cdots & x_{n-1,hms-1} & x_{n,hms-1} \\ x_{1,hms} & x_{2,hms} & \cdots & \cdots & x_{n-1,hms} & x_{n,hms} \end{bmatrix} \quad (1)$$

Improvise a new harmony:

A new harmony vector is improvised by the following three rules:

(1) Random selection, (2) HM consideration and (3) Pitch adjustment.

In random generation the value of variable x_i is randomly chosen from the possible value range. In the memory consideration, the value of the variable x_i for the new vector is chosen from the values in the specified HM range. Every component obtained by the memory consideration is examined to determine whether it should be pitch-adjusted.

Random selection and HM consideration: As a musician plays any pitch out of the preferred pitches in his/her memory, the value of variable x_i is chosen from any pitches stored in HM with a probability of HMCR (0 < HMCR < 1) while it is randomly chosen with a probability of (1 HMCR) in random selection process as previously described.

$$x_i^{new} = \begin{cases} \{x_{i,1}, x_{i,2}, \ldots, x_{i,hms}\}^T & \text{with probability} \quad HMCR \\ X_i & \text{with probability} \quad (1-HMCR) \end{cases} \quad (2)$$

X_i is the set of possible range of values.

Pitch Adjustment: Once one pitch is obtained in the HM consideration step, a musician can further adjust the pitch to neighboring pitches with a probability of HMCR×PAR (0<PAR<1) while the original pitch obtained in HM consideration is just kept with a probability of HMCR×(1 PAR).

Is x_i^{new} to be pitch-adjusted?

$$\begin{cases} \text{Yes} \quad x_i(k+m) \quad \text{with probability} \quad \text{of } HMCR \times PAR \\ \text{No} \quad \text{with probability} \quad \text{of } HMCR \times (1-PAR) \end{cases} \quad (3)$$

m (m {..., – 2, –1, 1, 2, ...}) is a neighboring index (m is normally +1 or –1).

To satisfy the requirement to assign each activity to a different location, we associate a data structure, called a tabu list, for each instrument. This memorizes the locations already used and stops' assigning them to a new activity before a cycle is completed. Figure 1 explains the performance of the tabu list.

For example if "Do" is chosen for instrument 1, Do will appear in tabu list for instruments 2 and 3.

Update the harmony memory: If the new harmony vector is better than the worst harmony in the HM, judged by objective function value, the new harmony is included in the HM and the existing worst harmony is excluded from the HM.

Check the stopping criterion: If the termination criterion or the maximum number of improvisations is reached, computation is stopped. Otherwise, Steps 3 and 4 are repeated.

The computational testing of the HS algorithm was carried out applying the method to standard test problems from the literature, and comparing the results to those of an established heuristic. As well as solving the problems, we were also interested in studying the behavior of the effect of HS parameters, and therefore a sensitivity analysis is performed for one of the case studies. In order to obtain descriptive measures of performance we apply the HS algorithm to two case studies.

3. Case study 1: Site pre-cast yard layout

The use of modular construction has wide acceptance in the housing sector. Standardization enables wider use of pre-cast technique [10].

This example is taken from Refs. [20-21]. There are 11 facilities to be positioned in the yard together with their designated numbers are given in Table 1. For example, the main gate and the lifting yard are designated as facility 1 and 11, respectively. The eleven locations are also determined with the coordinates given in Table 2.

With the coordinates, the rectangular distance matrix for the locations are then calculated and presented as in Table 3. The next step involved the researchers determining the logistic of resources flow between the facilities. The four types of resource considered are:

1. Aggregate, sand and cement/concrete, Mk =1;
2. Reinforcement bars, Mk= 2;
3. Formwork, Mk =3;
4. Completed pre-cast units, Mk =4.

Their frequencies of trips (in one day) made between facilities are based on the type of resource, as listed in the Table 4.

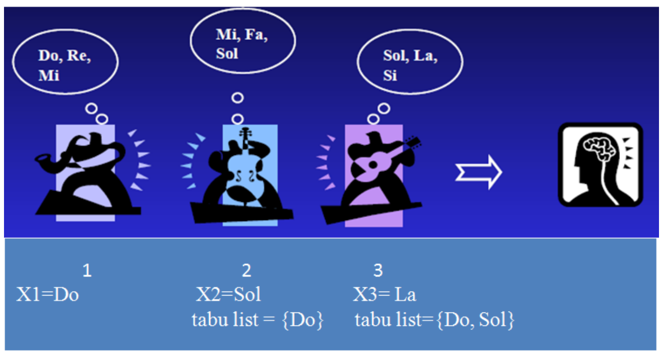

Fig. 1. Structure of the harmony memory and tabu list

Table 1. Facilities to be located in a site pre-cast yard

Number	Facilities
1	Main gate
2	Side gate
3	Batching plant
4	Steel storage yard
5	Formwork storage yard
6	Bending yard
7	Cement and sand and aggregate storage yard
8	Curing yard
9	Refuse dumping area
10	Casting yard
11	Lifting yard

Table 2. Coordinates of the locations

Location number	X(m)	Y(m)
1	15	40
2	13	30
3	22	30
4	25	20
5	20	10
6	12	10
7	40	10
8	48	20
9	48	35
10	5	20
11	32	42

In this study, the objective function is considered as the total cost per day for transporting all resources necessary to achieve the anticipated output. The objective function is therefore given by:

$$\text{Total cost}=min\ (\sum_{k=1}^{n}\sum_{i=1}^{q}\sum_{i=1}^{q} TCL_{\text{Mk,i,j}}) \tag{4}$$

$$TCL_{Mk,i,j} = M_{LMij} \times C_{Mk} \tag{5}$$

$$M_{LMij} = FL_{Mkij} \times D_{ij} \tag{6}$$

Where

D_{ij} = the rectangular distance between location *i* and *j*

C_{Mk} = the cost per unit distance for resources *Mk* flow

$TCL_{Mki,j}$ = the total cost of resource *Mk* flow between locations *i* and *j*

$M_{LMki,j}$ = the distance traveled of resource *Mk* flow per unit time between locations *i* and location *j*

$FL_{Mki,j}$ = the frequency of resource *Mk* flow between location *i* and *j* per unit time.

The harmony search algorithm parameters are taken as:

HMS = 30, HMCR = 0.85, PAR = 0.85

These values of harmony search algorithm parameters are obtained after some iteration with different values. Changing these variables will naturally affect the iteration number to reach the optimal solution.

In the example the possible layout arrangements are given by 11! (39,916,800). The attainment of the optimal solution at the 739rd trial represents only coverage of 0.001851% of the search space that demonstrates the robustness and searching ability of the HS. A comparison of the best layout for Case 1 is shown in Table 5. The results show that in this case study the HS perform better than GA and TS (HS result is 2.21% which is better than TS and 7.04% better than GA). The history of trials is shown in Fig. 2.

4. Case study 2: Milan multi-national company

This problem is the optimum allocation of services in the offices of a Milan multi-national company, originally described in [22].

The offices available are clustered into units, which are the elements of the three following buildings [22]:

I. Tower: A building with six identical floors, each divided into three units, numbered from 1 to 18 (three per floor).

II. Building A: A three-floor construction near the tower building, with direct pedestrian connections at the level of the first two floors (as well as the outside passage) and with three units per floor, numbered from 19 to 27.

III. Building B: A construction with several floors, of which the first three are available for the company in question, detached from the previous buildings and connected to them by footpaths. Two units are available on each usable floor, numbered from 28 to 33. The entire office units are shown in Figure 3.

The distance matrix is made of the times (in seconds) spent by an employee to move from location *i* to location *j*. The distances are estimated on the basis of the conditions of normal

Table 3. Distance between the locations (meter)

i\j	1	2	3	4	5	6	7	8	9	10	11
1	0	12	17	30	35	33	55	53	38	30	19
2	12	0	9	22	27	21	47	45	40	18	31
3	17	9	0	13	22	30	38	36	31	27	22
4	30	22	13	0	15	23	25	23	38	20	29
5	35	27	22	15	0	8	20	38	53	25	44
6	33	21	30	23	8	0	28	46	61	17	52
7	55	47	38	25	20	28	0	18	33	45	40
8	53	45	36	23	38	46	18	0	15	43	38
9	38	40	31	38	53	61	33	15	0	58	23
10	30	18	27	20	25	17	45	43	58	0	49
11	19	31	22	29	44	52	40	38	23	49	0

Table 4. Frequency of resources flow between facilities per day

r\s	1	2	3	4	5	6	7	8	9	10	11
(a) Aggregate, sand and cement											
1							20				
2							15				
3							35			35	
4											
5											
6											
7	20	15	35								
8											
9											
10			35								
11											
(b) Reinforcement											
1				30							
2				20							
3											
4	30	20				50					
5											
6				50						50	
7											
8											
9											
10											
11						50					
(c) Formwork											
1											
2											
3											
4											
5										48	
6											
7											
8											
9											
10					48						
11											
(d) Complete pre-cast units											
1											28
2											20
3											
4											
5											
6											
7											
8										48	48
9											
10								48			
11	28	20						48			

Table 5. Comparisons of the best layout for Case 1

Algorithms	Layout solution	Transport cost
Genetic Algorithm*	1,11,8,10,6,4,9,5,3,2,7	99,788
Multi-Searching Traveling Salesman**	5,10,8,11,1,7,2,4,6,3,9	94,858
Harmony Search	5,10,8,11,1,4,2,7,3,6,9	92,758

* Data Taken from [10]. ** Data Taken from [11].

activity of the offices themselves (waiting times for the service lifts and/or any use of alternative routes, walkways or stairs).

As "flow between activities" we decided to use the number of personal contacts necessary on average in a week by the employees of various offices, weighted according to the qualification of the person involved (the employees were assigned weight 1 and the managers weight 2), thus trying to correlate the movements to the effective burden in terms of working costs. The matrix of the flows between the various activities was obtained by qualiquantitative indications obtained from all the managers of the various services. The distance and flow matrices are reported in the Appendix. The

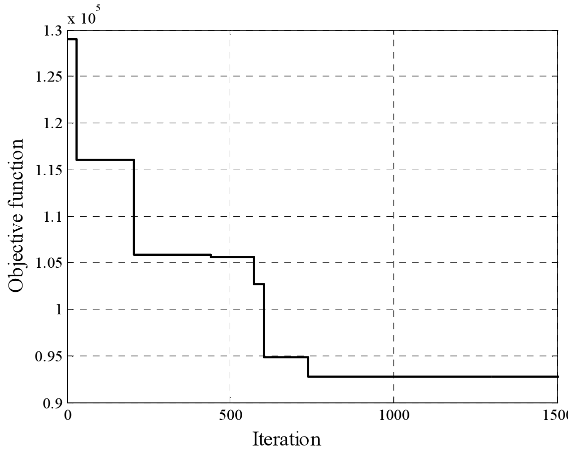

Fig. 2. History of trials for case study 1

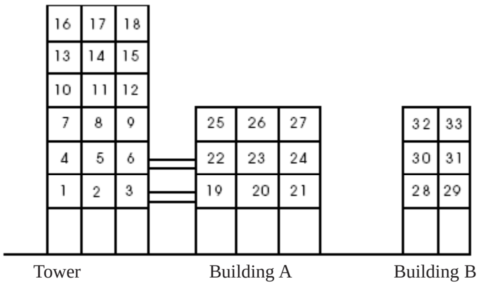

Fig. 3. Structure of the harmony memory and tabu list

harmony search algorithm parameters for this case are taken as

HMS=80, HMCR=0.85, PAR=0.65

In this example the possible layout arrangements are given by 33! (8.683317619E+36). The attainment of the near optimal solution at the 346,256th trial represents only coverage of 3.987600307E-33% of the search space. The best permutation found with the HS algorithm after only 346,256 trials has a value of 347,956 man-sec (equal to 96.65 man-hours). A comparison of the best layout for Case 2 is shown in Table 6. The history of trials is shown in Fig. 4.

5. Sensitivity analysis of the harmony search parameters

The results of the study showed that the HS algorithm may be used for layout optimization, but sensitivity analysis is required to obtain the best values of the HS parameters. This shows the effect of the harmony search parameters on solution quality.

In this section, a sensitivity analysis is performed for the harmony search parameters involved in the case study 1. The parameters of the sensitivity analyses carried out to determine the appropriate values of the harmony search parameters and the different intensification iteration for each set of parameters are given in Table 7. Design histories for the first 6 cases are shown in Fig. 5.

Sensitivity analysis of the HS parameters consisting of harmony memory matrix size (HMS), harmony memory considering rate (HMCR) and pitch-adjusting rate (PAR) is performed to obtain a better idea of the algorithm parameter values. After carrying out a sensitivity analysis with different values of harmony search parameters for cases C1 to C27, it is noticed that the values of 30 for HMS, 0.85 for HMCR and 0.85 for par , respectively, produces the best performance for optimization algorithm (Case 3). Other cases reached to optimal solution with more iteration. The results show that no single choice is superior to the others. In general, using a small HM seems to be a good and logical choice with the added advantage of reducing space requirements. It seems that using relatively large values of HMCR and PAR improves the performance of the HS for the present study.

Table 6. Comparisons of the best layout for Case 2

Algorithm	Transport cost
GRASP	339416*
Harmony Search	347956**

*best result, data Taken from [12] **result after 380,000 iterations

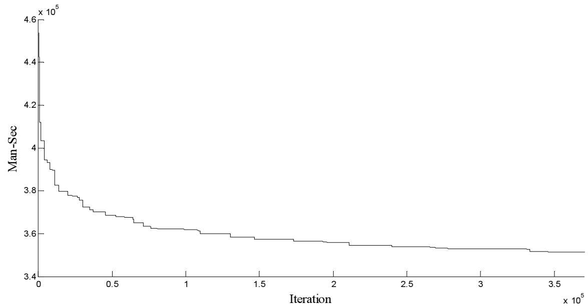

Fig. 4. History of the trials for the case study 2

Table 7. Harmony search parameters used for the sensitivity analysis

Case	HMS	HMCR	PAR	Iteration number*
1	30	0.85	0.45	1235
2	30	0.85	0.65	808
3	30	0.85	0.85	739
4	55	0.85	0.45	1276
5	55	0.85	0.65	875
6	55	0.85	0.85	744
7	80	0.85	0.45	1125
8	80	0.85	0.65	880
9	80	0.85	0.85	742
10	30	0.65	0.45	1432
11	30	0.65	0.65	921
12	30	0.65	0.85	812
13	55	0.65	0.45	1354
14	55	0.65	0.65	930
15	55	0.65	0.85	881
16	80	0.65	0.45	1395
17	80	0.65	0.65	951
18	80	0.65	0.85	927
19	30	0.95	0.45	1249
20	30	0.95	0.65	943
21	30	0.95	0.85	741
22	55	0.95	0.45	1345
23	55	0.95	0.65	954
24	55	0.95	0.85	740
25	80	0.95	0.45	1254
26	80	0.95	0.65	856
27	80	0.95	0.85	736

*Number of iterations to reach optimal solution

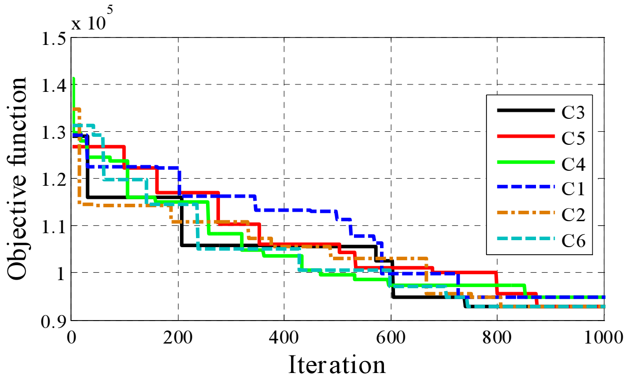

Fig. 5. Design history for cases C1,C2,C3,C4,C5 and C6

6. Concluding remarks

The optimization is performed by the recently developed adapted harmony search method. This mathematically simple algorithm sets up harmony search matrix, each row of which consists of randomly selected feasible solutions to the problem. In every search step, it searches the entire set rather than a local neighborhood of a current solution vector. It neither needs initial starting values for the design variables nor a population of candidate solutions to the design problem.

In the first case study transport cost, the daily transport for resource movements to achieve the planned output reduced from 129,048 cost units (based on the best layout within the initial population) to 92,758 cost units (based on the optimal solution). A 28.12% reduction is achieved through the use of the HS model. The attainment of the optimal solution at the 739rd trial represents only coverage of 0.001851% of the search space, whereas the possible layout arrangements are given by 11!. This demonstrates the searching ability of the HS.

In the second case study, the objective function corresponding to the current location of the offices in the units (current assignment derives not only from cost considerations, but also from other less quantifiable objectives such as personal preferences, prestige of a location) produces a value of 438114 man-secs per week (equal to 121.7 man-hours) and the average value of a random arrangement between 100 permutations generated at random produces a value of 565541 man-sec per week (equal to 157.09 man-hours). The best permutation found with the HS algorithm has a value of 347956 man-secs (equal to 96.65 man-hours). This solution is 20.57% better than the current logistic situation and 38.47% better than the average value of a random arrangement between 100 permutations.

The results obtained show that the adapted harmony search method is a powerful and an efficient method for finding the optimum solution of facility layout optimization problems. It is observed that the newly framed algorithm is quite robust and efficient.

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